# A HIGH-RESOLUTION MICROPALEONTOLOGICAL AND SEDIMENTOLOGICAL ANALYSIS OF BURIED WASHOVER DEPOSITS FROM FOLLY ISLAND, SOUTH CAROLINA: IMPLICATIONS FOR PALEOTEMPESTOLOGY

by

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# ABSTRACT

LANCE ALEXANDER ZURAWSKI. A High-Resolution Micropaleontological and Sedimentological Analysis of Buried Washover Deposits from Folly Island, South Carolina: Implications for Paleotempestology (Under the direction of DR. SCOTT HIPPENSTEEL)

A 40-meter transect consisting of eight equally spaced 2.44-m vibracores was taken across a marginal-marine salt marsh behind North Folly Island, a barrier island located in Charleston County, South Carolina. Analysis of storm signatures from this transect was conducted for the purpose of attaining a better understanding of the characteristics that define a storm layer. Previous studies in paleotempestology have focused on either sediment layers or microfossil proxies, but rarely both. This study analyzes down-core changes in microfossil assemblages and sediment grain size. Spatio-lateral continuity and storm layer preservation are additional focal points in this examination as little investigation has occurred to expand scientific understanding of variables that affect how storm events are identified and conserved over time.

Two buried storm layers were identified in the marsh strata along the transect. The upper storm layer is characterized by a thick sand lens of medium to fine grained sand. This sediment resembles the sand found at the beach front and dunes with respect to maturity, color and grain size. The lower sand lens is thin and appears in the middle of a 5-cm silt deposit. Both storm layers were laterally continuous and displayed a sharp contact between the bottom of the storm layer and marsh facies. Differences in grain size between the two storm layers suggest changes occurring over time caused by bioturbation, but also may be due to the differences in geomorphic environment or sediment source for the overwash. Microfossil assemblages from the sand lenses included multiple offshore-indicative calcareous Foraminifera genera. High-resolution analysis of these foraminiferal assemblages suggests that dissolution and abrasion result in a decrease in the correlation between sand content and marine taxa. Microfossil destruction is caused by the drying cycles and acidity typical of the high-marsh and intermediate-marsh environments. The lower storm layer contains a surprising diversity and richness of offshore genera, including many taxa not found within the larger, younger storm deposit. Variability in the storm signature, with respect to both sedimentary and micropaleontological proxies, exists for multiple cores in this study. While the fragility of the offshore-indicative and agglutinated microfossils may confuse paleoenvironmental interpretations and destroy the utility of the Foraminifera as a natural tracer, an increase in grain size accompanied with the presence of offshore foraminiferal assemblages is clearly the best indicator of the source of sediment in an overwash deposit and the method of deposition - (hurricane) - for the sand layer.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| USACE | United States Army Corps of Engineers |
| GPR | Ground Penetrating Radar |
| FORAM | Foraminifera |
| FM | Folly marsh core designation |

# CHAPTER 1: INTRODUCTION

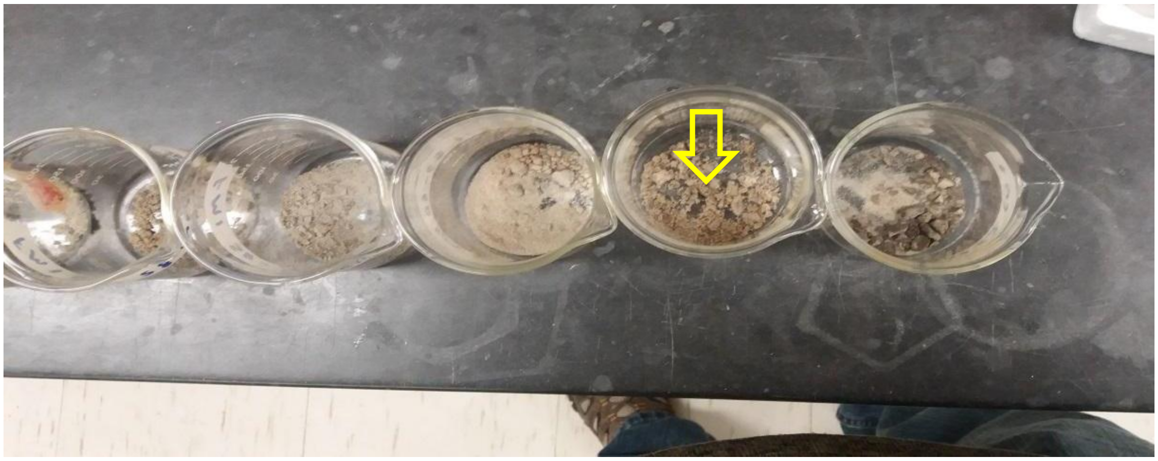
## 1.1 Background

An accurate record of cyclonic return intervals is in high demand due to population density along the Atlantic coast and the expansion of infrastructure caused by this growth. Sea level is rising at a rate of 16 to 18 inches (40.6-45.7 cm) per century which is the highest rate seen in the past 200 years along the North and South Carolina coast (Riggs et al., 2008). These storm-hazard areas are also vulnerable to major coast line changes due to intense erosion. Coastal communities have turned to science in order to predict the cycles of catastrophic storms and how much of an increase can be expected as the climate changes and the anticipated staggering economic loss in the near future becomes more threatening. An accurate record of past storm activity is necessary in order to understand what the expected increases in storm occurrence will be due to climate change, and what that could mean for the future. For such an accurate storm record to be obtained through paleostorm-layer analysis, a consensus as to the features (or signature) of a storm deposit must be reached. There must also be an understanding as to how storm deposits are preserved over time and what tracers are adequate to interpret a layer of sediment as being deposited by a strong hurricane and that which may be misplaced through weaker, more common storm activity.

Paleotempestology is a relatively new science in which sediment deposits have been used as indicators of storm activity. Sedimentary analyses of storm deposits have endured much criticism due to the poor understanding of how paleo-storm layers are deposited and preserved. Sources for the deposits cannot always be identified; therefore, microfossil proxies such as Foraminifera have the potential to act as a tracer for sediment source and method of deposition (Li et al., 1998; Hippensteel and Martin, 1999). Foraminifera are particular to the depositional environment in which they live and are abundant in marine and marginal-marine settings. The preferential nature of these microfossils makes it possible to determine the source of the sediments composing storm deposits (Hippensteel and Martin, 2000). Some species of foraminifers are common in many marsh environments and thus they are not useful for investigating the origins of transported sediment. Foraminifera that are not typical to marsh environments have the capacity to not only trace the origins of the sediment, but also determine the strength of the storm that impacted the coast hundreds of years in the past (Collins et al., 1999). Near-shore foraminiferal species may not be as useful for interpreting the strength of a storm as those species that were derived from a deeper-marine environment. Therefore, it is important to be selective of the foraminifer species used to identify a storm layer and indicate storm strength.

Stratigraphic features that allow storm layers to be identified are dependent on the preservation of the deposit. Sedimentological characteristics such as sand lenses, changes in grain size, sediment composition and microfossil content may differ from one hurricane deposit to another. However, indicators of paleo-storm deposition can be interpreted through such distinct features as bedding, grain size, and microfossils found in overwash fans (Collins et al., 1999). The deposits collected from storm surge and the resulting overwash fans can be found in coastal environments such as salt marshes or coastal lakes. One such example of sediment analysis from a strong hurricane can be found in the study of the depositional characteristics of hurricane Rita conducted by Williams (2009).

Hurricane Rita was a Category 3 storm and had generated a storm surge of 4 to 5 meters (Williams, 2009). The deposit left by the storm surge and the accompanying waves was 0.5 meters thick and reached a half a kilometer inland. Such an environment is comparable to the deposits that can be found on the coast of North Carolina as the slope of Louisiana's coastline is nearly as shallow with a rise over run of 0.001 (Riggs et al., 2008). The first layer of deposition left by Rita was described as consisting of fine grained materials such as silt, mud, and sand which is characterized by planar laminae and calcareous Foraminifera found in shallow marine environments (Williams, 2009). This feature suggests that the deposit is a suspension load created from early surge accumulation. This layer is relatively thin, but reaches 500 meters inland. The second overlying deposit is a coarse-grain sand layer 0.5 meters thick, that abruptly stops at 100-150 meters inland. This layer displays prominent foreset laminae with rare findings of Foraminifera tests (Williams, 2009). Williams (2009) described a series of events indicating that the paleostorm deposits were created during a two-stage inundation sequence. The first is a thin suspension load of fine grain material that directly covers pre-existing soil and sand layers (Figure 1.1). This layer is then overlain by coarse grained material from a traction load caused by a violent and high energy stage of storm surge. This distinct geological signature is indicative of paleostorm surge and can be used for paleo storm deposit identification.



(Figure1.1). Subsamples from core FM1. A fine layer of silt was found preserved between the sharp contact of the sand lens and marsh facies in the younger storm layer. The yellow arrow indicates the sample containing the silt layer.

Other such structures of storm deposits include layers of preserved organic materials deposited on topographically raised areas and inorganic deposits that form overwash terraces. These terraces are variable in thickness and expanse, but run parallel to the shoreline. According to Deery and Howard (1977), sedimentary structures produced during a washover event are directly related to the size and energy of the storm and resulting water volume inundating the marsh environment. Such features include subhorizontal stratification, ripple lamination, planar foreset crossbedding, trough crossbedding, and convolute bedding (Figure 1.2).

Figure1.2. Core FM1 is from the high-marsh subenvironment. The upper sand lens displays convolute laminae. Note the wavy pattern of the sediment at the point of the arrow. The arrow also points to the direction of the cores top.

These sedimentary structures are preserved in buried storm deposits, but seem to lose definition and detail when observed in a core recovered from an environment that has a high rate of bioturbation. The sand layer and the microfossil content persist after some degree of mixing, but the natural system of island rollover may only leave a thin tail end of sediment over time. Storm layers that are beyond a few hundred to a couple thousand years old may be destroyed depending on how quickly the rate of erosion and redeposition occurred for the location of study.

Marsh strata preserve the storm sequences as coarse sands that are overlain by organic layers of mud and silt common in the marsh environment that continue to accumulate. Thick deposits that raise the land elevation above the level of storm surge erosion have a slightly greater preservation potential (Morton, 2011). Non-marsh plants may colonize raised wetlands due to inundation which may also aide in preservation.

Storm surge deposits that have been studied by Williams (2013) displayed a preservation characterized by a wedge shaped deposit that tapers inland. It is important to note that the spatial and lateral continuity observed in a sand lens within a transect of cores may vary somewhat in elevation due to changes in the land morphology, as dips and rises are common throughout the marsh environment. Bioturbation of study sites from Williams (2013) had shown that there was very little change in sedimentation over the course of 15 months with 0.1-0.8 cm gain or loss due to wind and rain redistribution of sand. Root systems from vegetation and other creatures did not disturb the sharp contact between the storm overwash deposit and the organic rich marsh muds. This, of course, would be dependent on the overwash deposit exceeding a thickness of 10 cm which is the range of fiddler crab burrowing in a coarse sand substrate (Hippensteel, 2008). As these sand layers are found, the record of storm intervals can be interpreted. The study described herein was conducted only tens of meters from the Hippensteel (2008) study site and describes two well-preserved ancient storm layers undocumented by any other studies.

## 1.2 Justification

Historical storm records for the Atlantic coast only extend back 300 years. These records do not describe storm intensities and there is no way to prove the accuracy of this record. The use of foraminifera as a proxy within the overwash sediment found in marginal-marine environments may extend the record of storm activity back over the past 1,500 years. The record may not extend much past 1,500 years due to sediment erosion and recycling as the island is pushed landward through natural processes, particularly on Folly Island (Hippensteel and Martin, 2000). Storm return interval information would be valuable in establishing fair insurance rates and determining infrastructure needs. In order to obtain an accurate paleostorm record it is necessary to find sedimentary layers with Foraminifera deposits which can be dated by use of *in situ* carbon analysis or deposition rates that link to a time when a hurricane is likely to have occurred. There were three primary objectives of this study: 1) to find two storm layers of differing ages from the back-barrier marsh strata from Folly Island; 2) to measure and compare the storm signature left behind in both deposits by sediments and microfossils; and 3) to determine how both storm layers change along a traverse from high-marsh to low-marsh. This study provides a high resolution analysis of the changes in microfossil content and grain size with depth in the high-marsh and intermediate-marsh subenvironments. An analysis of spatio-lateral continuity and preservation potential along a transect is also provided.

Previous studies have found that microfossils have the potential to accurately decipher storm recurrence intervals for thousands of years (Lui and Fearn, 1993; Hippensteel and Martin, 1995, 1999, 2000; Sedgwick and Davis, 2003; Scott et al., 2003; Liu, 2004; Hippensteel et al., 2005; Donnely and Woodruff, 2007; Hippensteel, 2008, 2011; Williams, 2009; Hippensteel and Garcia, 2014). The difficulty in using microfossils as a tracer for sediment and determining storm strength through sediment bedding characteristics is that the record is subject to destructive processes. Specimens are commonly lost due to dissolution and abrasion. The second challenge was to find an environment in which sedimentary layers display stratigraphic completeness and lateral continuity. These storm layers have been found and were studied in great detail. Two distinct layers were recovered from North Folly much like those recorded by (Hippensteel and Martin, 1995, 1999, 2000; Hippensteel et al., 2005; Hippensteel, 2008, 2011; Hippensteel and Garcia, 2014), however; the storm deposits used for this study may not be the same as those detailed in Hippensteel's studies as the study site is further north.

The storm deposits recovered during the fieldwork portion of this study have significant similarities with respect to lateral continuity and offshore foraminifer content, but differences in sediment grain size and composition.  A much needed high-resolution study of storm layer sedimentology and the use of foraminiferal tracer fossils are discussed herein.  By merging data regarding grain size changes and sedimentary structures of a storm-produced sand lens with a high-resolution analysis of foraminiferal assemblages throughout the marsh environment, this study can be used to accurately identify hurricane-produced storm layers and create an archive of direct storm impacts to the southeastern Atlantic coast.  These data will be useful for studies of recurrence intervals and predictions of future impacts due to global warming.

# CHAPTER 2: PREVIOUS LITERATURE

## 2.1 Sedimentary Studies of Storm Deposits in Marginal-Marine Environments

Paleotempestology studies have been conducted along the Atlantic coast from the Gulf of Mexico to the North East Atlantic Coast (Lui and Fearn, 1993; Hippensteel and Martin, 1995, 1999, 2000; Scott et al., 2003; Sedgwick and Davis, 2003; Liu, 2004; Hippensteel et al., 2005; Donnely and Woodruff, 2007; Hippensteel, 2008, 2011, Williams, 2009; Hippensteel and Garcia, 2014). Methods for recognizing deposits created by storm overwash were described by Sedgwick and Davis (2003). Sediments and microfossils deposited in back-barrier marshes from overwash have been used to document both prehistoric storm history and recurrence intervals (Collins et al., 1999). However, the nature of their deposition, as well as the stratigraphic completeness and lateral continuity across the marsh strata, have been largely overlooked (Hippensteel, 2008). Storm derived overwash events are considered instantaneous event beds and the deposit created from such an event is called an “impulse” layer (Hippensteel and Martin, 1999).

The source material for overwash deposits varies in terms of grain size and shell debris content because the deposits are typically made from material that was eroded from multiple marginal-marine and marine environments. The sediment is carried into the back barrier by storm waves and comes to rest in horizontal layers of sand and shell fragments. According to Schwartz (1975), there is not much of a textural difference in the sediments found in front of the dune structures compared to that found behind the dunes in the overwash deposits. Models for storm layer features within a back-barrier marsh on the Gulf Coast of Florida were created by Sedgwick and Davis (2003). In this study, findings displayed overwash stratigraphy as containing landward-dipping laminae of shells and heavy minerals. Storm layers were found to contain well-sorted sand grains in plane beds. The study conducted by Sedgwick and Davis delineated five subfacies representing differences in composition, texture and bioturbation. They recognized key features of a storm deposit and found that small deposits would not persist over time in the presence of severe reworking and may not be distinguishable from similar non-storm related deposits. Nevertheless, it is possible for storm layers hundreds of years old to be found depending on the elevation of the deposit relative to sea level, and the rate and depth of burial.

According to Williams (2013), the depositional bedding structure and positioning of debris may be recognizable in a well-preserved storm layer. Other features to be observed upon closer inspection include low mud content in the sand lens within an area that is dominated by a relatively mud-rich back-barrier facies. Topography will determine the dimensions of the deposit while the thickness and lateral extent will vary depending on a combination of storm magnitude and tidal wave parameters (Maurmeyer et al., 1979). The general characteristics of interest in a core sample for this study included evidence of a two-stage inundation of water created by storm surge if such evidence can be found. Such evidence of the two-stage inundation allows the preservation potential of stratigraphic characteristics to be analyzed as well as provide evidence that the sand lenses are hurricane derived. The first surge of water is low velocity and carries fine grain sediments that blanket the existing marsh organic mud creating a sharp contact. This layer of fine grain material (likely silt) is followed by a high energy inundation of water that carries coarse grain sands and creates another sharp contact. These sediment layers will over time become covered by the organic marsh mud environment allowing for the preservation of the storm signature (Sedgwick and Davis, 2003). In the case where such sedimentological characteristics are not present, the existence and abundance of offshore foraminifers can be used as a tracer to identify a storm layer and help distinguish the origin of the sediment. These are the sedimentary characteristics of interest for this study, especially concerning the preservation of storm deposits and whether the individual layers from the two-stage inundation can be recognized in the strata.

## 2.2 Foraminifera

Foraminifera have been collected and studied for hundreds of years, but it was not until the 19$^{th}$ century that scientists began to classify them and use them in scientific investigations (Mohan et al., 2013). The use of Foraminifera in biostratigraphy began to grow in the 20$^{th}$ century particularly in the exploration for hydrocarbons. Foraminifera have become the global standard for biostratigraphic research since the mid-to-late 20$^{th}$ century, and have been particularly useful for stratigraphic investigations of Mesozoic and Cenozoic sediments and rocks (Mohan et al., 2013). The characteristics of some foraminifer that make them so useful for biostratigraphic research are the wide-ranging planktic foraminifer such as *Globergerina* spp., which can assist in stratigraphic dating due to the evolutionary status of the genera (Blow, 1967). Foraminiferal taxa useful as tracers for sediment origin are those that inhabit a small, specific habitat. Foraminifera in general may be wide-spread across marine and marginal-marine settings on the planet and abundant in sediments dating to the Paleozoic; nevertheless, at the genus- or species-level they often occupy a small temporal or geographic range. Currently, foraminifera are distributed throughout almost every coastal and open-marine environment on the planet. There are a few species that can survive in freshwater environments as well (Liu and Fearn, 1993). Foraminifers' tests can be preserved in sediment long after the organism has died, and with the unique morphology of each species, the microfossils can be identified by researchers and used for dating and tracking sediment origin (Kalbfleisch et al., 1998). Calcareous Foraminifera tests are particularly durable and useful for paleotempestology studies as agglutinated tests disintegrate upon drying and are not as diverse.

Foraminifers are usually around 1 mm or less in length (the majority of specimens are one tenth of a millimeter to a millimeter in length), but some species have been found that only measure a few micrometers across. Much larger species have been found, with the largest measuring 19-cm in length (Mohan et al., 2013). Populations can exceed two and a half million individuals per square meter on the sea floor (Phleger, 1970). In some areas of the ocean, the majority of the sea floor is made of calcareous tests of Foraminifera (Mohan et al., 2013). Due to their small size and abundance, small sediment or water samples (on the scale of one cubic centimeter) are able to yield statistically significant distributional data (Phleger, 1970).

The world's oceans exhibit 4,000 living species of foraminifera with 45 of these species being planktonic and 29 of those being cosmopolitan and found commonly throughout the world's oceans (Hemleden et al., 1989). Extinct species have a distinct record of first and last appearance in the fossil record which brings the number of useful taxa to 60,000 species (Mohan et al., 2013). For individual benthic species there is a wide range of preferred habitats for each order (Schafer, 2000). The characteristics of foraminifers' diversity, selectivity, and rapid evolution allows for easy sampling and identification, and these characteristics provide an advantage over other methods of environmental analysis and biostratigraphy. This diversity is caused by their short reproductive cycles that encourage rapid response to environmental changes (Armstrong and Brasier, 2009).

Foraminifera have proven useful to researchers because of their high species abundance and diversity in many marine environments. The Order as a whole is very adept at thriving in a wide range of marine and marginal-marine habitats, but at the species level, foraminifera are highly selective of their habitat (Schafer, 2000). These characteristics have contributed to the relative ease of sampling and identification that have provided a financial (e.g. for hydrocarbon exploration) and labor advantage over other methods of environmental analysis and biostratigraphy (e.g. macrofossils).

Marsh sediments usually contain agglutinated Foraminifera species. In the southeast, agglutinated species populations tend to decrease with elevation from low-marsh to high-marsh (Hippensteel, 2008). The most common species of agglutinated foraminiferal populations in the low-marsh are *Miliammina fusca* and *Trochamina inflata*. In the intermediate and high-marsh subenvironments *Jadammina macrescens* and *Arenoparella mexicana* are most dominant (Hippensteel, 2008). Other agglutinated species found throughout the marsh included *Ammonia salsum*, and *Textularia* spp. *Elphidium* spp., and *Ammonia* spp., are calcareous foraminifera that inhabit both marsh and near-shore environments. The cosmopolitan nature of these two species makes them unsuitable as an indicator of paleostorm activity (Hippensteel, 2011).

Previous studies conducted by Collins et al. (1995), (1999); Hippensteel and Martin, (1995), (1999), (2000); Collins, (1996); Hippensteel et al. (2005); Hippensteel, (2008), (2011); Hippensteel and Garcia, (2014); have concluded that overwash deposits will contain offshore foraminiferal assemblages that are benthic and calcareous. Such Foraminifera species are useful as a natural tracer that indicates the origin of sediments within a storm deposit. These species include: *Buccella* spp., *Bulimina* spp., *Buliminella* spp., *Cancris* spp., *Cibicides* spp., *Eponides* spp., *Fursenkiona* spp., *Hanzawaia* spp., *Nonionella* spp., *Quinqueloculina* spp., *Rosalina* spp., *Saracenaria* spp., *Siphogenerina* spp., *Stilostomella* spp., *Uvigerina* spp., and *Virgulina* spp., as well as planktic species (primarily *Globergerina* spp.). Preliminary analyses of the sediment samples in the cores from this study indicate that many of these calcareous taxa are present.

### 2.3 Previous Paleotempestology Research

Paleotempestology research has evolved as methods meet criticism and new tactics and resources are explored in hopes of obtaining an accurate geologic record of severe hurricane return intervals. Previous research has established anomalies found within the sediment layers of coastal environments as attributable to past hurricane events. Coastal freshwater lakes along the shoreline of the Gulf of Mexico in Alabama are quiet-water water environments that have been used for storm-layer research. Liu and Fearn (1993) were able to compare known records of hurricane impacts with layers of sand and shelly gravel within sharp contacts above and below organic mud and clay layers typical in the quiet lake environment. The use of $^{14}$C dating allowed them to date the layers to approximately 600 years between direct impacts from Category 3 or greater hurricanes. Liu and Fearn (1993) were also able to find a direct match between the storm deposits and known hurricane events. The process of deposition was hypothesized to be from storm-tides overwashing the dunes and coastal features. Seawater would inundate the freshwater lake leaving a layer of sand and shells between layers of naturally occurring lake sediment.

Collins et al. (1999), analyzed the percentage of organic carbon, took x-rays, and used microfossil content to document storm layers near Myrtle Beach, South Carolina. The specific locations were Price's Inlet, a non-tidal intra-beach ridge area and Sandpiper Pond, a non-tidal coastal pond near Murrells Inlet. These locations were in the path of Hurricane Hugo. This study used microfossils to separate marine from non-marine sediment sequences in the non-tidal intra-beach ridges and non-tidal pond. Displaced benthic foraminifera were used to identify storm derived sediments. Layers within the cores taken for this study were dated using $^{210}$Pb in order to obtain chronostratigraphic resolution of 100 years or less. The methods used by Collins et al. (1999) used nearshore foraminiferal assemblages to document transport of sediment from offshore at Price's Inlet. Sandpiper Pond analysis displayed a signal of Hurricane Hugo in the form of a layer of sediment containing off-shore Foraminifera sandwiched between layers of freshwater or brackish intervals. One critical flaw in this study was the choice of foraminifers for paleostorm identification: Nearshore and marginal-marine taxa were used for paleostorm identification instead of offshore-indicative foraminiferal species. Only the offshore variety can be considered reliable natural tracers for the origin of the storm sediment.

The paleotempestological record of Folly Island, South Carolina has been well studied (e.g. Hippensteel and Martin, 1995, 1999, 2000; Hippensteel et al., 2005; Hippensteel, 2008; and Hippensteel and Garcia, 2014). This wealth of studies includes analysis of storm deposits, descriptions of foraminiferal assemblages both within the marsh facies and offshore, as well as discussion of the continuity of storm layers and the effects of time and bioturbation on preservation. According to these studies, foraminifer content varies between marsh subenvironments and overwash layers and these different ancient microfossils can be used to differentiate previous depositional environments. Nearshore foraminifers such as *Elphidium* spp., and *Ammonia* spp., were determined to not be useful tracers for storm derived sediment. Though these two species are calcareous, their commonality within the marsh facies was established as inconclusive specimens. Offshore-indicative species to be expected in salt-marshes in the southeast were also listed in great detail. These species are listed in Table 2.3.

(Table 2.3). Offshore-indicative calcareous foraminiferal assemblages as described in literature from multiple studies from South Carolina.

| | | | | |
|---|---|---|---|---|
| Collins et al., 1995 | *Ammobaculites* spp | *Ammonia spp* | *Ammotium salsum* | *Buliminella* spp |
| Collins, 1996 | *Cibicides lobatulus* | *Elphidium* spp | *Eponides repandus* | *Hanzawaia spp* |
| Collins et al., 1999 | *Haplophragmoides spp* | *Haynesina* spp | *Polysaccammina* spp | *Siphotrochammina* spp |
| | *Centropyxis aculeata* | | | |
| | | | | |
| Hippensteel and Martin, 1995 | *Buccella* spp | *Bulimina* spp | *Buliminella* spp | *Cancris* spp |
| Hippensteel and Martin, 1999 | *Cibicides* spp | *Eponides* spp | *Fursenkiona* spp | *Hanzawaia* spp |
| Hippensteel and Martin, 2000 | *Nonionella* spp | *Quinqueloculina* spp | *Rosalina* spp | *Saracenaria* spp |
| Hippensteel et al., 2005 | *Siphogenerina* spp | *Stilostomella* spp | *Uvigerina* spp | *Virgulina* spp |
| Hippensteel, 2008 | *Globergerina* spp | | | |
| Hippensteel, 2011 | | | | |
| Hippensteel and Garcia, 2014 | | | | |

Several of these studies also investigated bioturbation rates throughout the marsh environments and its relation to storm layer destruction. Findings from Hippensteel (1999) described how bioturbation rates increased from high-marsh to low-marsh. It was determined that the softer sediment of lower marsh environments was favorable to fiddler crab burrowing and increased sediment mixing. Hippensteel (2011) also explored storm-layer spatio-lateral continuity, features of storm deposit preservation, and modes of sediment transport through the marsh environment. The findings from this study described a lack of continuity as a preserved overwash fan traversed the marsh strata.

Bioturbation may destroy all but the most robust sand lenses left by a hurricane landfall, and only a direct impact from a strong hurricane is likely to be preserved (Hippensteel, 2008, 2011; Hippensteel et al., 2005; Hippensteel and Garcia, 2014; Hippensteel and Martin, 1995,1999,2000). Storm deposit preservation is dependent on many of the same factors as those required for fossil survival. Quick burial at significant depth, (below 10 to12 cm- the approximate depth of the bioturbation mixing layer in South Carolina marshes), allows for better preservation of storm layers (Hippensteel, 2011).

Methods of tracking sediment transport within marsh or lagoon environments using foraminiferal assemblages were made possible by the selective nature of foraminifer as some prefer a particular marsh subenvironment (such as high-marsh, intermediate-marsh, or low-marsh) as well as using offshore-indicative taxa suggesting storm activity (Kalbfleisch et al., 1998). This microfossil proxy can be combined with sedimentological characteristics to successfully document paleo-storm events.

# CHAPTER 3: SITE DESCRIPTION

## 3.1 Barrier Islands

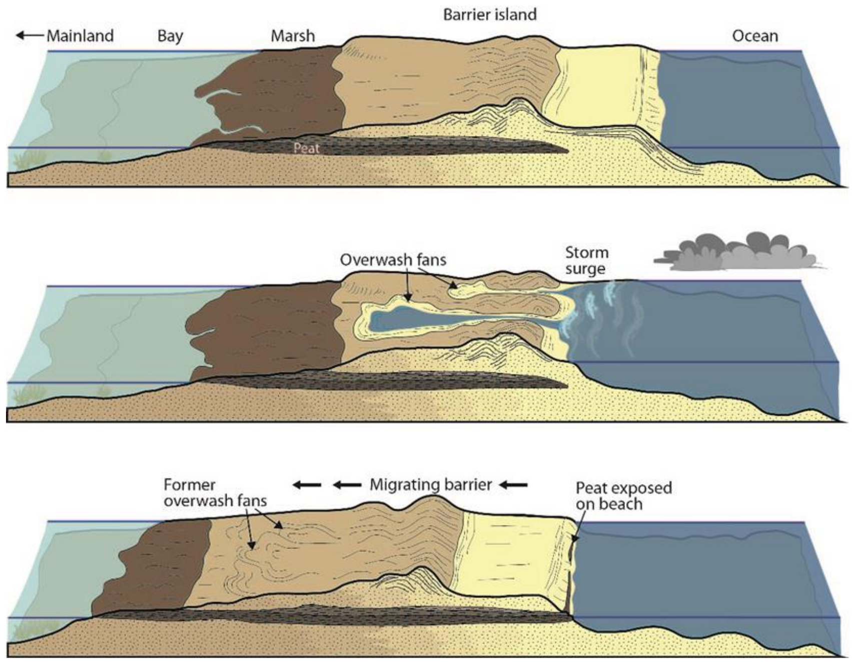
Barrier Islands protect the mainland from the ocean's energy and erosional processes. These collections of sediment and vegetation that make up elongated barrier islands are created by the deposition and transportation of sand and sediment by wind, tides, waves, and storm surge. Because barrier islands are situated parallel to the shoreline of the mainland, these features bear the brunt of the energy brought by the ocean. This high-energy environment causes barrier islands to be highly unstable, thus unsuitable for human development. Coastline and island morphology are constantly changing and evolving as they erode and accrete in a dynamic, ever-moving process. Higher inland portions of barrier islands may remain stable for hundreds of years. This is the case with Folly Island. However, barrier islands tend to migrate toward the mainland in a process known as barrier island roll-over (Stutz and Pilkey, 2001; South Carolina Department of Health and Environmental Control, 2015). The processes which cause the barrier islands to migrate are also responsible for their survival rather than the island becoming submerged. Because the island beaches have shallow slopes, forces from storm energy are absorbed or dispersed. The overwashes from storms breach the dunes and distribute sand and shells throughout the grassy marshlands and estuaries. When this occurs, sand and sediments are being moved from one subenvironment to another and sediment might be added to the system as it is brought via beach drift from other islands. In this system, the island is maintained by the addition of sediment to the dune structures as well as adding sediment to the marshes which elevates these areas for the survival of future storms. This process also adds to the island by extending the island laterally into the estuary as sandy sediments from the ocean are brought onshore.

There are differences in the geomorphology of barrier islands. Though they are mostly thin and elongated, the larger islands are known as beach ridge islands (Hayes et al., 1979). These islands are composed of a beach, sand dunes with shrubs and other vegetation, as well as a dense maritime forest. Examples of such islands are Hilton Head and Kiawah Island. The vegetation and inland waterways of these islands are much more stable than transgressive barrier islands. Folly Island is a beach ridge island that is in danger of becoming a transgressive island as development increases to accommodate a growing population. Transgressive barrier islands are extremely unstable. These narrow islands are characterized by the lack of dunes and vegetation and have nothing to prevent ocean waves from washing over them. Some of these transgressive islands are said to be the result of beach-ridge islands as the dunes are removed through anthropogenic or natural processes (South Carolina Department of Health and Environmental Control, 2015). This sand is then eroded to form the transgressive islands, which would not exist for very long as they erode much faster than they accrete. These islands may erode so fast that the marsh stratum is exposed on the beachfront after a storm. Morris Island, the next barrier island to the north of Folly, is an example of a beach ridge island becoming a transgressive island. In 1779 this island had the dunes necessary to protect it from storms. The removal of these dunes along with the removal of the shoals that nourished Morris Island's beaches when Charleston Harbor was dredged has caused massive erosion. Studies have shown a loss of 30 feet (9.14-m) per year on average for Morris Island with some areas experiencing 50 feet (15.24-m) of loss per year. This has been exacerbated by the construction of the jetties that keep Charleston Harbor open (South Carolina Department of Health and Environmental Control, 2015). In 1850 the shoreline was 300 ft. (91.4 m) seaward of the present lighthouse. The lighthouse, originally constructed on the dune field towards the back of the island, was at the edge of the shore by 1935 due to the constant rapid erosion. In 1981 the shoreline had retreated past the lighthouse by 1600 ft. (487.7m) and now it stands partially submerged in the ocean (South Carolina Department of Health and Environmental Control, 2015). There have been three lighthouses built on Morris Island point and all have been submerged. This rapid erosion illustrates the instability of such a dynamic environment. The site of the original lighthouse, which was built 170 years ago, is now two miles off the coast (SC Department of Health and Environmental Control, 2015).

## 3.2 Island Processes

Eustatic sea level has been rising at a rate of one ft. (30.5 cm) per century (Hunter, 2010). If this trend continues or increases, the barrier islands may be submerged in the near future. Barrier island sediments and strata are important for archaeological and paleostorm research, and future sea-level rise may destroy these records. Coastal geologists have found that there was an increase in the rate of sea-level rise over the past fifty years (Horton et al., 2008). This is the result of the greenhouse effect and global warming causing acceleration in glacier melt and thermal expansion as warmer water takes up more volume and space. Ten thousand years ago the shoreline was about 50 miles (80.5 km) further seaward than it is today (South Carolina Department of Health and Environmental Control, 2015). During the end of the last ice age, billions of cubic meters of water were being released by glaciers as they melted. This caused a rapid rise in sea level and the land that was behind a structure of large sand dunes at the ancient coast ten thousand years ago became submerged. The dunes that remained above sea level became the barrier islands and have been migrating ever since. They travel about 5 feet (1.52 m) per year on average (South Carolina Department of Health and Environmental Control, 2015).

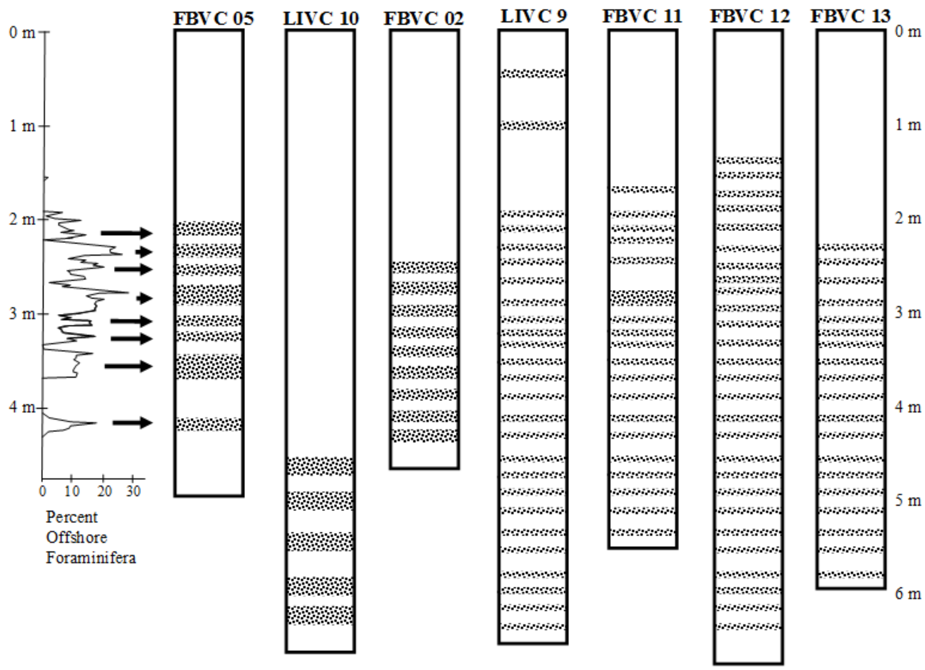
A rise in the sea level results in waves breaking higher up on the shore. As storm surges occur, waves will often cap the sand dunes and breach or break through places of lower elevation between dunes. Changes to the morphology of the barrier island over time will continue to cause the beach front to erode and sediment to be transported to the back of the island. As the island retreats toward land so does the vegetation. This change affects all plants, and includes the dune plants, shrubbery, and even the maritime forest. The shrub area and previous sand dunes evolve into a new beach front and dune structure parallel to its former position. Old marsh areas are replaced with new marshes and slowly make their way towards the mainland. This is particularly characteristic for South Carolinas barrier islands that exist so close to the mainland as sea levels continue to rise (SC Department of Health and Environmental Control, 2015).




(Figure 3.2). The three-step process of barrier island rollover. Image from Warner College of Natural Resources.

Processes such as barrier island rollover (Figure 3.2) cause dramatic changes to the beach fronts of the barrier islands; however, the saltmarshes can remain stable for hundreds of years even with such natural disturbances. Folly Island saltmarshes hold sedimentological records back into the mid-Holocene (Hippensteel, 2000). These saltmarshes are a dynamic region, but the processes that would cause changes to morphology within the marsh are well studied, therefore, sources of sediment transport can be tracked. The mechanism for sediment transport and deposition are fairly well understood, therefore, the existence of offshore foraminifera and anomalous stratigraphic layers would indicate the effects of paleo-storm activity (Hippensteel, 2000).

The salt marsh of Folly Island is separated into three subenvironments. Each subenvironment has a distinctive assemblage of microfossils containing foraminiferal genera, which exhibit a distinct preference for that particular area. The subenvironment closest to the beachfront and dunes is the high-marsh. The subenvironment closest to sea level is the low marsh, and the intermediate marsh lies between high and low marshes. In the high-marsh and intermediate-marsh, the foraminifer genera that are particularly abundant include: *Jadammina macrescens* and *Arenoparella mexicana* (Hippensteel, 2008). Low-marsh subenvironments are mostly dominated by *Miliammina fusca* and *Trochamina inflata.* Cosmopolitan taxa can be found throughout the marsh, which include: *Ammonia salsum*, *Textularia* spp., Elphidium spp., and *Ammonia* spp. Storm layers of Folly Island are typically dominated by offshore-indicative species which are used as tracers for sediment transport. Offshore-indicative species all have calcareous tests, but may be benthic or planktic. Such tracer species include: *Buccella* spp., *Bulimina* spp., *Buliminella* spp., *Cancris* spp., *Cibicides* spp., *Eponides* spp., *Fursenkiona* spp., *Hanzawaia* spp., *Nonionella* spp., *Quinqueloculina* spp., *Rosalina* spp., *Saracenaria* spp., *Siphogenerina* spp., *Stilostomella* spp., *Uvigerina* spp., and *Virgulina* spp., and *Globergerina* spp. (Hippensteel, 2008). The different foraminiferal genera found in the marsh of Folly Island are useful as tracers of sediment transport and also as indicators of changes to island morphology (Goldstein and Watkins, 1999). The paleostorm record of Folly Island is characterized by discrete overwash fans enriched with offshore foraminifera. These overwash fans occur beneath layers of organic material and marsh mud which are displayed in core samples as sand-rich layers. Storm records from cores retrieved by Hippensteel (2008) depict a decreasing frequency in storm activity as the upper 2 meters of most cores less commonly contain sand lenses enriched with offshore foraminiferal taxa.




(Figure 3.3) Storm layers based on the percentage of offshore-indicative foraminifera and increase in sediment grain size (Hippensteel, 2008). The storm layers are indicated by an increase of offshore-indicative Foraminifera. Stippled lines indicate sand layers containing offshore-indicative Foraminifera.

## 3.3 Folly Island, South Carolina

The salt marsh site used in this study is located on the northern most end of Folly Island in Charleston County, South Carolina. This barrier island is 9 miles (14.5 km) from the main land, separated by estuaries, marshland, and narrow inlets. This island faces southeast toward the Atlantic Ocean and would bear the brunt of a direct strike in that area from hurricanes as there are no other land masses between the South Carolina coastline and the Atlantic Ocean (Figure 3.4).


Figure 3.4. Map view of Folly Island. The saltwater marshes at the north end of the island are of interest for this study. (Aerial photograph from Google Earth Images).

Folly Island has an extensive history dating back to before the American Revolution, but was most prominently used during the Civil War as an outpost and staging ground for the invasion of Morris Island. This island is seven miles (18 km) long and gets its name from the dense vegetation found on the island in the 1600s (SC Department of Health and Environmental Control, 2015).


Figure 3.5. Google Earth aerial photo image of North Folly Island with coring site transect of 5 meter intervals marked to 40 meters in length.

Figure 3.6. Salt marsh of Folly Island South Carolina in a panoramic photo. Storm deposition created raised features (overwash fans) which allow for preservation of storm deposits. The organic layers created by vegetation allow for noticeably sharp contacts as storm deposits will bury existing organic layers with sand layers. The sandy storm layers are overlain by organic layers as sea level rises.

Folly Island is a Holocene-age barrier island (U.S. Army Corps of Engineers, 1979). The barrier islands in this region are characterized by gently sloping sand beaches on the east side of the island facing the ocean. The western sides of these islands that face landward contain large salt marshes. According to the Army Corps of Engineers (1979), the islands exhibit tidal rivers and tidal creeks which drain the salt marshes. Natural sediment transport is dominated by easterly and northeasterly waves that produce a southerly direction of net sediment drift (DuMars, 2007). Silty sand reaches depths of 7 meters below mean sea level at the beachfront. From the shoreline, sediment displays an increase in silt content moving towards mainland. Sands of these beaches are described as fine grained and rich in shell content (U.S. Army Corps of Engineers, 1979).

The climate of this region is marine subtropical. The average high for Folly Island is 88 °F (31.1°C) for the summer with an average humidity of 75% for the months of April through October. Rainfall averages 127-cm per year, which could account for sediment transport and losses from preserved storm deposits caused by precipitation and runoff (South Carolina Department of Health and Environmental Control, 2015). Folly Island was once densely vegetated. Since occupation of the Island during the Civil War, much of the vegetation has been removed. The removal of plant life causes the island to be dominated by erosion for the beach areas, but also allows storm layers to be deposited more readily.

# CHAPTER 4: METHODOLOGY

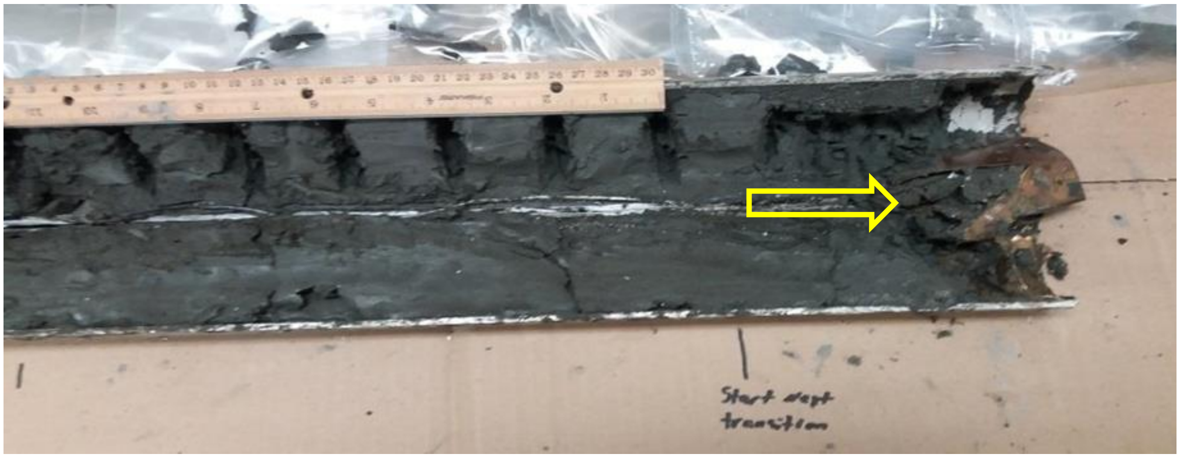
## 4.1 Field Methodology

In the summer of 2016 eight 3-inch diameter vibracores were taken along a transect across the marsh of Folly Island. This transect began in the high-marsh and terminated in the low-marsh using five meter intervals between vibracore locations. The transect ran in a straight line from high-marsh, to intermediate-marsh, to low-marsh. The site of the vibracoring was chosen during a previous reconnaissance trip on which distinctive sand lenses were detected when probing with a gouge auger (Figure 4.1 A). Five-meter intervals where marked using a 30.5 meter tape measure and surveyor flags were used to mark the sites for vibracoring. Each core tube was cut from aluminum drainage pipes at a length of eight feet or 2.44 meters. Aluminum sediment catchers were constructed and riveted into the bottom of each core to insure no sediment was lost during the extraction process (Figures 4.1-B and 4.2).

Vibracoring commenced during low-tide to prevent excess water from entering the cores of an already semi-saturated salt-marsh facies. Extraction of each core was made possible by means of using a pry-and-lever system (Figure 4.1 B) to lift the core tubes from the subsurface. Once the vibracores were in place, the top was capped using a 7.62-cm diameter aqueduct cap and sealed in place with duct tape before extraction. Upon extraction, the bottom of the core was also capped and sealed. Each core was marked for location and core number. GPS coordinates for each core location were recorded. Each core was stored in an upright position and wrapped with packing blankets to increase stability within the core during transport to the laboratory.

(Figure 4.1-A) Gauge auger probing for sand lenses.

(Figure 4.1-B) Lance Zurawski and Steven Ortiz using the pry-and-lever system to remove a vibracore.




(Figure 4.2) Remnant of sediment catcher applied to prevent sample loss at yellow arrow.

The cores were transported to the Environmental Micropaleontology Laboratory at the University of North Carolina at Charlotte and stored in an upright position. The cores were bisected along the long axis using a circular saw at the shallowest blade position to insure minimal sediment mixing. After each core was cut open, samples were collected from the middle of the core for the purpose of avoiding sample contamination due to smearing from the outer core wall during the coring and extraction process. The cores were measured in centimeters from the top of the core tube to the start of the sediment within the core, then from the top of the sediment to the bottom of the core tube. The vibracoring process and de-watering caused sediment compaction which means that sediment recovery does not begin at the top of the core tube. Approximately 12 inches (30.5-cm) of core tubing is unused due to the vibracore's head. Two samples were taken at each depth within the core being sampled. Each sample was 1-$cm^3$. One sample was sealed in a zip lock bag and labeled "sediment", with the depth and core number. The other was labeled "Foraminifera" and its corresponding core location (Figure 4.3)

(Figure 4.3) Samples from each site labeled for sedimentary and microfossil analysis.

## 4.2 Laboratory Procedures: Sedimentology

Samples were taken at 1-cm increments from the top of the core to 5-cm below the first contact between marsh facies and sand lens. This was done because the sediment from the top of the core to the upper sand lens appeared to be highly bioturbated and displayed a transition from marsh facies to the sand lens. Homogeneous sediment sections within the core were sampled every 4-cm until approaching the sharp contact of the bottom of the sand lens to ensure an adequate record of foraminifer and grain size changes were obtained. Samples were then taken every centimeter from 5-cm above the contact area to 5-cm below the contact. Successive samples through the sharp contact layer allowed nuances in microfossil content and grain size to be recorded. Sediment samples were soaked in a solution of 10-ml of deionized water. Twenty-five ml of 30% hydrogen peroxide was added to the sediment samples at 5-ml increments. Once 25-ml of the hydrogen peroxide had been added the samples were placed into a hot bath to accelerate the chemical reaction to digests away any organic matter. After two hours the solution was stirred and another 25-ml of hydrogen peroxide was added to the sediment and the solution was left in the hot bath for another 4 hours until the chemical reaction was complete. This process allowed the sediment grains to be left behind unharmed while disposing of any organic material such as plant and animal particles. The digested samples were then set inside a drying oven for a minimum of 12 hours to remove all liquids. The dried grains were scraped into marked petri dishes. A Sartorius Analytic Precision Weighing Scale was used to weigh 0.2-0.4 grams of fine grain and 1 – 1.4 grams for coarse grain samples. After samples were weighed, they were put inside 13-ml auto sampler test tubes and suspended in 5-ml of 10% sodium pyrophosphate deflocculant. After 24 hours of suspension the samples were loaded into a sonic bath (Branson 3510R-MTH) for 30 minutes to insure no grains were stuck together. Once these processes were complete, the sediment samples were loaded into a Laser Diffraction Particle Analyzer (Beckman Coulter LS 13 320). This machine analyses one sample at a time and is able to detect the percentage of grains sizes within the sample. The range is calibrated to detect grains as fine as clay and silt to very coarse grain sand.

Dating of sediment layers was done by multiplying depth by a sedimentation rate of 1.1 mm per year (Hippensteel and Martin, 2000). The rate of deposition for the Folly Marsh was determined by radiocarbon dating of *Mulinia* shells taken at 2.45 meters and 4.65 meters down core in a nearby study from Hippensteel, (2011). If the *Mulinia* shells occurred *in situ*, the date of 1,985 ± 80 yr. B.P. at 2.45-m and 4,685 ± 85 yr. B.P. at 4.65-m indicates a deposition rate between ~1.0 – 1.1 mm/yr. When calculations were made excluding the overwash deposit, it was found that the 1.9-m of marsh deposit from the 4,685-yr interval accumulated at a rate of 0.6 mm/yr (Hippensteel, 2011). According to Hippensteel (2011), these rates are consistent with those obtained by Sharma et al. (1987)

whose study of salt marsh sequences near North Inlet, South Carolina rendered a sedimentation rate of 1.4 to 4.5 mm/yr.

### 4.3 Laboratory Procedures: Micropaleontology

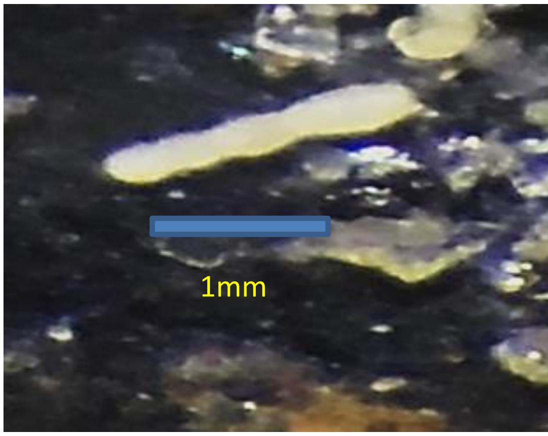
The 1-$cm^3$ that was collected and marked for microfossil study was placed into a series of sieves. These samples were taken at the same time sediment samples were retrieved and marked accordingly to be distinguished from the sediment analysis. The first sieve had a 0.71-mm mesh which was used to primarily remove large shell fragments and plant material. The second sieve in the series was 0.177-mm mesh, and was fine enough to capture sand and larger foraminifera. The third sieve in the series was designed to capture small grain sediments and smaller foraminifers with a 63 micro-meter mesh. The sieves were then gently washed into 10.16 x 7.62 cm sample trays for analyses under a high powered reflection binocular microscope (EMZ-8TR/PLS-2). Under the microscope, each sample was meticulously analyzed by grid row with a fine-tip picking brush. By doing so, every individual foraminifer specimen was recorded. The numbers of each individual genus were entered into a spreadsheet along with its corresponding depth for an assessment of changes of biofacies throughout the cores. Individual taxa were photographed and the typical environments in which they inhabit were recorded (Appendix Figure X14-18).

# CHAPTER 5: RESULTS

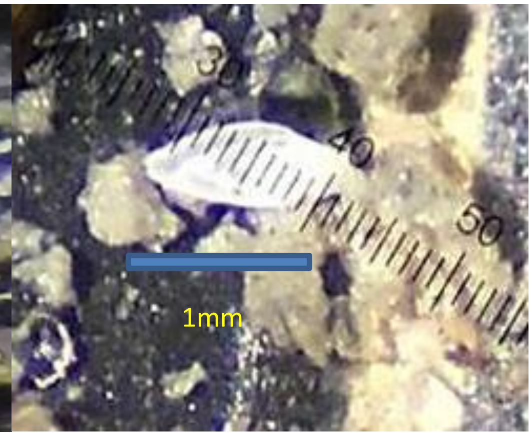
## 5.1 Foraminifera Abundance

Total population of foraminifera present per 1-$cm^3$ sample of sediment varied between zero and 3,500 specimens. The most common and abundant genera were *Elphidium* spp. and *Ammonia* spp. These genera are marginal-marine taxa and are common in marshes. Though the presence of these genera may not be applicable tracers for the origin of a storm deposit, patterns observed in the locations where these species appeared to have extremely high populations, along with other stronger offshore-indicative species, may indicate their usefulness as storm-layer indicators. Other taxa which exceeded 100 individuals in a single sediment sample where *Globergerina* spp., *Cibicides* spp., *Rosalina*, *Bolivina* spp., *Jadamina macrescens* and *Trochamina inflata*.

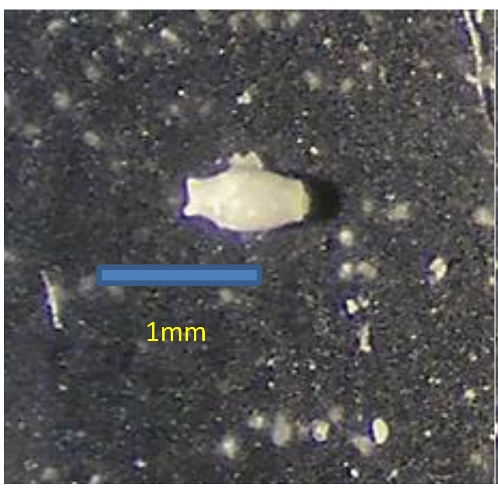
The following genera have been documented by Hippensteel (2008) and Armstrong and Braiser (2009) to represent offshore-dwelling taxa and, when recovered in a marsh setting, likely represent storm deposition: *Astacolus* spp., *Baggina* spp., *Bolivina* spp., *Buccella* spp., *Bulimina* spp., *Buliminella* spp., *Cancris* spp., *Cassidulina crassa* spp., *Cassidulinoides* spp., *Cibicides* spp., *Cyclomina* spp., *Fissurina* spp., *Florensis* spp., *Florilus grateloupi*., *Florilus pizarrensis.*, *Globulina* spp., *Globobulimina* spp., *Guttulina* spp., *Gyroidina* spp., *Gyroidinoides* spp., *Hopkinsina* spp., *Legenina* spp., *Melonis affinis*, *Milionella* spp., *Nodosaria* spp., *Nonionella* spp., *Petallina* spp., *Planularia* spp., *Pullenia* spp., *Quinqueloculina* spp., *Rosalina* spp., *Siphogenerina* spp., *Sphaeroidina* spp., *Stilostomella* spp., *Triloculina* spp., *Uvigerina* spp., *Vaginulinopsis* spp., *Valvulineria* spp. (See Figure 5.1 for examples of offshore-indicative foraminifer found in the storm layers). (Figure 5.2 displays the abundance of foraminiferal assemblages with depth and grain size throughout the core).



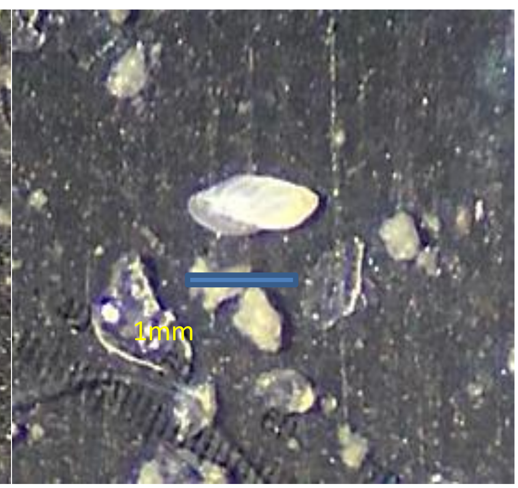

(Figure 5.1 A) *Stilostomella* spp.



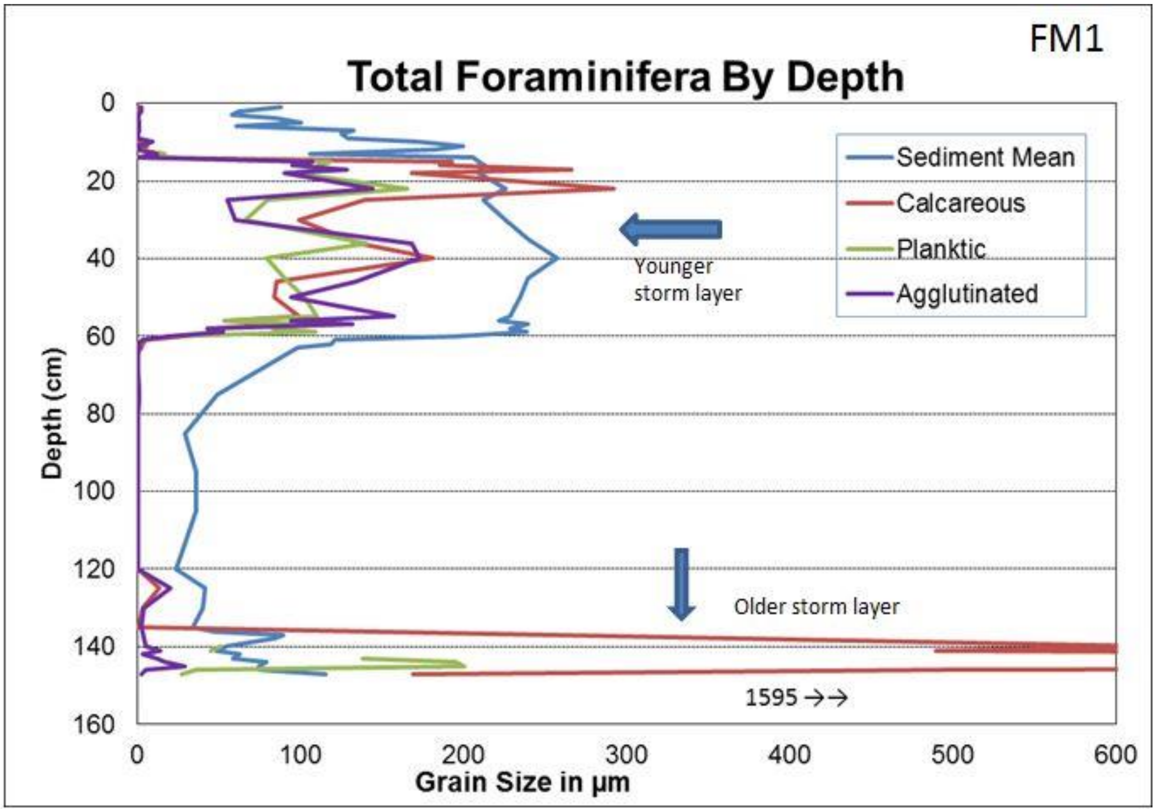

(Figure 5.1 B) *Planularia* spp.




(Figure 5.1 C) *Lagenina* spp.

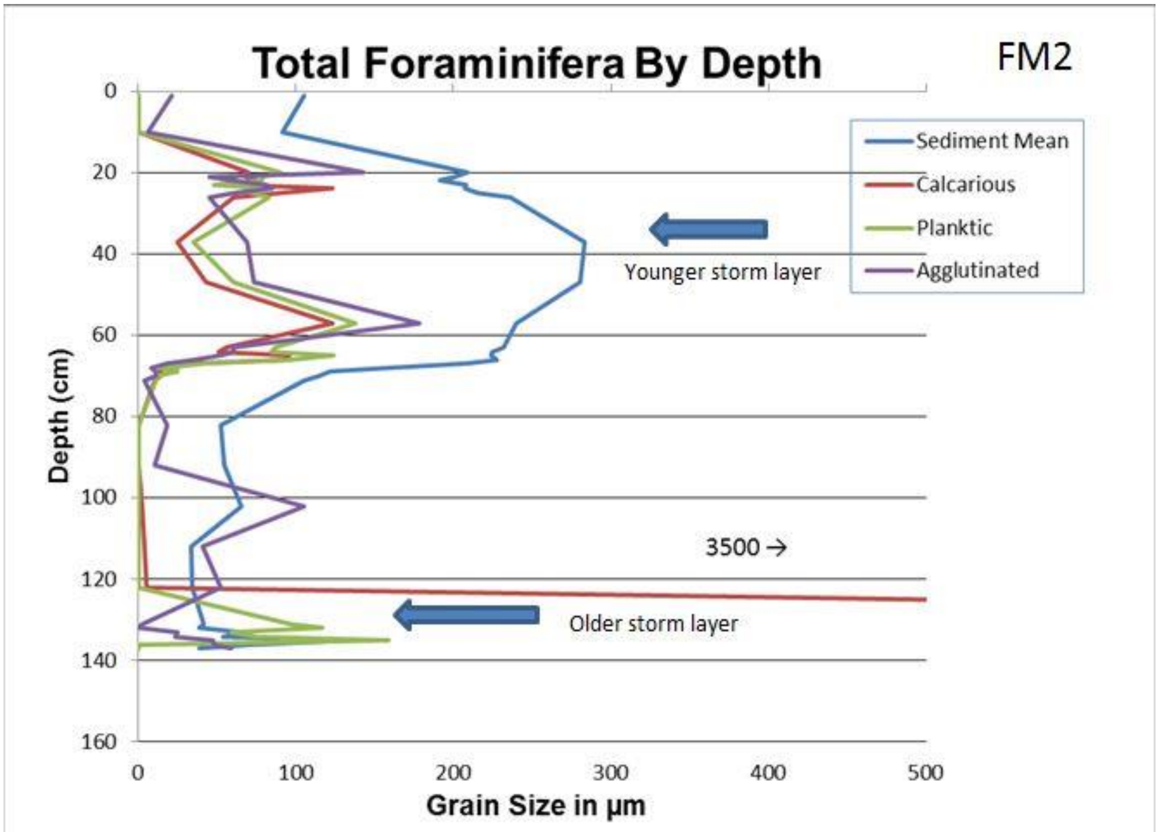



(Figure 5.1 D) *Astacolus* spp.




(Figure 5.2). Foraminiferal assemblages and mean grain size for FM1. The "X" axis is set with a maximum of 600. In a scale that depicts over 1,000 individuals such as the maximum stated in the study, graphic features are no longer discernable.

The younger storm layer found within all eight cores is very thick, ranging from 42-cm of sand in core FM1 to 12.5-cm of sand at core FM8 (Figure 5.4). The sediment 18-30-cm above the sand lens display large grains within the marsh facies caused by heavy bioturbation as sand grains have been mixed upward. The younger sand lens displays a sharp contact layer with underlying marsh facies with very little, if any, evidence of bioturbation breaching the bottom of the upper storm layer (Figure 5.2).




(Figure 5.3). Changes in foraminiferal species with mean grain size FM2. Note stronger agreement between agglutinated foraminifer and marsh facies without cycles of drying destroying the record of agglutinated genera within marsh facies.

The younger storm layer is thick and robust and occurs at a depth of approximately 20-cm and reaching a depth of approximately 65-cm in cores FM1 and FM2. However, even with the appearance of offshore foraminifer genera, the diversity of these species are not as rich as that of the older storm layer found approximately 130-cm in depth and 5-cm in width, nor are the microfossils as abundant. Comparisons were made between offshore-indicative species and agglutinated foraminifera species for the purpose of displaying correlations between taxa used as storm deposit tracers. The correlation data also indicate foraminifer genera that spike with increase in grain size and those that disappear with increases. Information gathered from the correlations suggests that agglutinated genera rise in species numbers within the storm layer, particularly in the high and intermediate marsh. Agglutinated foraminifer persisted within the marsh facies, but not to the degree expected. Specimen numbers increase for agglutinated genera when samples were taken in low-marsh and deeper low-marsh environments. In the low-marsh, agglutinated genera displayed higher numbers of 20 to 70 individuals per 1-$cm^3$ within the marsh facies and very few within the storm layers. The marsh facies was defined by these foraminifers: *Ammonia salsum, Jadamina macrescens, Arenparrella mexicana* spp., *Miliamina fusca, Parkinsoniana* spp., *Textularia* spp., and *Trochamina inflata.* Marsh taxa were expected to be present to some degree throughout the marsh facies; however, observations have proven that this is not the case. FM1 displays very few species of marsh taxa within the first 14-cm with as few as one to two individuals found per 1-$cm^3$ sample. Marsh taxa within the first 14-cm were also mixed with offshore and nearshore taxa which ranged from 0 to 8 individuals per sample. Marsh taxa were not well preserved within the high marsh environment. Upward mixing of the top 5-cm of the storm layer were indicated by the presence of offshore and nearshore taxa existing within the first 14-cm of the core and in similar quantities as agglutinated marsh assemblages.

The numbers of individual Foraminifera rise and fall in conjunction with rise and fall of grain size within each $cm^3$ sample. Offshore facies are represented by a diverse range of foraminifer genera that include: *Astacolus* spp., *Baggina* spp., *Bolivina* spp., *Buccella* spp., *Bulimina* spp., *Buliminella* spp., *Cancris* spp., *Cassidulina crassa* spp., *Cassidulinoides* spp., *Cibicides* spp., *Cyclomina* spp., *Fissurina* spp., *Florensis* spp., *Florilus grateloupi*., *Florilus pizarrensis.*, *Globulina* spp., *Globobulimina* spp., *Guttulina* spp., *Gyroidina* spp., *Gyroidinoides* spp., *Hopkinsina* spp., *Legenina* spp., *Melonis affinis*, *Milionella* spp., *Nodosaria* spp., *Nonionella* spp., *Petallina* spp., *Planularia* spp., *Pullenia* spp., *Quinqueloculina* spp., *Rosalina* spp., *Siphogenerina* spp., *Sphaeroidina* spp., *Stilostomella* spp., *Triloculina* spp., *Uvigerina* spp., *Vaginulinopsis* spp., and *Valvulineria* spp. as identified in this study (Armstrong and Brasier, 2009; Hippensteel, 1999). Correlation data show these genera as only appearing with increases in grain size. Inconsistency with the percent of offshore genera rise and fall with grain size has caused the weakest correlation to grain size in the upper and lower layer compared to other assemblages. All correlation data was calculated using Pearson's correlation coefficient. By using this model, the rate of increase or decrease of grain size to changes in the abundance of microfossils are displayed in a scale from 1 to 0 to -1. Numbers closer to +1 are positive correlations and those closer to -1 are negative correlations. Numbers close to 0 indicate no correlation at all. (Figure 5.4-A and Figure 5.4-B) display the plotted data with trend lines for the correlations calculated for FM2. FM1 and FM2 display the strongest correlation to grain size belongs to planktic genera with values of 0.78 for the upper layer and 0.34 for the lower in FM1. Correlation values for grain size and planktic genera in FM2 are 0.73 in the upper layer and 0.52 in the lower. The second strongest correlation to grain size was agglutinated genera with values of 0.75 for the upper layer of FM1 but a -0.01 in the lower layer. Correlation values for grain size and agglutinated genera in FM2 were 0.60 and 0.22 for the upper and lower layer respectively. Planktic and agglutinated genera display a strong correlation to each other. Benthic calcareous genera may not correlate strongly with the rate of change in grain size, however only appearing within sand lenses agrees with storm events as a means of transport.

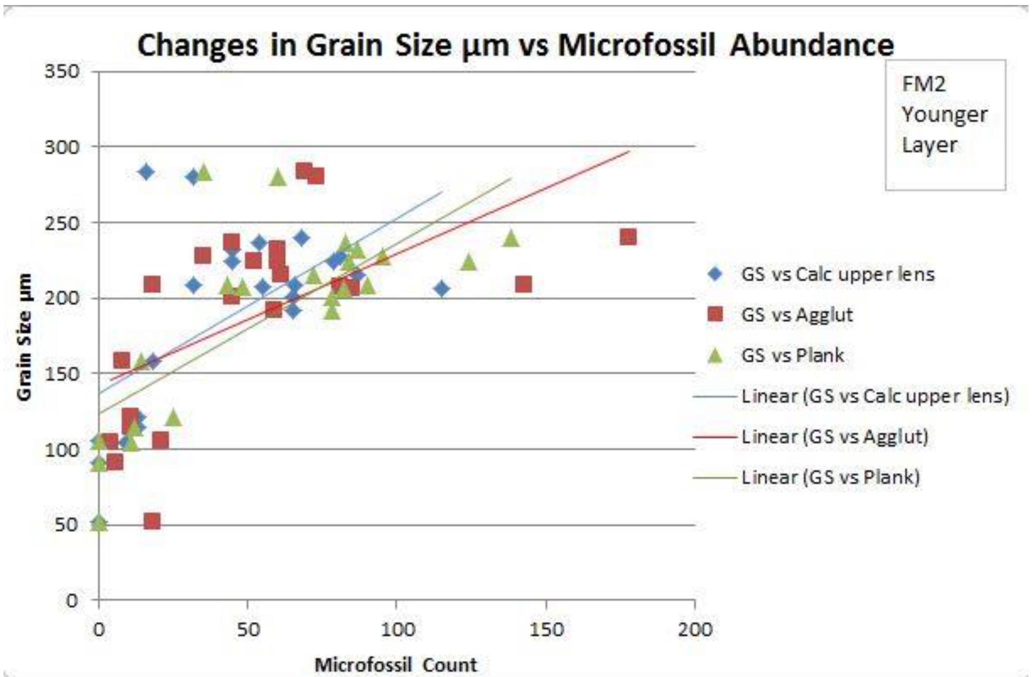



Figure 5.4-A Scatter plot of the correlation between grain sizes in microns to the number of individuals per genera with trend lines.

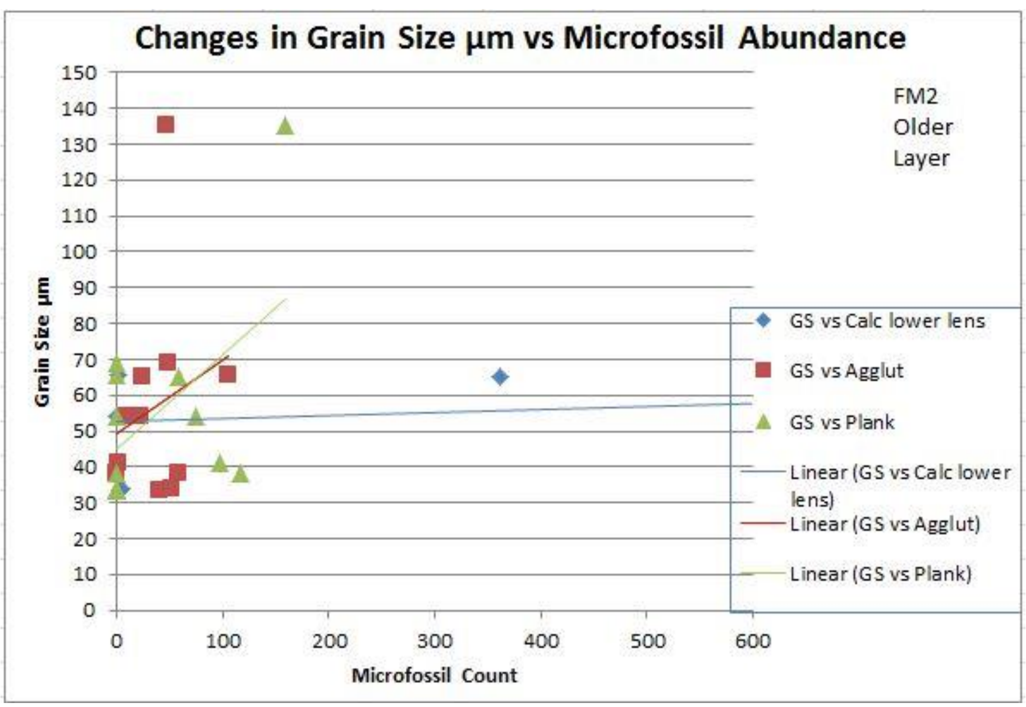



Figure 5.4-B. Scatter plot of the correlation between grain sizes in microns to the number of individuals per genera with trend lines. Note the change in scale between Figure 5.4-A and 5.4-B. This change in scale is due to much higher microfossil abundance in the older storm layer.

Interestingly, after the sharp contact between the bottom of the first storm layer at 62-cm and the underlying marsh facies, no foraminifera were found between 65-cm and 124-cm. Dissolution and abrasion caused by intensive bioturbation appears to be the reason for the absence of taxa within this 50-cm of FM1. Cycles of drying are common in high and intermediate marsh environments causing agglutinated taxa to disintegrate when their organic lining dries.

## 5.2 Grain Size Data

Two overwash intervals were identified along a transect of eight vibracores taken at the north end of Folly Island. The upper storm layer is about 40-cm thick and well preserved. It is referred to here as the younger storm layer. This layer was likely a product of Hugo in 1989 due to its depth and the marsh background sedimentation rate in this area. The older storm layer is a very thin, but distinct, sand lens that is thought to be approximately 1,000 years old. The older storm layer may display evidence of pedogenesis as the formation of peds due to weathering can be seen in core FM1 and core FM2. This would indicate that the storm layer was at or near surface for at least a decade before burial. Both storm layers display spatio-lateral continuity, which is an important characteristic for reliable storm signature proxy along the transect. The upper sand lens proved to be spatio-laterally continuous throughout the entirety of the transect. The upper sand lens at core FM1 located in the high marsh was 44-cm thick and 42.5-cm thick at FM2 at a distance of five meters into the intermediate marsh. The upper sand lens, though continuous throughout the transect, did not exhibit the wedge formation expected with distance inland (Figure 5.5).

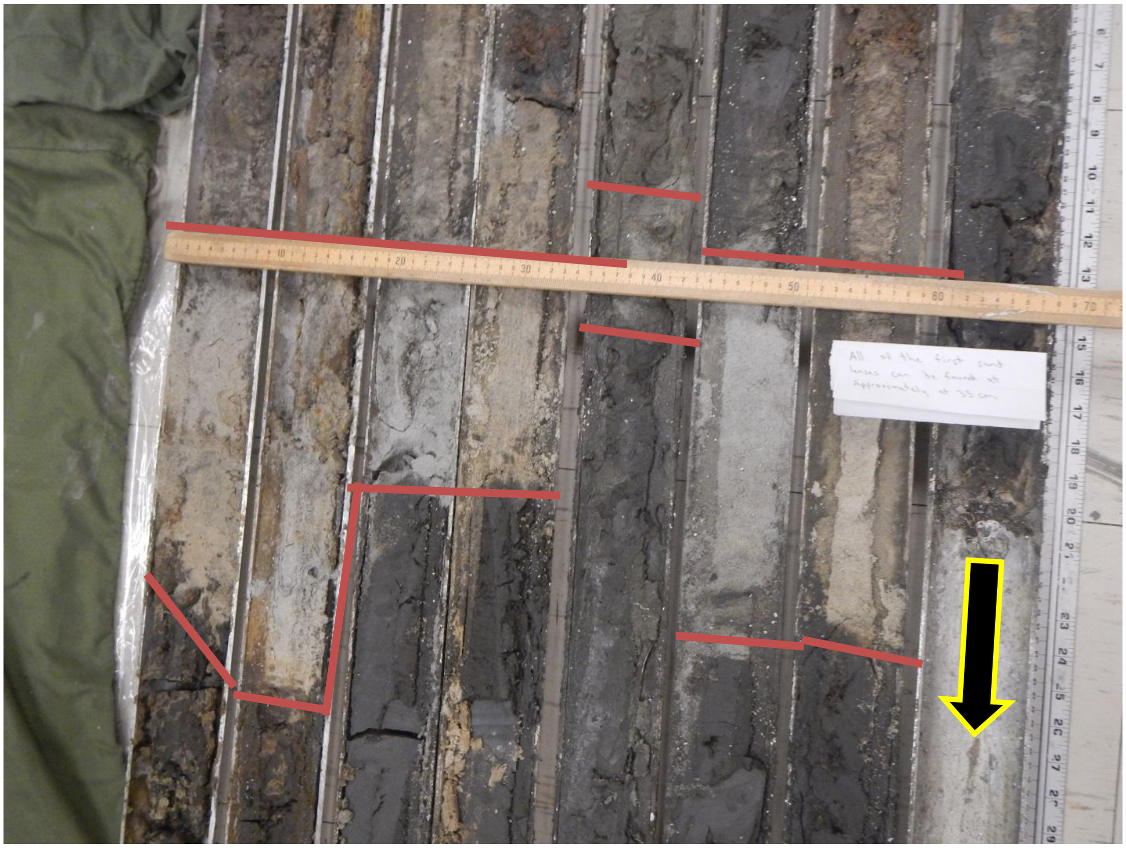
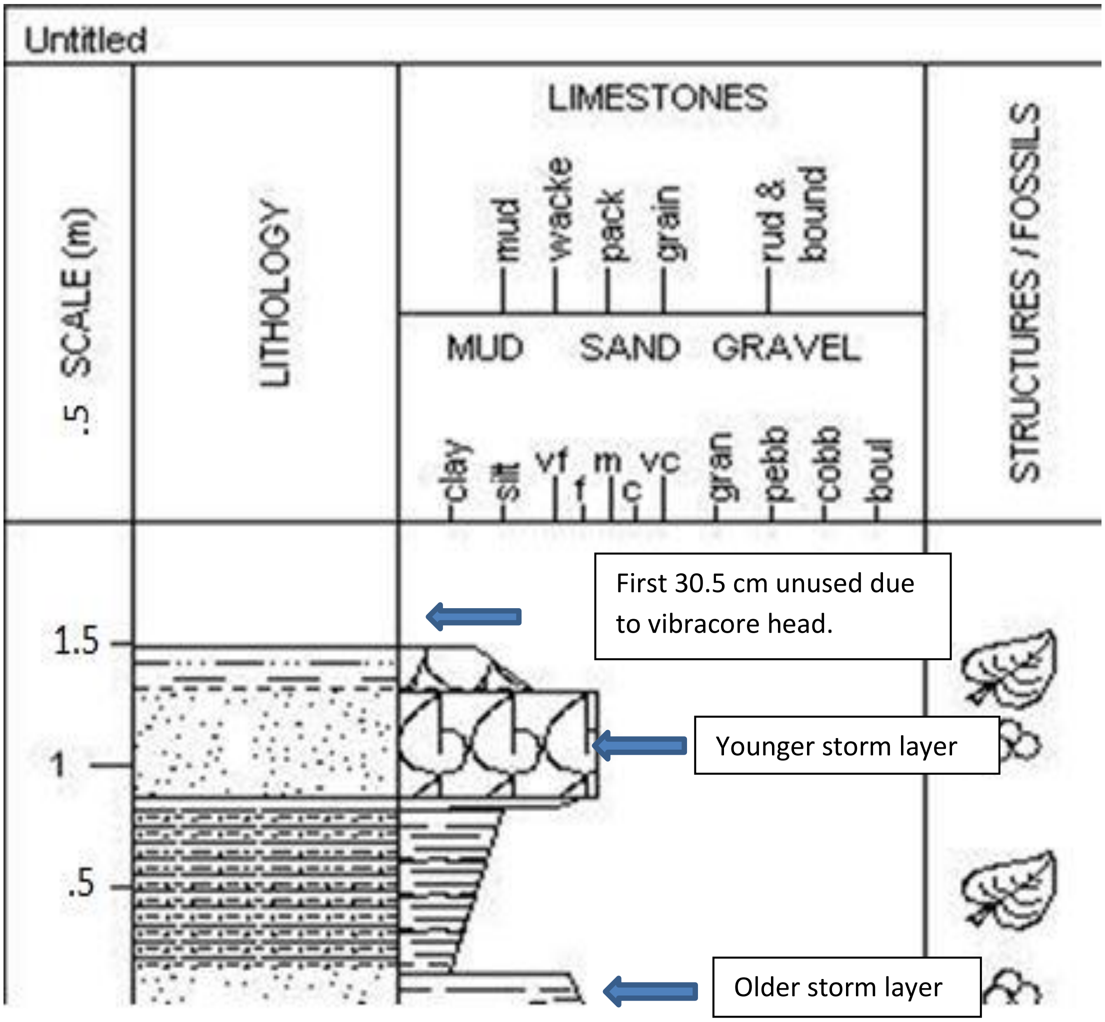


Figure 5.5. Moving from left to right FM1, FM2, FM3, FM4, FM5, FM6, FM7, and FM8. Continuous sand lenses appear to thin in the middle and thicken at the ends of the transect. Red lines depict the upper and lower contacts of the upper sand lens. Arrow at FM8 points to the direction the sand lens is found due to slumping of the sediment.

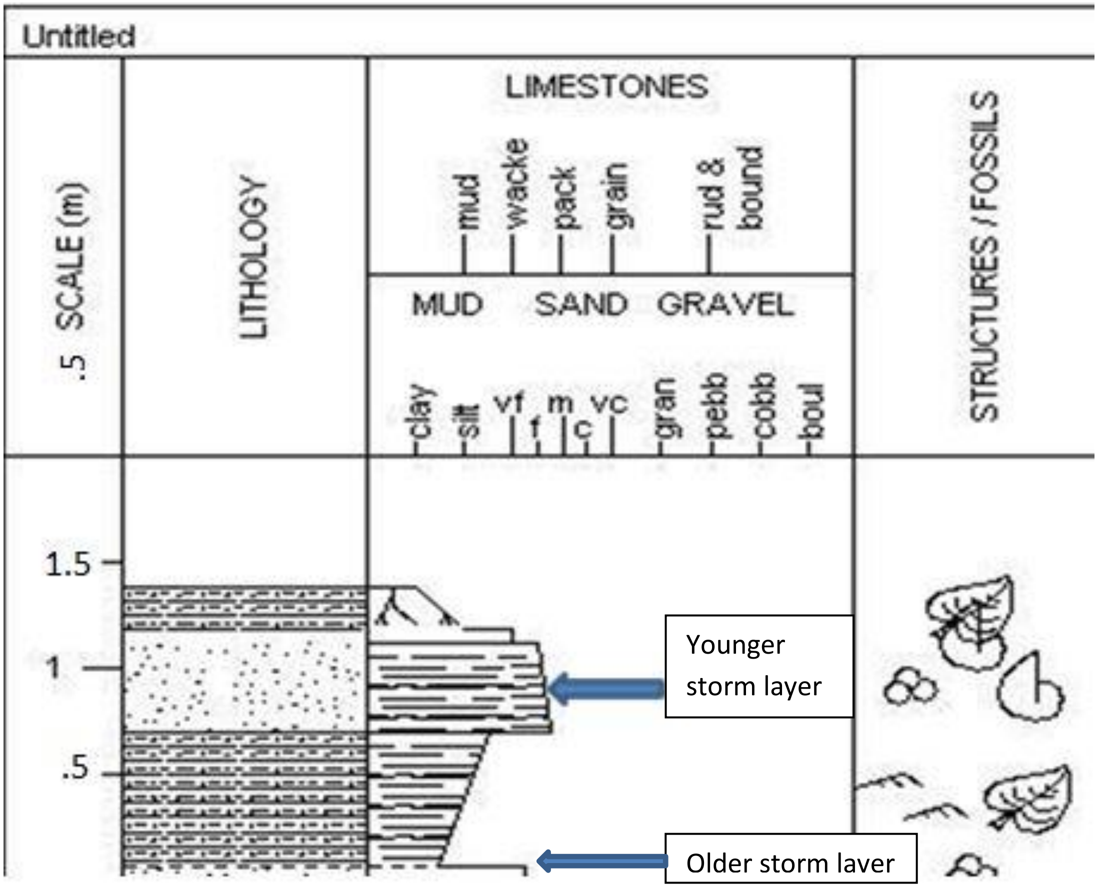
The variance in sand lens thickness may be attributed to marsh surface morphology at the time of deposition. Dips and rises are common in marsh environments and may cause areas of accumulation while thinning of the sand lens would be caused by rises or small elevated areas. The upper sand lens at core FM7 was 20-cm thick, with another 22.5-cm of mildly bioturbated sand above suggesting that the upper sand lens may continue for a much longer distance before terminating. It is likely that the upper sand lens was thicker at the time of deposition. The sand lens at FM8 was 13-cm thick, and bears evidence that this location has been bisected by inlets or meandering marsh creeks in the past as several intervals of sand, silt, and clay were present down core. As an interesting note, FM5 displays two additional storm layers containing offshore taxa.

The first anomalous sand lens is 10-cm below the sharp contact at the base of the younger sand lens. This lens is wedge shaped and intrudes half way into the core as if it were the edge of a sand lens deposited to the left of the transect. The second anomalous sand lens is 2-cm wide and 5-cm above the base of the core (see appendix Figure X11). The second anomalous lens contains clean sand and displays no evidence of bioturbation. Its appearance is in only one core within a transect of eight and is conceivably due to the depositional area of an unrelated overwash deposit that only an edge was incidentally sampled. Both anomalous sand lenses are likely edges of storm deposits not associated with those analyzed in this study.

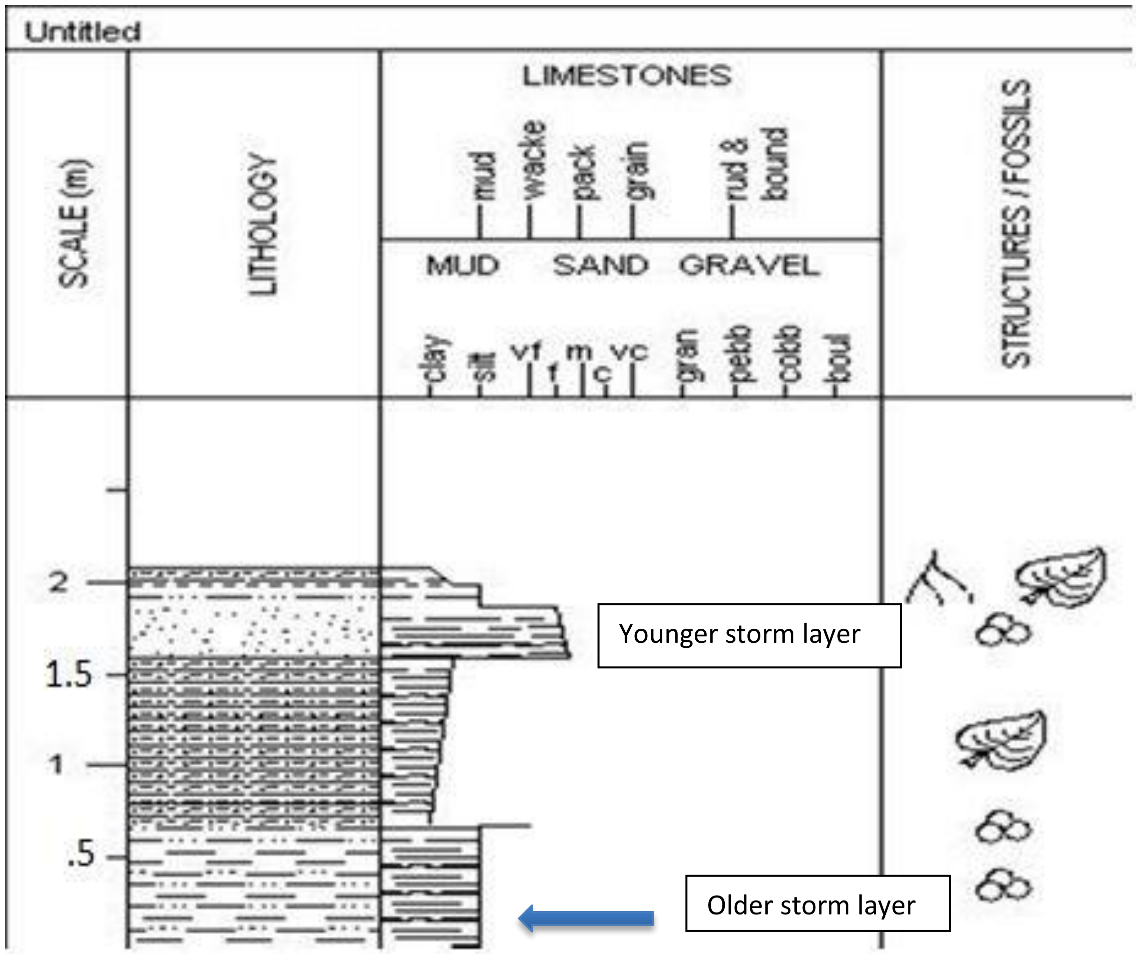
An interesting note from the observation of the bisected cores is the shape of the storm layers studied. The younger storm layer is very thick and easily visible throughout all eight cores. The wedge shaped structure mentioned from studies by Riggs et al. (2008) and Sedgwick and Davis (2003) is present with a landward dipping slope to some degree along the cross-section of all eight cores, but the increase in storm layer thickness past the mid-point of the transect was unexpected. Eight core logs produced to illustrate changes in grain size down core throughout the transect are presented below (Figures 5.6-5.13).



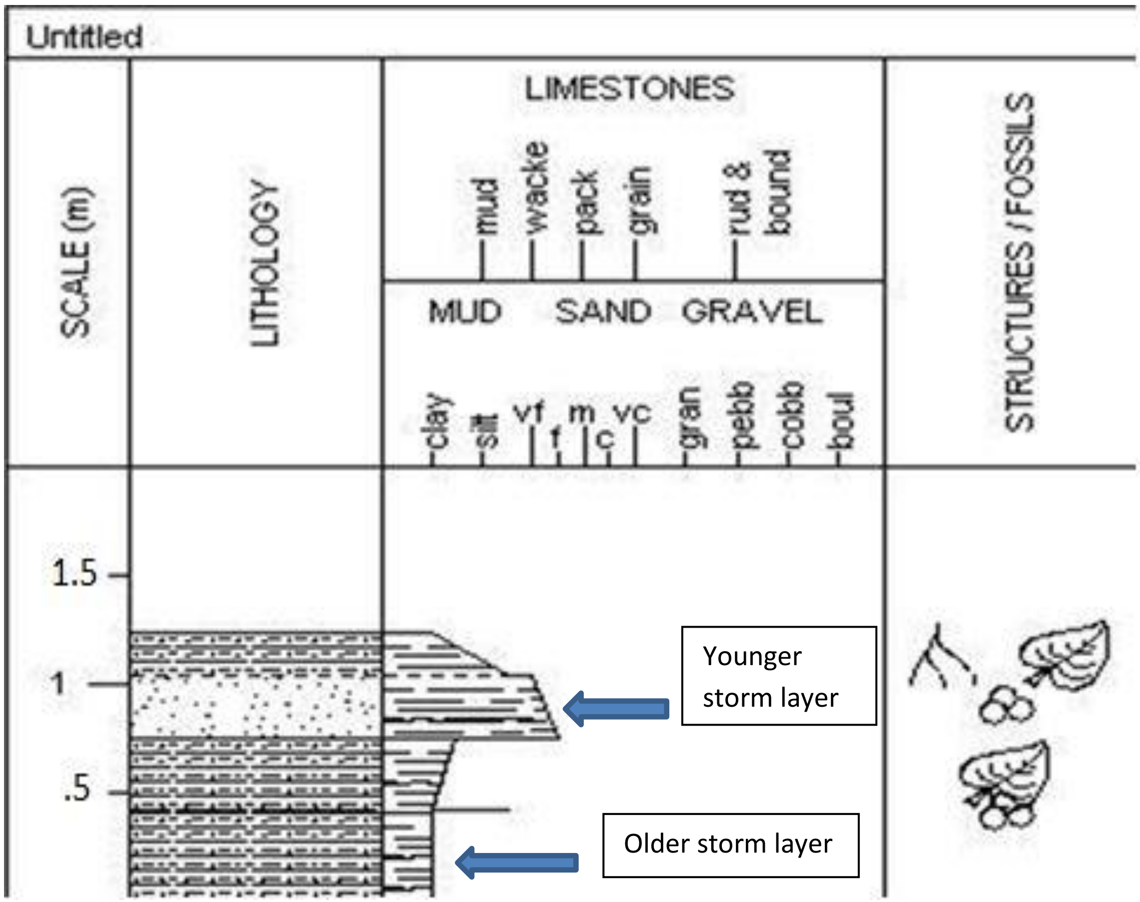

(Figure 5.6) Core log for FM1. Moving from the base of the core to the top, the older storm layer appears as a silt layer with fine grained sand that contains an abundance of microfossils from 139-cm to 134-cm. This is followed by a sharp decline in grain size that gradually increases until encountering the sharp contact between the marsh facies and the overtopping younger sand lens. The younger storm layer is a thick sand lens of fine to medium grain sand also rich in calcareous microfossils. Above the upper sand lens is fine grain organic mud containing plant material and sand bioturbated upward from the storm layer.



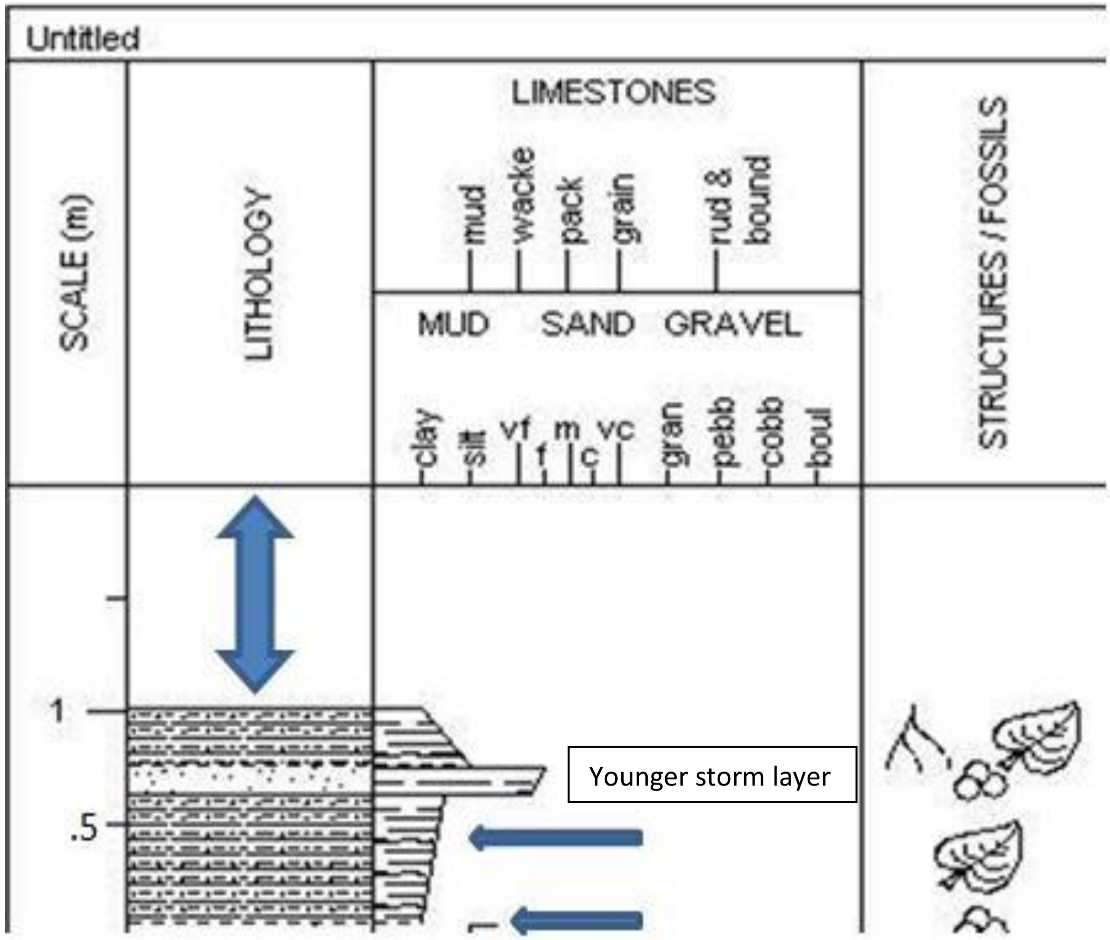

(Figure 5.7) Sediment contains echinoid spines and sponge spicules within the sandy layers of both the older and younger storm layers. These ocean remnants were found in FM1, but were more prominent here in FM2 at the blue arrows.



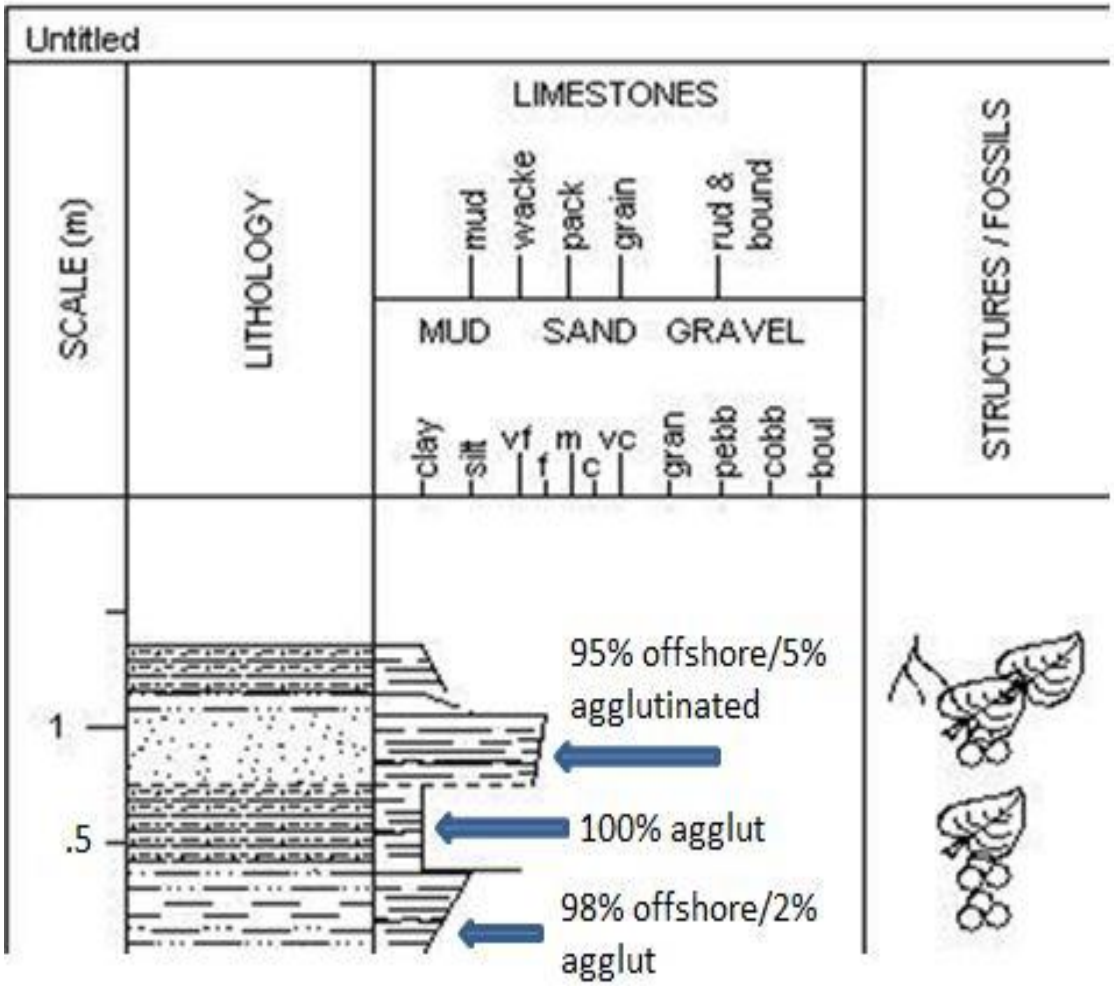

(Figure 5.8) Good recovery of sediment and deepest core. FM3 has a thicker silt layer at the older storm layer (at the blue arrow). Though FM3 was not analyzed in the high resolution as FM1 and FM2, the increase in agglutinated genera in the marsh facies and offshore-indicative genera in the storm layers are noticeably divided.



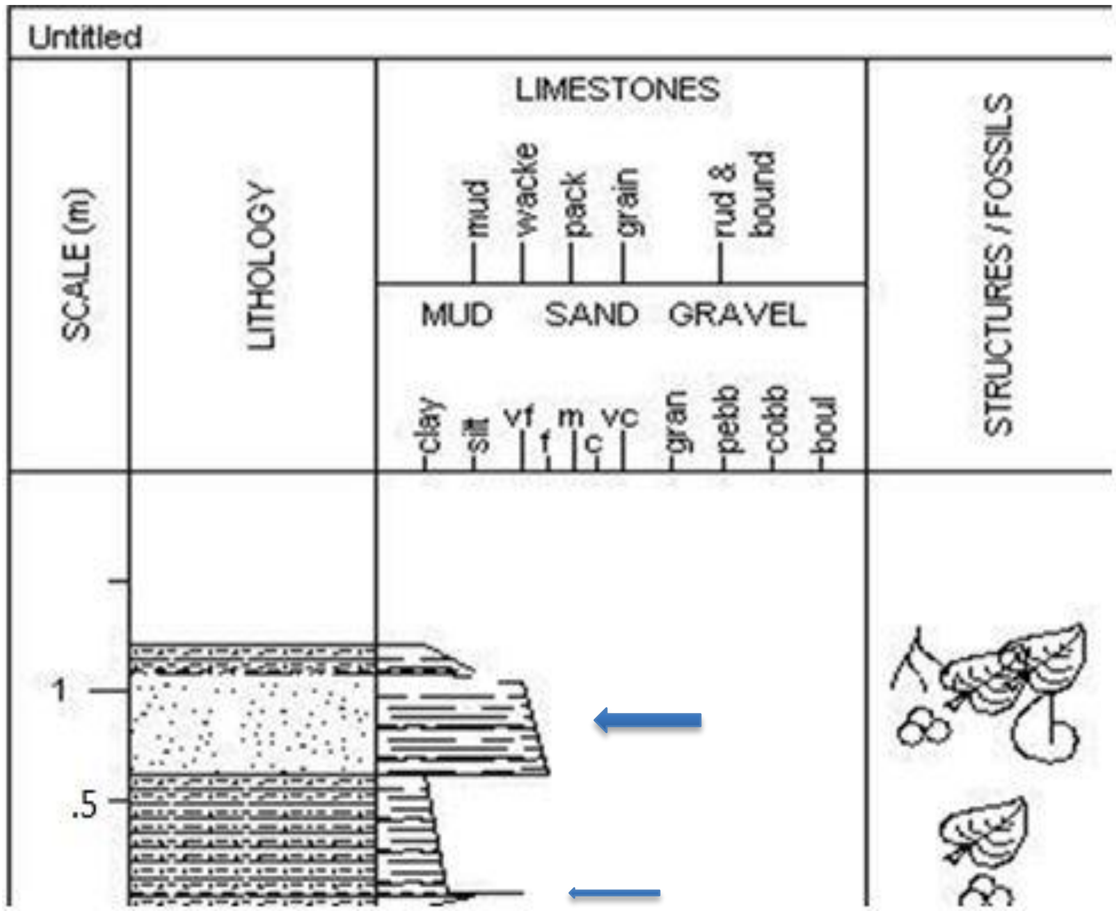

(Figure 5.9) FM4 contains nearly the same sediment recovery as FM1 and FM2. The older storm layer is highly bioturbated making the difference in grain size barely perceptible (lower blue arrow). A smaller sand lens at the younger layer shows the wedge feature along the transect described by Sedgwick and Davis, 2003. The sand lens at the upper blue arrow has tan sand instead of the white sand from the other cores.



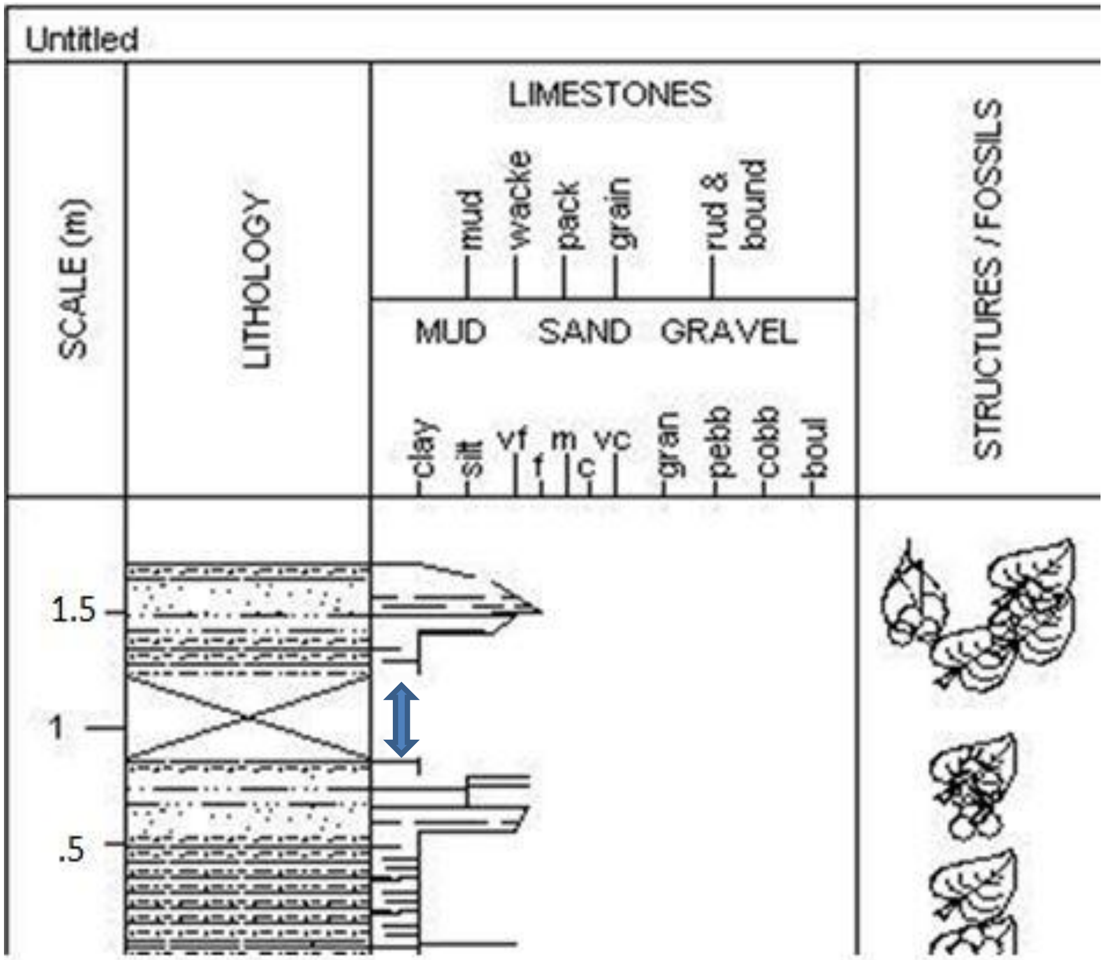

(Figure 5.10) FM5 had a smaller sediment recovery, but did contain two other storm layers not found elsewhere in the transect (located at the two smaller arrows). The top 112-cm of the core is empty due to compaction as depicted by the blue, two pointed arrow.




(Figure 5.11) FM6 has an older storm layer with normal graded bedding. Offshore-indicative genera maintain a sharp rise within the storm layer. The older storm layer is only visible upon partial drying (lowest blue arrow). There is a sharp rise in agglutinated genera within the marsh facies as noticeable segregation of taxa has occurred (middle blue arrow). The younger storm layer shows thickening of the sand lens containing white sand and maintains a sharp rise in offshore-indicative genera with very few marsh taxa.

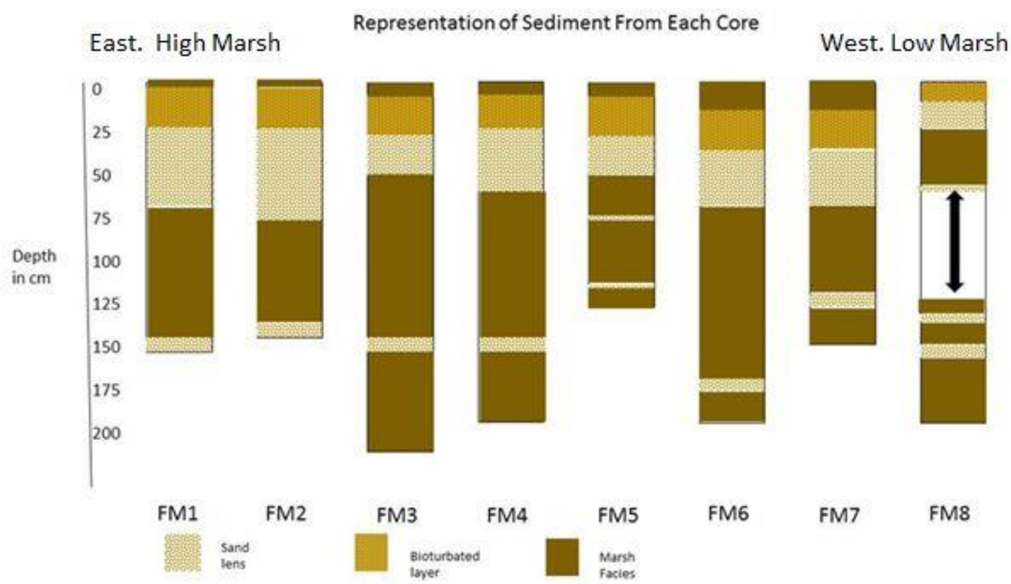



(Figure 5.12) FM7 contains a younger sand lens the same width as FM6. A smaller portion of the older storm layer is evident by offshore foraminiferal assemblages only. The lower layer is texturally unrecognizable from the marsh facies. Storm layers are located at the blue arrows.




(Figure 5.13) FM8 displays fair sediment recovery with several intervals of clay, silt and sand along with marsh facies. Slumping in the middle has left 36-cm empty at 48-cm in depth to 84-cm (blue arrow). The sediment intervals of sand, silt, clay, and marsh mud is likely due to tidal channel sequences caused by meandering marsh creeks.

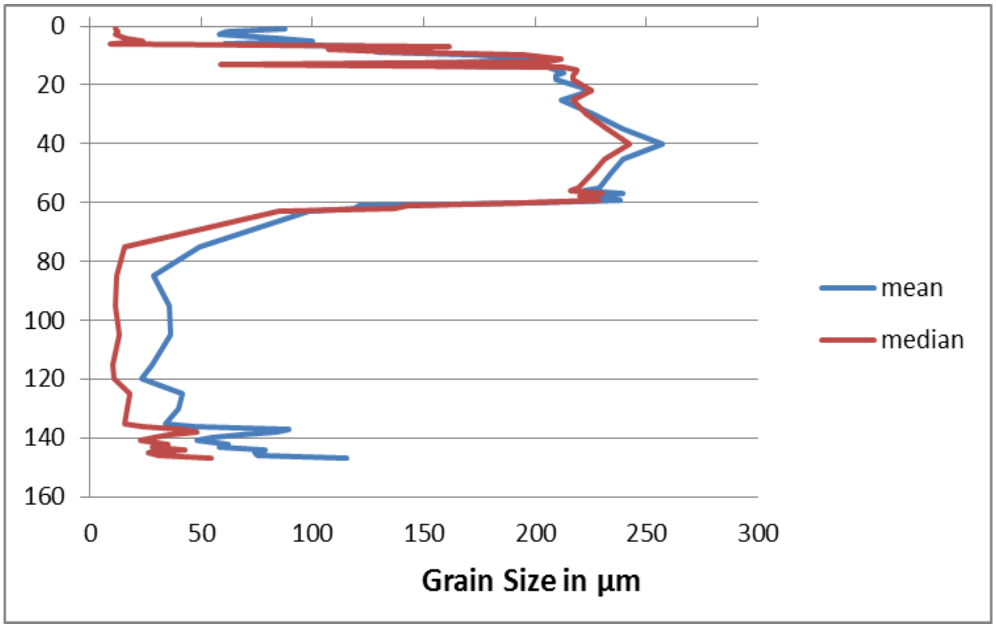
The youngest storm layer was thick and massive with little to no distinguishable bedding or laminae caused by its deposition. The upper storm layer, though continuous, did not provide the ideal wedge shaped structure expected from an overwash deposit as it seems to thicken at the landward end of the deposit. The lateral extent of the upper storm layer continues beyond the end of the 40 meter transect. FM1 and FM2 displayed a clean sand lens over 40-cm thick. FM3 also had a sand lens that was clean and white at a thickness of 28-cm. FM4 was cored 5 meters away and had a similar thickness of 29-cm, but contained a tan sand color as opposed to the white sand of the cores before. FM5 contained white sand 12-cm thick with marsh mud intruding into the sand lens (likely due to bioturbation). FM6 displays a clean, white sand lens 31-cm thick and is lacking evidence of bioturbation. FM 7 is characterized by a sand lens 42-cm thick and tan in color. FM 8 had a clean sand lens of 13-cm thick and white in color. The approximation of FM8 to a marsh creek made interpreting storm deposits more difficult. The upper sand lens of FM8 does coincide with the presumed Hugo deposit, however, intervals of sand lens, clay, silt, and mud intermittently displays clearly the influences of fluvial stream sequences which would obscure storm layer data (Figure 5.14).



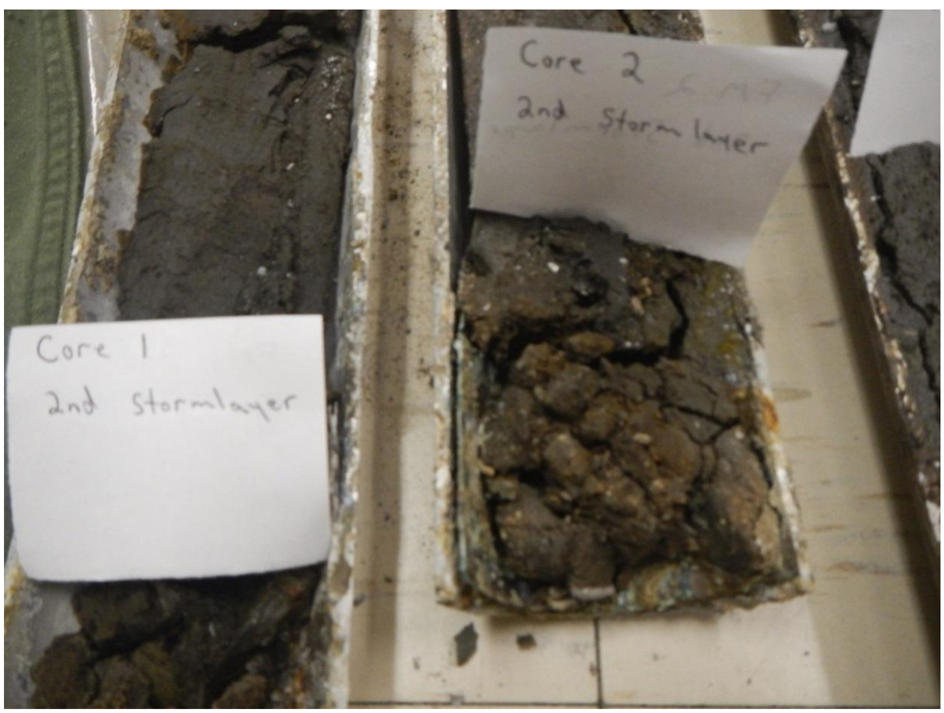

(Figure 5.14) Core transect with depth and sediment layers. The arrow at FM8 represents empty space due to slumping.

The older sand lens is a heavily bioturbated layer approximately 145-cm down core from the sediment surface. Taking into account approximately 30 cm of compaction from the vibracoring process measured from the bottom of the vibracore head where it stopped at the ground surface. This approximation means the older sand lens would have come from 175-cm down core from the marsh surface. FM1 and FM2 display this older sand lens as developing pedogenesis suggesting prolonged exposure to the surface and slow burial (Figure 5.16). Such exposure allows for moderate to intense bioturbation that obscured the lens, making the lens not readily identifiable. Increase in sand content is noticeable within the texture of this deposit and spans 5-cm wide. Peak grain size occurs in a 1-cm thick interval located in the center of the deposit. Preservation characteristics of the older storm layer indicates that the marsh environment at the time of deposition may have been lower intermediate marsh transitioning to high marsh due to the obscuring of the sand lens by bioturbation and the likelihood that the dunes have pushed landward as Folly Island is transgressing.

Below the older storm layer, plant material is found along with a sharp decline in grain size suggesting a boundary to underlying marsh facies. FM3 through FM6 displays this older storm layer as a thin sand lens of 1-cm to 1-mm thick. FM5 failed to recover a complete core and does not contain the older storm layer. FM8 also does not contain a distinguishable older storm layer. Intense bioturbation caused the older storm layer to be visually unrecognizable, but not undetectable. A thin sand layer was intact, though the majority of the original storm signature had been mixed through bioturbation according to grain size results. Grain-size analysis using the laser diffraction particle analyzer presents a clear increase in both mean and median grain size within a 5-cm range from 142- 148 cm in depth in FM1 (Figure 5.15) and from 132-137 cm in depth for FM2.




(Figure 5.15) FM1 mean and median changes in grain-size down core. Note the clear rise in grain size for the older storm layer in the interval between 142 and 148-cm.




(Figure 5.16) Pedogenesis developing within the older storm layer containing clay and sand. The development of peds indicates the weathering processes responsible for soil development. Textural differences created by the storm layer, the presence of clay and silt, and the organic content together give the appearance of a soil horizon.

FM4 displays the older storm layer as a clearly defined layer of silt and fine grain sand amidst marsh mud facies (figure 5.17)


(Figure 5.17) FM4 displays the older storm layer with sharp contacts both above and below the layer (blue arrows).

## 5.3 Correlations of Storm Proxies

Correlation analysis was performed in order to compare storm-layer proxies (Table 5.3). For example, it was expected that offshore-indicative calcareous foraminifer populations would correlate strongly with increases in grain size and the number of agglutinated taxa would be inversely correlated with increased sediment coarseness. This analysis also provides data for comparing changes in foraminiferal assemblages and grain sizes that can be expected in a relatively young storm layer and a much older storm layer.

In core FM1, a relatively strong correlation value of 0.76 (using Pearson's coefficient Figure 5.4-A) was found between the number of agglutinated specimens present and the average sediment content of 85% sand when analyzing the younger storm

$$r = \frac{\Sigma(X-\overline{X})(Y-\overline{Y})}{\sqrt{\Sigma(X-\overline{X})^2}\sqrt{(Y-\overline{Y})^2}}$$

Where, $\overline{X}$ = mean of X variable
$\overline{Y}$ = mean of Y variable

layer. The equation for Pearson's correlation coefficient is:

Graphic data also shows an increase in agglutinated specimen numbers with the increase in grain size for the younger storm layer (Figure 5.2). Correlation data for FM2 displays the same pattern with agglutinated assemblages in the upper layer at a 0.60 positive correlation with grain size. Planktic foraminifera comprised of *Globergerina* spp. were found to have the strongest correlation to coarsening of grain size. Upper sand lens data display a 0.78 positive correlation to coarser grain size in FM1 and a 0.73 positive correlation in FM2 (Table 5.3).

Offshore-indicative foraminifera, which include shelf species, planktic genera, and reworked older microfossils, display correlation values of 0.65 in FM1 and 0.60 in FM2 for the upper (younger) storm layer. Though this correlation is strong, graphic and grain size data displays a noticeable spike in the first 6-cm of the storm layer, but does not persist in abundance throughout the storm layer (Figure 5.2 and Figure 5.3).

The lower (older) storm layer displays a unique set of features such as the thin sand lens within a mostly silt matrix along with a spike in offshore microfossils that are not present in the upper storm layer (Figure 5.2 and Figure 5.3). Agglutinated species assemblage in the lower storm layer has a -0.01 correlation to grain size in FM1 and a 0.22 in FM2. Data from FM1 shows a drop in agglutinated taxa with the rise in grain size and in FM2 the rise in agglutinated taxa with grain size is very weak. The lower storm layer most likely had similar characteristics as the upper storm layer in terms of agglutinated taxa richness and abundance when first deposited.

Planktic correlation values with grain size for FM1 were 0.34 and FM2 0.52 for the lower storm layer. Storm layer preservation appears to be moderately intact when comparing grain size data with peaks in planktic species assemblage. The lower storm layer displays a sharp rise in offshore-indicative foraminiferal assemblage; however, the increase in grain size is not very strong. Correlation data for FM1 is 0.37 and 0.15 for FM2. The lower storm layer for FM1 displays a small peak in grain size at 138-cm in depth, but a tremendous peak in offshore-indicative assemblage with approximately 1,595 individuals. Grain size begins to drop from 138-cm to 142-cm and rises once again toward 147-cm. Though the correlation is moderate in FM1, increase in grain size is weak and does not parallel the extreme increase in foraminiferal abundance. Correlation data from FM2 reflects a sharp increase in offshore assemblage at 131-cm in depth, but without an accompanying peak in grain size. The peak in grain size for the lower storm layer occurs at 135-cm. The number of offshore-indicative species rise to 3,500 (Figure 5.2) individuals and remains high until the end of the core at 138-cm. Data used for the correlation calculations can be found in Figures X1-X6 of the appendix.

Table 5.3-A and Table 5.3-B also contain the P values for each Pearson coefficient calculation. The P-value is the probability that the results from the correlation coefficient were derived by chance or are significant. Values that are less than 0.05 are statistically significant and, therefore, can be used to identify the strength of the correlation between the values being investigated. Negative P-values indicate the strength of a negative correlation between the values investigated.

(Table 5.3-A) This table displays correlation data between foraminiferal taxa and grain size as well as correlation between different foraminiferal taxa to each other. (Note: GS= grain size)

| FM1 Correl | | |
|---|---|---|
| TOTAL | CORR | P Value |
| Planktic vs. GS | 0.475027 | 0.00049 |
| Benthic vs. GS | -0.21543 | -0.13297 |
| Agglut vs. GS | 0.756953 | 2E-10 |
| | | |
| UPPER LAYER | CORR | |
| Planktic vs. GS | 0.776761 | 4.00E-09 |
| Benthic vs. GS | 0.647949 | 5.54E-06 |
| Agglut vs. GS | 0.757184 | 1.56E-08 |
| | | |
| LOWER LAYER | CORR | |
| Planktic vs. GS | 0.337096 | 0.311 |
| Benthic vs. GS | 0.372704 | 0.259 |
| Agglut vs. GS | -0.01038 | -0.976 |
| | | |
| TOTAL DATA | CORR | |
| Benthic vs. Aggl | -0.02631 | -0.939 |
| Planktic vs. Ben | 0.606822 | 0.048 |

| FM2 Correl | CORR | P Value |
|---|---|---|
| UPPER LAYER | | |
| GS vs Benthic | 0.600 | 0.003 |
| GS vs Planktic | 0.734 | 0.0001 |
| GS vs Agglutinated | 0.602 | 0.003 |
| | | |
| LOWER LAYER | CORR | |
| GS vs Benthic | 0.153 | 0.653 |
| GS vs Planktic | 0.525 | 0.097 |
| GS vs Agglut | 0.217 | 0.522 |
| Total Forams vs GS | -0.398 | -0.225 |

(Table 5.3-B) This table displays correlation data between foraminiferal taxa and grain size as well as correlation between different foraminiferal taxa to each other (Continued). (Note: GS= grain size)

| FM2 | | P Value |
|---|---|---|
| Correlation Mean Grain Size: Total Forams: | -0.398 | -0.067 |
| | | |
| Correlation Calcareous vs Mean GS: | -0.458 | -0.032 |
| | | |
| Correlation Offshore vs Mean GS: | -0.436 | -0.043 |
| | | |
| Correlation Agglut vs Mean GS: | 0.481 | 0.005 |
| | | |
| Correlation Planktic vs Mean GS: | 0.480 | 0.005 |
| | | |
| Correlation Calcareous vs Agglutinated: | -0.140 | -0.534 |
| | | |
| Correlation Offshore vs Agglutinated: | -0.123 | -0.586 |
| | | |
| Correlation Planktic vs Agglutinated: | 0.339 | 0.054 |
| | | |
| Correlation Calcareous vs Planktic: | 0.162 | 0.368 |
| | | |
| Correlation Offshore vs Planktic: | 0.173 | 0.336 |

Data from the upper storm layer displays an incongruity between grain size and foraminiferal species. Throughout the sand lens, grain size steadily increases through the bioturbated top layer and levels out to medium sand with the lens of pure sand as expected. However, all foraminiferal species decline between 24-cm and 57-cm (Figure 5.3).

# CHAPTER 6: DISCUSSION

## 6.1 Spatio-Lateral Continuity

Storm-layer sedimentology has been described by several researchers during the last twenty years (e.g. Collins et al., 1999; Donnelly and Woodruff, 2007; Hippensteel, 2011; and Horton et al., 2009). These reports consistently describe storm deposits as containing landward dipping laminae and larger shell fragments toward the landward end of the storm deposit. The transect taken from the marsh of North Folly Island in July 2017 did not render strong depositional characteristics such as bedding structure, only laminae. The upper storm layer consists of a thick, clean sand lens that was relatively featureless and homogeneous. Laminae were no longer visible after exposure to open air for 24 hours.

The lower storm layer has evidence of heavy bioturbation due to the mud content and smeared storm signature with a very thin sand lens still intact. The evidence of pedogenesis found in the lower layer of FM1 and FM2 are more indicative of the environment in which the layer was deposited and duration of exposure, but displayed no other distinctive sedimentological characteristics, such as lamellae, when it was deposited. The lower storm layer is characterized by a distinctive 5-cm thick layer of silt deposited from high to low-marsh. This layer became visible after partial drying of the transect cores. Two storm layers were consistently found throughout the entirety of the eight-core transect. This creation and preservation of lateral continuity can be difficult to find as overwash fans are directly related to storm surge and will occur in unpredictable locations. Preservation of the sand lens throughout the transect is directly related to the extent and thickness of the original deposit as well as the amount of bioturbation and speed of overlying deposition and burial; nevertheless, the upper sand layer was found at a depth of approximately 35-cm in all eight cores. This depth is out of bioturbation range and is important to the preservation of the deposit.

Buried storm layers may not overlap deeper storm layers in their entirety causing these layers to seem discontinuous when sampled down-core. Overwash deposits occur intermittently throughout the length of the marsh, depending on where the energy is concentrated and inundates the marsh environment. The location of deposition is also dependent on the direction of travel and strength of the storm (Kiage et al., 2011). Coring as a method of storm layer analysis may only sample the edges of underlying storm deposits and would explain the discrepancies described in (Hippensteel, 2011) as completely different storm records were found in cores only 10 meters apart. The extent of the storm deposit would also be dependent on available energy, causing some deposits to truncate, while other layers may be more extensive. Therefore, buried storm layers may be continuous, but difficult to sample in their entirety without prior knowledge of the exact location and parameters of the overwash fans (Figure 6.1). Prior to coring, ground penetrating radar (GPR) assistance in locating the different layers of storm deposit may be appropriate.


(Figure 6.1). Hypothetical back-barrier marsh featuring possible patterns of overwash and reasons lateral continuity may be difficult to obtain. In this Image the blue lines represent the oldest overwash deposits, the green represents the second oldest, and the red lines represent the most recent deposit. Black dots represent a hypothetical transect of cores. This figure illustrates the differences in sediment units encountered depending on the location sampled.

Barrier islands such as Folly Island are a dynamic, ever-changing environment that experience barrier island roll-over processes, tidal inundations, and storm activity. Quiet waters within the marsh, subject to cyclical influx of ocean water, allow large populations of fiddler crabs, clams, and other burrowing marine and marginal-marine life to flourish (South Carolina Department of Health and Environmental Control, 2015). This environment can be detrimental to the preservation of storm layers as the rate of bioturbation is high and the corresponding rate of deposition needed for rapid burial and preservation is relatively low. This study shows that a storm layer may not be destroyed and that even very old storm signatures can be preserved to some degree.

The upper storm layer was likely deposited during hurricane Hugo's landfall in 1989. This assessment has been reached due to the depth of the sand lens, its location, and the thickness of the deposit. Other studies in the area indicate that the average sedimentation rate of the marsh at this location is 1.1 mm per year (Hippensteel, 2011) (Sharma et al., 1987). Since the sandy deposit was buried 18 cm below the surface, and the mixed sand and mud starts approximately 3-cm below the surface, this sand lens was created between approximately 30 to 180 years ago. It is important to note the possibility of a higher sedimentation rate in the high-marsh and intermediate-marsh as the dunes encroach on the marsh over time. Hugo impacted the coast of South Carolina as a Category 4 hurricane. The eye of Hugo passed over the Isle of Palms approximately 8 miles (12.9 km) north of Folly Island. The size and strength of Hugo, coupled with the proximity of landfall in regards to the site of the coring transect has made it likely that the upper storm layer was created by this storm. The characteristics of a storm layer as described by Morton and Barras (2011); Sedgwick and Davis (2003); and Williams (2013) agree on the structure of a storm deposit as being wedge shaped and containing forward dipping laminae, normal graded bedding, or other sedimentological characteristics created by the process of deposition. These features were not preserved in the cores for this study.

Sand lens thickness from FM1 to FM7 displays a continuous layer, however, does not contain the expected wedge feature described in other studies. The sedimentological oddity in the shape of the first sand lens may depict the dynamics of storm layer deposition. Direct landfall of Hugo was close enough to North Folly that the inundation of the marsh was violent enough as to displace a large wall of sand which was thrust to the front of the storms overwash. Hugo passed 8 miles (12.9 km) north of Folly Island with an eye 40 miles (64.4 km) wide. Folly Island endured the winds and storm surge of a nearly direct impact from Hugo; however, due to the counter-clockwise wind patterns from the left side of the storm, some scouring could be expected. This may be the cause of the thinning of the sand lens in the middle of the deposit as the majority of the material would occur at the beginning and end of the deposit's expanse. Marsh morphology could be responsible for the depth which the storm layer is found.

FM1 and FM2 display the lower storm layer as highly bioturbated and showing the development of peds (pedogenesis) that comes from a weathered surface layer transitioning into a soil horizon. This would indicate a period of time which the storm layer was exposed to the atmosphere and surrounded by vegetation, allowing soil formation to occur. If average sedimentation rate, calculated from Hippensteel and Martin (1999) is accurate for an adjacent coring locale, the older storm layer is about 1,000 years old or older. It is reasonable to assume this layer may have been deposited closer to the intermediate marsh rather than the high marsh depending on the rate of island roll-over. The older layer seems to be the final remnant of the initial storm signature, yet it appears in all eight cores as a sand lens 1-cm to 1-mm thick. The condition of this thin layer of sediment, with a condensed foraminiferal assemblage, suggests the preservation of a highly-altered storm deposit with most of the sedimentary signature destroyed. Sediment data gathered from the second storm deposit depict sediment that would have been subjected to intense bioturbation if exposed long enough to develop pedogenesis within the intermediate marsh.

FM3 displays the older sand lens as less than a centimeter thick surrounded by 5-cm of silt. This deposit persist throughout the transect and is characterized as 5-cm of silt and fine grain sand mixed in FM4, but can still be found to FM6 where it pinches out by

FM7. Similarly to the upper sand lens, it appears that the lower lens also thins toward the middle of the transect and becomes slightly thicker toward the end of the deposit before it is undetectable. In the case of both storm layers, exposure to surface conditions is likely to have an influence on the characteristics of the sand lens. Protective deposition layers form slowly, allowing lateral drift of layers from the sand lens during normal storm events as well as aeolian transport to occur. Mixing of the first 18-cm of sediment from each core caused by bioturbation indicates a much thicker original deposit. Evidence would concur with findings from Hippensteel (2011) that preserved storm records may only display the thickest and most robust deposits. The second sand lens was found deep enough to have been protected from recent bioturbation as fiddler crab burrowing for the species common in South Carolina is approximately 10 to 20-cm (Hippensteel, 1999). The sharp contact between the sand lens and underlying marsh facies displays the absence of bioturbation beyond the upper layer. The characteristics of the sand lens in both the upper and lower layer agree with Hippensteel and Martin (1999) and Sedgwick and Davis (2003); two studies that describe bioturbation as non-continuous, but dependent on the depositional subenvironment. The upper storm layer shows moderate bioturbation by the amount of sand mixed upward in FM5, located in the low marsh, yet the same cannot be said for FM6. Cores FM6 and FM7 display large upper sand lenses indicating other variables than bioturbation as important factors of storm layer preservation. Scouring from outwash during deposition may have been localized to the area of FM5.

Preservation of the second storm layer is somewhat of a mystery. Grain-size analysis does not display a large increase in particle size at the area surrounding the thin deposit, but seems to be localized to the thin sand lens present in the middle of a silt deposit. Mixing of the lower sand lens is restricted to 2-cm above and below the site of highest concentration of larger grain size. Laser diffraction particle analysis was performed only on FM1 and FM2. Physical textural analyses were performed on all eight cores experiencing no detectable changes in grain size above and below the second sand lens from FM3 through FM6. Persistence of the second storm layer is somewhat unlikely as it appears to have been preserved as a thin sand lens within a layer of silt and still contains an abundance of foraminifer. The existence of the lower storm layer is extraordinary as it should have been completely destroyed by bioturbation due to its thinness, as a sand lens surrounded by silt. It is conceivable that the older storm layer was once much thicker and robust, however, there is no trace to prove this assumption in over or underlying sediment. Preservation due to burial for over 1,000 years should not cause deterioration if beyond the reach of bioturbation. Preservation would be possible if deposited in the high marsh, away from intense bioturbation, and buried quickly. Slow burial and extended time within the boundaries of bioturbation may be the source of alteration of this layer; however, remnants from mixing should be detectable in surrounding sediment.

The study conducted by Hippensteel (2011) was located in the immediate vicinity of this study, less than 50 meters to the south. The 20-m X 40-m gouge-auger grid method from the Hippensteel (2011) study is a good reference for sedimentological and micropaleontological comparisons. The gouge-auger grid reportedly found several discontinuous sand lenses. Thin sand lenses were found between 1.5-m and 1.8-m, but only in the high-marsh cores. Four layers were detected between 2.2-m to 2.7-m in depth, which were recovered in 11 of the 15 cores. Inconsistency in storm layer lateral continuity seems to be localized to cores in the middle of the study's multiple transects. The disappearance of sand lenses mid-transect may be related to the thinning of the storm layers mid-transect in this study as well. Several of the sand lenses recovered in the Hippensteel (2011) study were described as thin, with offshore-indicative foraminifera mostly present in high-marsh samples. The upper sand lens of this study is thick in comparison to those described in Hippensteel (2011), and is consistently found throughout the transect. Of all the sand lenses recovered in the 2011 study, several were found to be devoid of offshore foraminifer. The storm layers found between 2.2-m to 2.7-m did contain sharp contacts, even in the low-marsh. This is consistent with the findings in this study as well as the indication of quick burial taking the storm layer out of the bioturbation zone of 10 to 20-cm before complete destruction.

This study complements the earlier work reported by Hippensteel (2011) because it analyzes storm layers at a higher stratigraphic resolution. A sharp contrast between these two studies is that this study found only two storm layers with offshore-indicative foraminiferal assemblages throughout the transect. Dissolution of calcareous foraminifer or other geologic processes creating the sand lenses found in the 2011 study has provided different return intervals between sedimentological and microfossil proxies. Variability in depositional mode for these sand lenses in a back barrier marsh results in differing storm signatures, although both studies agree that a multi-proxy approach is necessary to discern a storm record even if only the largest hurricane strikes are detected.

## 6.2 Comparisons of Foraminifera Assemblages

Different taxa are found in the younger, thicker storm deposit than the lower, thinner storm interval. The first storm layer is characterized by off-shore indicative microfossils. Shell fragments, sponge spicules, and echinoderm spines abound within this deposit. These microfossils indicate a marine source for the sediments and a high-energy mode of transport from offshore and into the marsh. Microfossil data contrast with reports from previous studies (e.g. Hippensteel and Martin (1999) (2000) and Hippensteel (2011). Foraminiferal assemblages were not as divided between agglutinated taxa in the marsh strata and calcareous taxa within the sand layers. Findings from Hippensteel and Martin (1999) and Hippensteel (2011) describe very few samples containing both calcareous and agglutinated taxa. Data from FM1 displays an agglutinated dominated facies for the first 18-cm of mixed layer with very few calcareous species. Below 18-cm begins a clean sand lens with little to no mud from the overlying marsh facies. From 19-cm to the sharp contact with underlying marsh facies at 60-cm there is a sudden increase in the number of both agglutinated taxa, calcareous taxa, and planktic taxa.

The calcareous genera recovered are similar to those reported from Hippensteel (1999, 2000, 2011). However, the presence of all foraminiferal assemblages increasing within the storm layer causes a positive correlation between grain size and taxa assemblage for marsh species as well as calcareous and planktic taxa. This may be a result of marsh Foraminifera being concentrated as they are swept up by the two-stage inundation of overwash. The absence of agglutinated taxa within marsh mud facies was also unexpected. Foraminiferal diversity and richness were centered on the storm layer deposit, meaning they all happened at once and they all disappear from the stratigraphic record concurrently.

Planktic foraminifers only occur within the storm layer and do not appear before or after the clean sand lens of the storm signature. Though planktic foraminifers are subject to bioturbation, the absence of this species within the marsh facies until acted upon by a violent storm event allow for a stronger correlation with an increase in grain size as marsh facies transition into storm layer and back to marsh facies. Planktic foraminifera are only present in locations where the grain size is increasing and abruptly truncated as the sediment moves back to marsh facies, allowing for a stronger correlation. Correlation of offshore taxa abundance and increased grain size was not as strong as expected. This weak correlation is due, in part, to the lack of significant quantities of sand in the lower, foraminifer-rich storm layer. Sediment and grain size does not support bioturbation as the cause for the increase of all foraminiferal taxa within the storm layer. Concentration of the different foraminiferal assemblages within the storm layer may be caused by the suspension of existing marsh foraminifer and mixing with transported offshore taxa causing the mixing of assemblages in the cores. The increase in grain size within overlying marsh sediment is indicative of a sand lens obscured over time by bioturbation. The extreme rise in offshore-indicative foraminiferal assemblages is evidence that the sediment has been transported from open ocean sources (compare Figure 5.2 and 5.3).

One interpretation of the foraminifer populations within the sand layer is a three-layer model: two layers of offshore-derived storm deposition with a thick layer of interbedded dune sand. This is evident in the drop in foraminifer populations between 20-

cm and 40-cm in FM1 and 20-cm to 60-cm in FM2. Samples taken from the low marsh in cores FM4, FM5, and FM6 display expected correlations of small grain sizes and the presence of marsh foraminiferal taxa. Foraminiferal analyses suggest a low-marsh environment with high numbers of common marsh species above the upper sand lens and below the sharp contact of this lens. Very few marsh species were found within the sand lens itself, indicating a difference in the dynamics of foraminifer preservation dependent on marsh environment. Agglutinated taxa existing above the upper storm layer in the high-marsh are not as abundant as those within, leading to the possibility of marsh foraminifers becoming swept together in a concentrated location and deposited with non-marsh species. The inclusion of high numbers of marsh specimens within the upper storm layer can also be attributed to bioturbation over the length of time during which 18-cm of deposition has occurred on top of the sand lens. This depositional model may also explain the distribution of agglutinated foraminifer occurring in two distinct spikes in species numbers at the top and bottom of the upper sand lens.

Though the upper sand lens was measured visually as starting after 18-cm of mixed layer above, grain size data from the laser diffraction system reveals an abrupt increase in grain size at 14-cm in depth. This depth coincides with the first spike in marsh foraminiferal assemblage and relates to the depth in which fiddler crab burrowing would cease as they prefer softer sediment as opposed to the coarseness of the sand lens. The second spike in agglutinated marsh taxa occurs at 57-cm in depth toward the bottom of the first sand lens and can be attributed to present marsh taxa being suspended and concentrated during the first stage of storm surge. This evidence causes correlation data to be less useful for determining relationships between species and grain size. The absence of any foraminiferal taxa below the sharp contact of the upper storm layer is a quandary. This absence of foraminifera would suggest complete dissolution of agglutinated taxa or a marsh facies devoid of foraminifera. FM1 and FM2 were analyzed in highest detail and both are located in high and intermediate marsh environments respectively.

Low PH levels in marsh facies causes dissolution of calcareous species as plant material ferments and deteriorates (Jonasson and Patterson, 1992). Agglutinated Foraminifera are subject to bacterial breakdown of the organic cement that adhere the grains composing their tests within the first 10-cm of marsh facies (Goldstein and Watkins, 1998). High marsh and intermediate marsh environments periodically dry as tidal cycles and semidiurnal low tides cause low water levels. Drying of the high and intermediate marsh causes dissolution of agglutinated tests (Jonasson and Patterson, 1992; Goldstein and Watkins, 1998). FM4, FM5, and FM6 are cores from the low-marsh which displayed agglutinated Foraminifera dominated marsh facies both above and below the storm layer. Assemblages within the storm layer from FM4 and FM5 were similar to those found in FM1 and FM2, but with far fewer marsh taxa. Differences in foraminiferal assemblages from high to low-marsh illustrate the importance of sampling location and changes to be expected within the sediment. Foraminiferal assemblage data from the low-marsh were similar to those discussed by Hippensteel and Martin (1999) and Hippensteel (2011). Data from FM4 through FM6 strongly correlate agglutinated foraminifera with decreases in grain size. Low-marsh samples allow the correlation between offshore and planktic assemblages and the increase in grain size to become much more pronounced. Results from the low-marsh cores FM4 and FM6 display a weak negative correlation between agglutinated foraminiferal taxa to grain size as marsh species are present within the storm layer, but fewer individuals per $cm^3$ were observed compared to surrounding marsh facies. This distribution of agglutinated foraminifers is similar to those reported by Hippensteel and Martin (1999) as taxa numbers and richness are lower in core FM1 and FM2 which are taken at high-marsh and transitional-marsh respectively.

There is a sudden spike in foraminiferal population and diversity found within the lower storm signature, which is thought to be over 1,000 years old (calculated using the average sedimentation rate of 1-mm to 1.2 mm/year and depth of the presumed storm layer (Hippensteel and Martin, 2000; Morton, 2011). The lower storm layer may have been located in a lower marsh subenvironment when deposited and gradually became high marsh by the process of barrier island roll-over. This does not account for the preservation of the taxa within what would be a heavily bioturbated environment. The high-marsh is subject to high levels of deposition from aeolian transport and runoff from the dunes during normal rain events. The low marsh is subject to high levels of deposition from organic material build-up over time as tides flood the low- marsh bringing in thin layers of sediment (1.0 to 1.2-mm/yr.). In any case, deposition must have been rapid enough that all offshore-indicative species were preserved and contained mostly within the sand lens and the 5-cm of silt surrounding it as a mixed layer.

The older storm layer, though much thinner and less defined, contained the highest abundance and diversity of foraminifera. Marsh species were present, but scarce. There is a noticeable spike in marsh foraminifera along with the appearance of offshore taxa in both the upper and lower storm layers. Data from core FM1 displays a pattern of suspension of marsh foraminifera during hurricane impacts that cause a concentration of marsh taxa alongside the appearance of offshore-indicative foraminifer. This may also be evidence of the two stage inundation sequence described by (Williams, 2009), (Sedgwick and Davis, 2003) and (Riggs et al., 2008). FM2 displays much the same patterns as those from FM1 with the exception of the continued presence of marsh taxa below the sharp contact of the upper sand lens, in at least a small degree, with population ranges of 10 to 104 individuals per $cm^3$. FM2 being in the intermediate marsh would not be exposed to as much drying as FM1.

*Globergerina* spp. is a genus of planktic calcareous foraminifer that is common in open-ocean environments. The presence and abundance of *Globergerina* correlates strongly with changes in grain size. This suggests that *Globergerina* is a good indicator of a storm signature. The importance of the strong correlation value for these planktic foraminifer is their usefulness in samples taken in both the high and low-marsh sub-environments. Cores FM1 and FM2 have peaks in total Foraminifera per sample that coincide stratigraphically with peak abundances of offshore Foraminifera taxa. Data from FM4, FM5, and FM6 display a high number of agglutinated species within the first 20-cm of marsh facies that persist at a lesser degree into the storm layer. Lower-marsh core samples display a negative correlation between marsh taxa and increase in grain size. Planktic and other offshore-indicative taxa display a stronger positive correlation with an increase in grain size. The sharp increase in offshore foraminiferal specimens, both in species and diversity with the small increase in grain size for the lower storm layer, is the reason planktic foraminifer hold the strongest correlation to changes in grain size.

Calcareous foraminifer assemblages in the lower storm layer proved to be diverse and containing several species not previously found in the upper storm layer. Calcareous Foraminifera may be less susceptible to dissolution due to drying (Collins, 1996), which is why they were preserved in the older storm layer. Evidence of pedogenesis would suggest long-term exposure to surface conditions before the lower layer was buried, but when burial did occur it happened rapidly. The population and diversity increase of offshore-indicative species within the lower layer may be a product of the ability to withstand conditions of exposure compared to the fragility of agglutinated taxa to desiccation. High marsh, and in some cases intermediate marsh environments are not as exposed to low PH caused by plant decomposition as lower- marsh environments, and this may be responsible for the survival of this calcareous assemblage. If the original sand lens was larger than that found within the core, it is possible that the sand lens offered some protection to the calcareous foraminifer, allowing their survival until buried. The foraminiferal assemblages were deep ocean species, indicating a direct strike from a strong hurricane. The poor preservation of this storm deposit is likely due to the depositional environment of the storm layer at the time of deposition and the possibility of outwash partially destroying the storm record if the storm deposit was at the left side of the hurricane as it moved on land (Hippensteel and Martin, 1999). The other theory for this thin storm layer is that it is the last remaining remnant of the tail end of an ancient storm deposit. The appearance of exotic foraminiferal species indicates that the storm layer is most likely the result of a direct impact from the right side of a strong hurricane, but most of the deposit has been recycled through natural island processes and more of this storm layer may be found moving from the high marsh environment toward the ocean.

## 6.3 Geologic Influences

Differences in species diversity and richness may be controlled by environmental and anthropogenic changes. Storm layer deposition and preservation are influenced by the direction the storm is traveling, and the geomorphology of the site near the location of direct impact. Folly Island was reportedly heavily vegetated from the 1800's and earlier according to historical documents from General Gillmore of the Union Army recorded in The Sanitary Commission Bulletin in 1863 and (SC Department of Health and Environmental Control, 2015). Marine and beach sediment from storm activity would encounter much resistance from dune structures and stable marginal-marine vegetation. Inundation of sea water would be slowed by thick vegetation cover and theoretically produce smaller deposits. Direct impacts from a Category 3 or greater hurricane would still leave a noticeable trace in the paleostorm record during the time Folly Island was well vegetated, but could be a logical cause for less robust storm layers containing greater foraminiferal species richness and diversity than a more recent storm layer. Pilkey and Stuntz (2005) explain how vegetation removal and dune destruction encourage natural erosion and allows transport of larger amounts of sediment during storm events. North Folly Island is separated from Morris Island to the north by Lighthouse Inlet. Because North Folly lies further seaward than Morris Island, storm surge from a direct impact at Sullivan's Island further north would produce heavy inundation at Folly. This surge would approach in the direction of Lighthouse Inlet where vegetation is sparse and surrounding dunes are 2 to 3 meters lower than those directly facing the ocean. Hugo passed north of Folly Island, therefore; the counter-clockwise winds would have a scouring ebb surge toward the ocean after the initial inundation of water, bringing offshore sediment from Lighthouse Inlet.

Jetties constructed in the 1880's at Charleston Harbor to the north of Folly Island affects sediment transport from long-shore drift as well as foraminiferal species found in Lighthouse Inlet. As new sediment is trapped around Sullivan's Island by the jetties and erosion is dominant for Morris and Folly Island, Foraminifera species may be impacted by lower numbers in the diversity that would occur in a storm layer. Shallow dunes and sparse vegetation allows for the development of large, robust storm layers in North Folly, but the anthropogenic features such as jetties and artificial dunes seem to have affected foraminiferal diversity with lower species richness found within the upper storm layer. The lack of anthropogenic changes to the island 1,200 years ago resulted in a more stable island with larger dunes and dense vegetation for protection. A stronger storm or a direct impact from the south where winds are pushing landward would be required to produce the storm signature and transport the diverse foraminiferal assemblage found within the lower storm layer.

# CHAPTER 7: CONCLUSION

The major contributions of this study are a high-resolution analysis of two storm layers along a complete transect of the marsh and the comparison of sediment and micropaleontological proxies. Evidence of paleostorm layer survival has been affirmed by this study. The byproduct of an intense storm is an overwash fan. Individual sand lenses along with offshore-indicative foraminifera are the best tool for the documentation of a storm layer. Without microfossils, storm deposition is more difficult to identify, especially in environments with high rates of bioturbation. Analysis of the sediment using the laser diffraction system indicates the presence of an increase in grain size in heavily bioturbated sand lenses that are not readily identifiable visually or by use of textural analysis. Sand that has been mixed due to bioturbation had been discovered in a 4-cm interval directly above and below the original lower storm layer. Location of the original layer was determined by the intensity of the increase in grain size at a single point and gradual decrease in the number of grains $\geq$.125 mm from that point until only marsh mud and silt were detected. Preservation of a mixed storm layer can be found to some degree when using such resources as the laser diffraction system, but an increase in grain size along with offshore foraminifers must be present in order to be used in stratigraphic records for storm return intervals. High-marsh sub-environments were found to better preserve storm layers as bioturbation intensity tends to be less active (Hippensteel and Martin, 1999; Hippensteel, 2008; Hippensteel, 2011). This study found that the high and intermediate marsh subenvironments were likely to produce weaker correlation values between agglutinated marsh foraminiferal assemblages and smaller grain size. This weak correlation value is due to the lack of preservation of agglutinated taxa within the marsh facies in the high and intermediate marsh. Foraminifer tests can be destroyed two ways: Agglutinated forms may disarticulate after drying and calcareous forms may dissolve if exposed to low pH porewaters. As a result, there is not a direct correlation between grain size and offshore-indicative species or agglutinated species. A multi-proxy approach (sediment and microfossils) is not always possible because of this taphonomic overprint. Low-marsh sub-environments are subject to a greater intensity of bioturbation, however, the lack of drying allows for an accurate analysis of foraminiferal taxa present both in the marsh facies and those brought by storm activity.

Devegetated locations with altered dune structures are likely to produce larger storm deposits (Pilkey and Stuntz, 2005). Human habitation of a coastal area or barrier island such as Folly Island may result in thicker storm deposits after a hurricane. Consequences of anthropogenic modifications in barrier islands or coastal areas may also alter the strength of storms required to leave a deposit. Hugo devastated Folly Island in 1989, leaving a large storm deposit several centimeters thick and extending over 40-meters into the marsh (Stauble et al., 1991). This event occurred after modifications to dune structures and vegetation that would have otherwise stabilized the island and caused resistance to storm inundation. If such anthropogenic modifications do encourage storm layer deposition, paleotempestology research may find a robust geologic record of direct hurricane strikes in coastal and island locations inhabited for hundreds or thousands of years. Natural barriers of vegetation and dune fields undisturbed by human intervention may cause smaller storm deposits such as the lower storm layer of this study.

This study was able to find two storm layers exhibiting spatio-lateral continuity and preservation of offshore-indicative foraminifer. Finding laterally continuous storm layers is somewhat difficult without prior knowledge of the location and dimensions of the overwash fans. Overwash fans will be produced where storm energy accumulates and breaches the dunes. This deposition is controlled by the direction and strength of the storm. Paths of least resistance play a role in deposit location, but may not aid in finding the precise location of a storm deposit as dunes are destroyed and rebuilt over time. Overwash fans may appear next to each other or overlap. The lack of previous knowledge of exact overwash fan dimensions, location, and extent can cause underlying storm signatures to appear discontinuous because of a lack of preservation or provide misleading paleo-storm interpretations as samples taken in close proximity of each other render different storm records.

Foraminiferal taxa data are important for demonstrating the storm-origin of a sand layer. Storms of considerable strength are required to erode and rework ancient taxa such as *Stilostomella* spp., from oceanic shelf environments (Hippensteel and Martin, 1995). *Stilistomella* spp. is an Oligo-Miocene taxa and when a specimen is found within marsh strata it is evidence of sediment being eroded from the continental shelf and transported into the back-barrier of the island. Other offshore species are also transported through the storm surge and deposited in marginal-marine environments. Therefore, genera such as *Bulimina* spp. and *Uvigerina* spp., (and those listed in section 5.1) are particularly useful in determining if a sand lens is storm-derived or caused by other coastal processes. Some benthic calcareous taxa are found in nearshore environments as well as marshes. Cosmopolitan genera such as *Elphidium* spp. and *Ammonia* spp. provide few insights into sediment mode of transport. Planktic foraminifera reside in the open-ocean water columns. The floating nature of these foraminifers result in susceptibility to being pulled out of the open ocean environment by weaker storm systems that may cause a brief appearance in non-hurricane derived deposits. After death, planktic genera settle to the bottom of the ocean and become a part of storm derived sediment deposits. However, the calcareous tests of planktic species are unlikely to have a long residence time in marsh facies as dissolution may occur.

Correlations indicate an important link between foraminiferal taxa and grain size. Offshore-indicative taxa only appear when grain size increases. Results from this study indicate that a sand lens absent of offshore or planktic foraminifera cannot be positively identified as storm derived. Offshore-indicative species found in a sample without a detectable increase in grain size is also not evidence of a storm layer. Studies by Goldstein and Watkins (1999) and Jonasson and Patterson (1992) found pH levels were too low for calcareous forams to persist within the first 10-cm of marsh facies. Therefore, offshore taxa in much deeper layers without an accompanying increase in grain size would only occur if mixed from an underlying or overlying sand lens after quick burial during the storm event and relatively non-acidic porewater. Thus, grain size and offshore-indicative foraminifer species must occur together for a sand lens or anomalous foraminiferal layer to be determined as a paleostorm layer.

This study demonstrates the importance of a multi-proxy approach when documenting ancient storm deposits. The two storm layers analyzed were deposited ~1,000 years apart and both are detectable using a grain-size and microfossil proxy. Uncertainty about sediment origin and the mode of deposition (hurricane) are diminished by the presence of an offshore microfossil assemblage within the strata. Without both proxies, doubt persists regarding the strength of the storm, and the other potential modes of deposition, including aeolian transport. Both storm layers were spatio-laterally continuous, meaning that storm layers thousands of years apart have the potential to be preserved if thick enough or buried quickly enough.  Sedimentological structures such as landward dipping laminae may not be preserved over time, and lateral continuity may not survive bioturbation. Nevertheless, sandy overwash fan deposits that are enriched with offshore-indicative, or Oligo-Miocene foraminifers, remains an effective tool for documenting hurricane strikes.

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# APPENDIX

(Figure X1) Planktic Foraminifera data with depth and individual count FM1. Depth is the far left column.

| | | PLANKTIC CALCAREOUS | |
|---|---|---|---|
| Core FM 1 | | Globergerina | TOTAL |
| 1 | | 1 | 1 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | 0 | 0 |
| 9 | | 0 | 0 |
| 10 | | | |
| 11 | | | |
| 12 | | 0 | 0 |
| 13 | | 17 | 17 |
| 14 | | 4 | 4 |
| 15 | | 118 | 118 |
| 16 | | 111 | 111 |
| 17 | | 109 | 109 |
| 18 | | 95 | 95 |
| 22 | | 165 | 165 |
| 25 | | 80 | 80 |
| 30 | | 66 | 66 |
| 36 | | 141 | 141 |
| 40 | | 79 | 79 |
| 46 | | 92 | 92 |
| 50 | | 102 | 102 |
| 55 | | 110 | 110 |
| 56 | | 53 | 53 |
| 57 | | 101 | 101 |
| 58 | | 83 | 83 |
| 59 | | 109 | 109 |
| 60 | | 18 | 18 |
| 61 | | | |
| 62 | | | |
| 63 | | | |
| 64 | | 0 | 0 |
| 65 | | 0 | 0 |
| 70 | | 0 | 0 |
| 75 | | | |
| 80 | | 0 | 0 |
| 85 | | 0 | 0 |
| 90 | | 0 | 0 |
| 95 | | 0 | 0 |
| 100 | | 0 | 0 |
| 105 | | 0 | 0 |
| 110 | | 0 | 0 |
| 115 | | 0 | 0 |
| 120 | | 0 | 0 |
| 125 | | | |
| 130 | | | |
| 135 | | | |
| 140 | | 51 | 51 |
| 141 | | 45 | 45 |
| 142 | | | |
| 143 | | 138 | 138 |
| 144 | | 195 | 195 |
| 145 | | 200 | 200 |
| 146 | | 36 | 36 |
| 147 | | 27 | 27 |

(Figure X2) Offshore-indicative benthic calcareous foraminifer count for FM1 depth in Figure X1.

| | | | | | | BENTHIC CALCAREOUS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rosalina | Bolivina P | Cibicides | Nonionell | Quinquel | Uvigerina | Bulimina | Buliminel | Stilistome | Elphidium | TOTAL |
| | | | | | | | | | 1 | 1 |
| | | | | | | | | | | 0 |
| | | | | | | | | | 1 | 1 |
| | | | | | | | | | | 0 |
| | | | | 1 | | | | | | 1 |
| | | | | | | | 1 | | | 1 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | 2 | | | 3 | | 1 | 6 |
| | | | | | | | | | | 0 |
| | | | | 8 | | | 6 | | 2 | 16 |
| | | | | | | | | | | 0 |
| 11 | | 11 | | 65 | 20 | 14 | 35 | 4 | 33 | 193 |
| 9 | | 6 | | 80 | 31 | 17 | 30 | | 12 | 185 |
| 7 | | 5 | | 111 | 52 | 30 | 52 | | 9 | 266 |
| 4 | | 2 | | 67 | 29 | 24 | 37 | | 5 | 168 |
| 18 | | 11 | 9 | 59 | 57 | 46 | 82 | | 10 | 292 |
| 13 | | 3 | 4 | 27 | 14 | 33 | 41 | | 4 | 139 |
| 6 | | | 7 | 19 | 20 | 18 | 26 | | 3 | 99 |
| 1 | | 4 | 10 | 28 | 25 | 24 | 30 | | 14 | 136 |
| 3 | | 7 | 6 | 61 | 40 | 30 | 25 | | 9 | 181 |
| | | 3 | 9 | 12 | 31 | 17 | 3 | | 10 | 85 |
| 1 | | 2 | 3 | 12 | 29 | 16 | 9 | | 12 | 84 |
| | | | 8 | 26 | 31 | 18 | 8 | | 8 | 99 |
| | | 2 | 3 | 8 | 14 | 12 | 10 | | 5 | 54 |
| 8 | | 4 | 7 | 6 | 23 | 31 | 9 | | 3 | 91 |
| 2 | | 1 | 4 | 2 | 13 | 10 | 7 | | 6 | 45 |
| 2 | | 2 | 2 | 9 | 13 | 12 | 7 | | 5 | 52 |
| 1 | | 2 | | 11 | 3 | 9 | 1 | | 1 | 28 |
| 1 | | | | 4 | | | | | | 5 |
| | | | | 2 | | | 1 | | | 3 |
| 2 | | | | | | | | | | 2 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | 1 | | | | 1 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| | | | | | | | | | | 0 |
| 3 | | 1 | 1 | | | | | | 8 | 13 |
| 1 | | | | | | | | | 2 | 3 |
| | | | | 1 | | | | | | 1 |
| 87 | | 135 | | | 17 | 21 | 11 | | 353 | 624 |
| 89 | | 102 | 10 | | 6 | 17 | 8 | | 257 | 489 |
| 246 | | 267 | | | | | | | 404 | 917 |
| 381 | | 493 | 16 | | 23 | 19 | 10 | | 653 | 1595 |
| 403 | | 310 | 46 | | 50 | 29 | 23 | | 583 | 1444 |
| 441 | | 319 | 52 | | 47 | 31 | 27 | | 612 | 1529 |
| 119 | | 144 | 5 | | 7 | 10 | 1 | | 208 | 494 |
| 29 | | 26 | 7 | | 6 | 5 | | | 96 | 169 |

(Figure X3) Agglutinated marsh foraminifer taxa count FM1, depth in Figure X1.

| | AGGLUTINATED | | | | | |
|---|---|---|---|---|---|---|
| Milamina | Jadamina | Ammonia Salsum | Trochamir | textularia | Mexicana | TOTAL |
| 1 | 1 | | | | | 2 |
| | | | 2 | | | 2 |
| | | | | | | 0 |
| | | | | | | 0 |
| 1 | | | | | | 1 |
| 1 | | | | | | 1 |
| | | | | 1 | | 1 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | 8 | 1 | | | 9 |
| 1 | | | | | | 1 |
| | | | | | | 0 |
| 5 | | | | 7 | | 12 |
| 1 | | | | | | 1 |
| 19 | 5 | 20 | 12 | 51 | | 107 |
| 22 | | 23 | 8 | 42 | | 95 |
| 25 | | 32 | 10 | 58 | 3 | 128 |
| 12 | | 16 | 14 | 48 | | 90 |
| 19 | | 21 | 35 | 62 | 7 | 144 |
| 6 | | 7 | 18 | 24 | | 55 |
| 8 | | 12 | 22 | 18 | | 60 |
| 9 | 50 | 22 | 70 | 17 | | 168 |
| 13 | | 37 | 106 | 17 | | 173 |
| 3 | | 28 | 101 | 2 | | 134 |
| 3 | | 17 | 69 | 5 | | 94 |
| 7 | | 38 | 111 | 1 | | 157 |
| 3 | | 18 | 70 | 3 | | 94 |
| 7 | | 26 | 91 | 8 | | 132 |
| 1 | 3 | 9 | 25 | 5 | | 43 |
| 1 | | 9 | 39 | 3 | | 52 |
| 4 | 1 | 2 | 11 | | | 18 |
| 1 | | 2 | | | | 3 |
| | | | | | | 0 |
| | 1 | | | | | 1 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| 1 | | | | | | 1 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | | | | | | 0 |
| | 11 | 8 | 1 | | | 20 |
| | 3 | 1 | | | | 4 |
| | 2 | | | | | 2 |
| 1 | 1 | | | 3 | | 5 |
| | 6 | | | 8 | | 14 |
| 3 | | | | | | 3 |
| 2 | 4 | | | 6 | | 12 |
| | 7 | | | 10 | | 17 |
| | 12 | | | 17 | | 29 |
| | 1 | 2 | 1 | 1 | | 5 |
| | 1 | | | 1 | | 2 |

(Figure X4) FM2 planktic Foraminifera count data with species and depth in cm.

| | | Planktic Calcarious | |
|---|---|---|---|
| Depth | Globergerina | | Total |
| 1 | | | 0 |
| 10 | | | 0 |
| 20 | 90 | | 90 |
| 21 | 78 | | 78 |
| 22 | 78 | | 78 |
| 23 | 48 | | 48 |
| 24 | 82 | | 82 |
| 25 | 72 | | 72 |
| 26 | 83 | | 83 |
| 37 | 35 | | 35 |
| 47 | 60 | | 60 |
| 57 | 138 | | 138 |
| 63 | 87 | | 87 |
| 64 | 84 | | 84 |
| 65 | 124 | | 124 |
| 66 | 95 | | 95 |
| 67 | 43 | | 43 |
| 68 | 14 | | 14 |
| 69 | 25 | | 25 |
| 70 | 12 | | 12 |
| 71 | 11 | | 11 |
| 82 | | | 0 |
| 92 | | | 0 |
| 102 | | | 0 |
| 112 | | | 0 |
| 122 | | | 0 |
| 131 | 97 | | 97 |
| 132 | 117 | | 117 |
| 133 | 59 | | 59 |
| 134 | 75 | | 75 |
| 135 | 159 | | 159 |
| 136 | | | 0 |
| 137 | | | 0 |

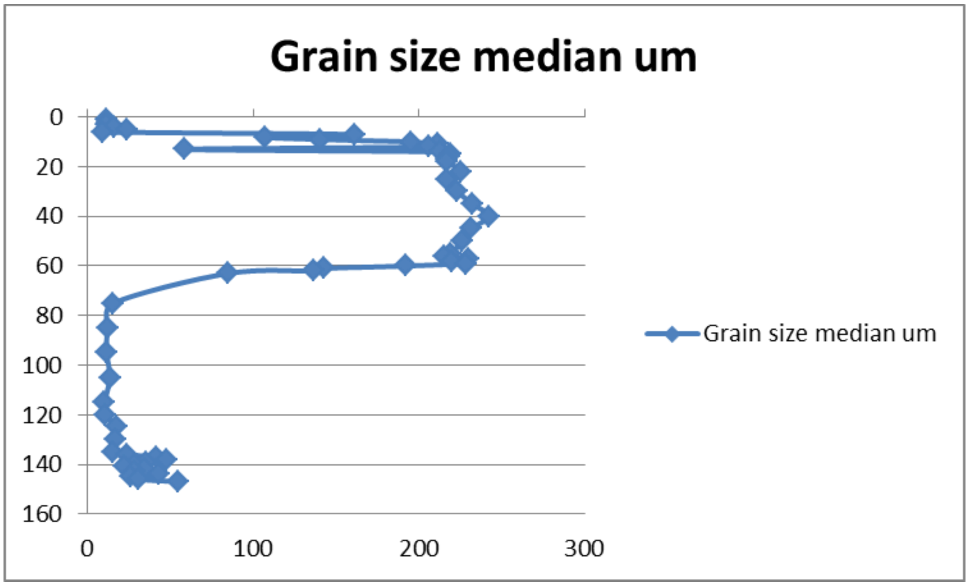
(Figure X5) FM2 offshore-indicative benthic calcareous foraminifer count with depth in Figure X4.

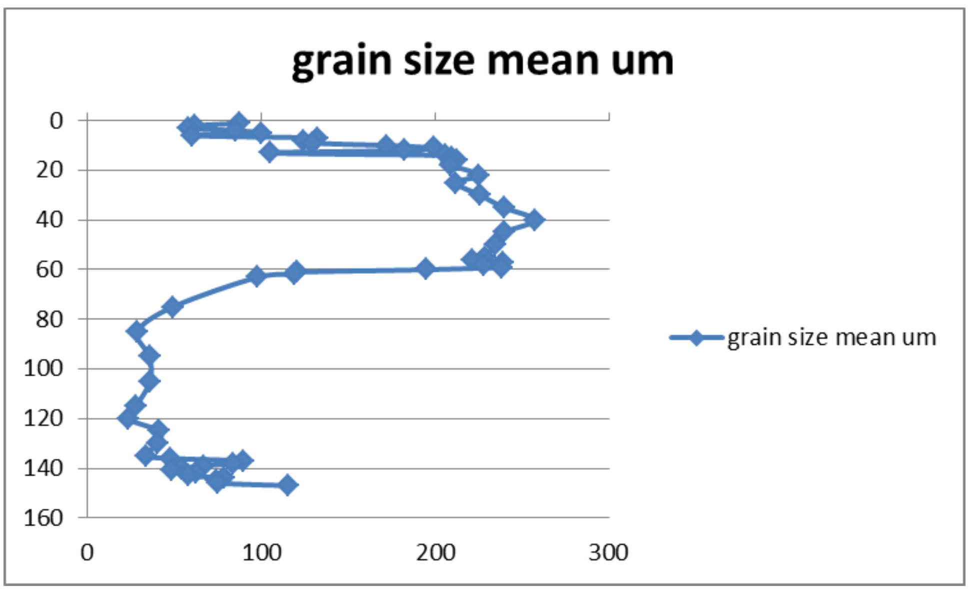
| | | Benthic Calcareous | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elphidi | AmmoniaE | AmmoniaBec | Uvigerir | Nonion | Quinque | Bulimin | Bulimin | Silicosme | Cibicid | Florilus | Florilus | Gyroidi | Vaginuli | Rosalina | Bolivina | Cassidul | Bagging | Astacol | Petallin | Fissurin | Lagenin | Florensi | triloculi | Gyroidi | Sphaer | Globob | Pulleni | Valvulir | Guttulir | buccella | melonis | miliolid | Globulin | Hopkins | Cancris | Cassidul | Cyclami | Nodosa | Sphaero | Planula | Total | total offshore |
||||||||||||||||||||||||||||||||||||||||||0|0|
||||||||||||||||||||||||||||||||||||||||||0|0|
|3|1||12||6|23|9||2||9||||||||||1|||4|||||||||||||||||70|6|
|1|2||24||5|17|12||3||1|||||||||||||2|||||||||||1||||||68|6|
|1|9||2|8|5|20|9||1||1||||||||||||||||||||||||||||||75|6|
|||5||20|4|2|18|5|1|1||3||||||||||||1||||||||||||||||||60|5|
|1|7||39|14|5|32|12||2|||4|||||4||||2|||||||||||||||1|||||60|11|
|1||3|31|12|2|23|8||1|2||1|||||1||||1|||||||||||4||||1|||||91|8|
|1||5|20|3|3|12|12||1||||||||1||||||||1|||||||1|||||||||60|5|
|2||7|7|1|1|2|4|1|||||||||||||||||||||||||||||||||25|1|
|7|4||16||1|18|||||||1||||||||||1||||||||||||||||||48|3|
|2|19|14|38|4||18|||1||4|7|1||||||||||||||||||||||||||||123|6|
|2||9|1|4|4|12|4||2|1||||||||||||||2|||||||||||1||4||||56|4|
|1||5|17|6|1|4|2||3||||||2||2||||2|||||||||2||1||1|2||||||51|4|
|3|14||23|1|6|18|6|1|4||||||||11|||||||1|||||||||1||2||||||96|7|
|1||10|27|7|4|22|7|1|3|3|||||||1|||||||3||||||1|1|1|||||||||92|8|
|1||4|1|3|1|6|5||1|1||1||||||||||||2|||||||||||1||||||37|3|
||||6|2||7||1|1||||||||1||||||||||||||||||||||||18|1|
||||4|1|2|1|1||||1|1|||||||||||||||||||||||1|||1|||13|1|
||1||6|||2|1||1||2||||||||||||||||||||||||1||||||14|1|
|||1|3|||3|1|||1||1||||||||||||||||||||||||||||||10|9|
||||||||||||||||||||||||||||||||||||||||||0|0|
||||||||||||||||||||||||||||||||||||||||||0|0|
||||||||||||||||||||2||||||||||||||||||||||2|2|
|1|||||||||||||||||||3||||||||||||||||||||||4|3|
||||||||||||||||||||5||||||||||||||||||||||5|5|
|47||23|14|16||9||1|29|||5||26|17|40|18|17||10|||||2||1|2|2||||||2||||||152|8|
|56||36|17|37||12||2|31|||18||29|14|3|3|23||2|1|18|||1||||||||||||||||||||187|9|
|20||14|6|13||6||1|12|||||11|5|1|15|6||2|5|||||1|||||||||||||||70|3|
|35||15|9|24||3|||20|||||22|7|1|1|13||6|1|10|||||||||||||2||||1||112|6|
|52||24|23|55||11|2|3|24|||||36|14|2|2|2||17|9|17||13|||||||||||2||||||107|9|
|5||25|9|45|1|2|9|3|24|||||27|17|2|1|27|8|28||4|2|17|1||||||||||7||||3|1|186|8|
|8||47|29|39|1|17|9|3|5|||14||5|25|4|1|5|2|34|6|7|2||||||||||6||2||||||294|16|

(Figure X6) FM2 agglutinated foraminifer count with depth in Figure X4.

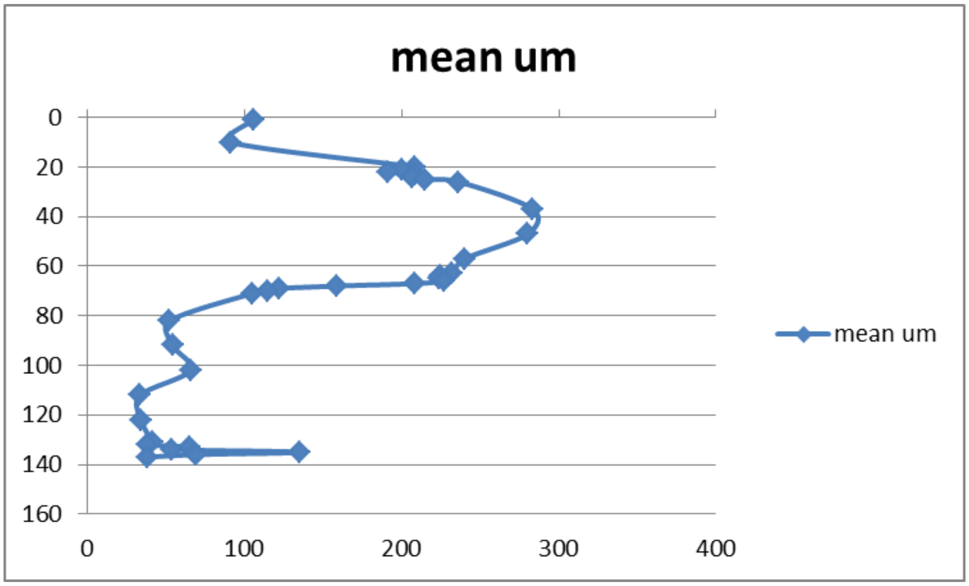
| Agglutinated | | | | | | | |
|---|---|---|---|---|---|---|---|
| Miliamina Fus | Parkinsoniana | Ammonium sal | Textularia | Jadamina Macrescens | trochamina Inflat | mexicana | Total |
| 5 | | 12 | 1 | 3 | | | 21 |
| 3 | | 1 | | 1 | 1 | | 6 |
| 8 | | | | 111 | 24 | | 143 |
| 2 | | 1 | 9 | 2 | 31 | | 45 |
| 2 | | 17 | 2 | 1 | 37 | | 59 |
| 3 | | 33 | 2 | 1 | 42 | | 81 |
| 5 | | 26 | 9 | | 45 | | 85 |
| 9 | | 17 | 11 | | 24 | | 61 |
| 5 | | 12 | 3 | 1 | 22 | 2 | 45 |
| 6 | | 13 | 11 | | 39 | | 69 |
| 4 | | 9 | 9 | 4 | 47 | | 73 |
| 4 | | 3 | 18 | | 153 | | 178 |
| 3 | | 18 | 13 | | 25 | 1 | 60 |
| 4 | | 16 | 3 | 1 | 32 | 4 | 60 |
| 1 | | 17 | 6 | | 25 | 3 | 52 |
| 1 | | 11 | 6 | | 16 | 1 | 35 |
| 1 | | 8 | 1 | | 8 | | 18 |
| | | 3 | | 1 | 4 | | 8 |
| | | 2 | | 2 | 7 | | 11 |
| | | 3 | 2 | | 6 | | 11 |
| | | 1 | | 1 | 2 | | 4 |
| 1 | | 2 | 1 | 14 | | | 18 |
| | | 4 | | 6 | | | 10 |
| 11 | | 36 | 5 | 47 | 6 | | 105 |
| 8 | | 13 | | 19 | 1 | | 41 |
| 8 | | 21 | | 23 | | | 52 |
| | | | | 2 | | | 2 |
| | | | | | | | 0 |
| | 25 | | | | | | 25 |
| | 21 | | 2 | | | | 23 |
| | 39 | | 7 | | 1 | | 47 |
| | 38 | | 10 | | | | 48 |
| | 43 | 4 | 12 | | | | 59 |

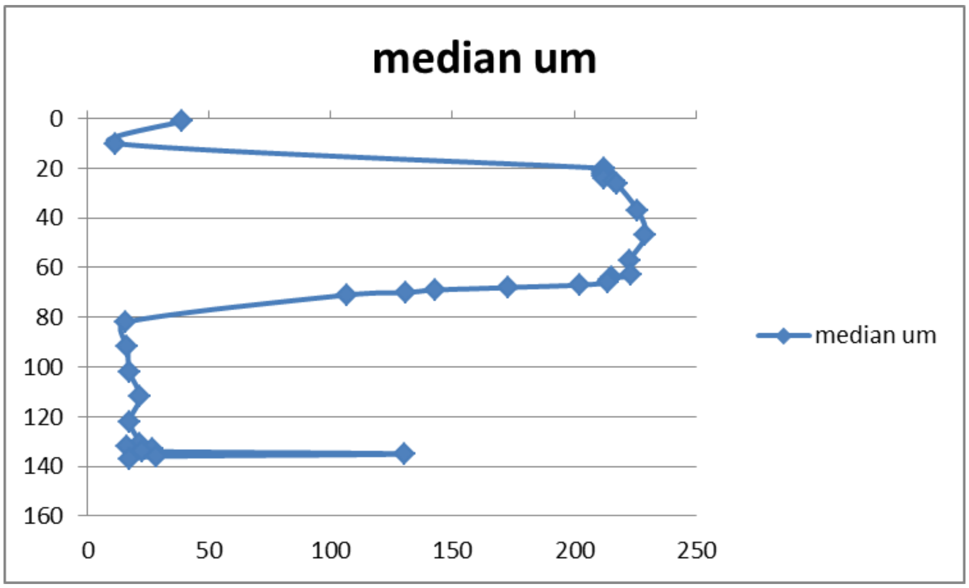
(Figure X7) Grain size graphs FM1



(Figure X8) Grain size graphs FM2



(Figure X9) Correlation Data FM1

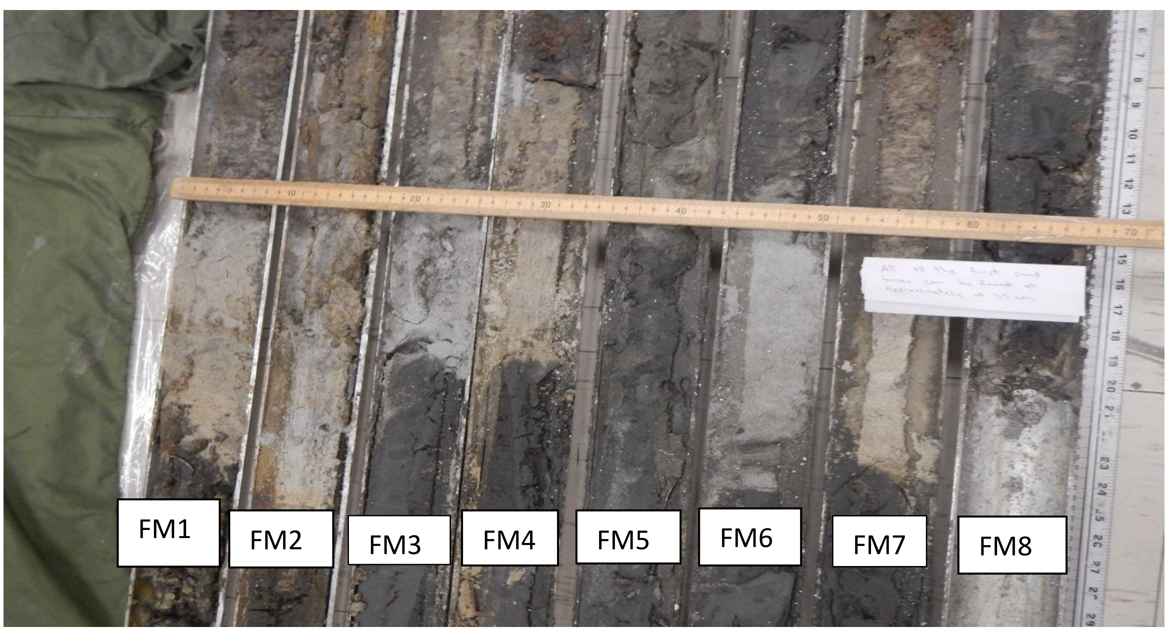
| Depth | Planktic | Benthic | Agglut | Mean GS |
|---|---|---|---|---|
| 1 | 1 | 1 | 2 | 87.61 |
| 2 | 0 | 0 | 2 | 61.92 |
| 3 | 0 | 1 | 0 | 57.94 |
| 4 | 0 | 0 | 0 | 85.16 |
| 5 | 0 | 1 | 1 | 99.93 |
| 6 | 0 | 1 | 1 | 60.31 |
| 7 | 0 | 0 | 1 | 132.6 |
| 8 | 0 | 0 | 0 | 124.6 |
| 9 | 0 | 0 | 0 | 129.3 |
| 10 | 0 | 0 | 9 | 172.4 |
| 11 | 0 | 6 | 1 | 199.3 |
| 12 | 0 | 0 | 0 | 182.7 |
| 13 | 17 | 16 | 12 | 105.4 |
| 14 | 4 | 0 | 1 | 206 |
| 15 | 118 | 193 | 107 | 209.4 |
| 16 | 111 | 185 | 95 | 212.7 |
| 17 | 109 | 266 | 128 | 209.6 |
| 18 | 95 | 168 | 90 | 209.1 |
| 22 | 165 | 292 | 144 | 225.4 |
| 25 | 80 | 139 | 55 | 211.9 |
| 30 | 66 | 99 | 60 | 225.9 |
| 36 | 141 | 136 | 168 | 239.6 |
| 40 | 79 | 181 | 173 | 257.3 |
| 46 | 92 | 85 | 134 | 239.6 |
| 50 | 102 | 84 | 94 | 234.4 |
| 55 | 110 | 99 | 157 | 228.6 |
| 56 | 53 | 54 | 94 | 221.5 |
| 57 | 101 | 91 | 132 | 239.4 |
| 58 | 83 | 45 | 43 | 228.3 |
| 59 | 109 | 56 | 52 | 238.3 |
| 60 | 18 | 28 | 18 | 194.6 |
| 61 | 0 | 5 | 3 | 120.6 |
| 62 | 0 | 3 | 0 | 118.9 |
| 63 | 0 | 2 | 1 | 98.03 |
| 75 | 0 | 1 | 1 | 49.14 |
| 85 | 0 | 0 | 0 | 28.77 |
| 95 | 0 | 0 | 0 | 35.68 |
| 105 | 0 | 0 | 0 | 36.01 |
| 115 | 0 | 0 | 0 | 27.95 |
| 125 | 0 | 13 | 20 | 41.47 |
| 130 | 0 | 3 | 4 | 40.08 |
| 135 | 0 | 1 | 2 | 33.98 |
| 140 | 51 | 725 | 5 | 54.59 |
| 141 | 45 | 588 | 14 | 48.23 |
| 142 | 0 | 1054 | 3 | 62.39 |
| 143 | 138 | 1769 | 12 | 58.14 |
| 144 | 195 | 1949 | 17 | 78.84 |
| 145 | 200 | 2079 | 29 | 74.21 |
| 146 | 36 | 550 | 5 | 75.18 |
| 147 | 27 | 169 | 2 | 115.4 |

(Figure X10) Correlation data FM2

| Depth | Mean Grain Size | Total Forams | Calcareous Forams | Offshore-indicative Forams | Agglutinated Forams | Planktic Forams |
|---|---|---|---|---|---|---|
| 1 | 105.4 | 21 | 0 | 0 | 21 | 0 |
| 10 | 91.29 | 6 | 0 | 0 | 6 | 0 |
| 20 | 208.6 | 303 | 70 | 66 | 143 | 90 |
| 21 | 200.5 | 191 | 68 | 65 | 45 | 78 |
| 22 | 191.4 | 212 | 75 | 65 | 59 | 78 |
| 23 | 208 | 189 | 60 | 55 | 81 | 48 |
| 24 | 206.9 | 290 | 123 | 115 | 85 | 82 |
| 25 | 214.9 | 224 | 91 | 87 | 61 | 72 |
| 26 | 236.4 | 188 | 60 | 54 | 45 | 83 |
| 37 | 283.4 | 129 | 25 | 16 | 69 | 35 |
| 47 | 280.2 | 176 | 43 | 32 | 73 | 60 |
| 57 | 240 | 439 | 123 | 68 | 178 | 138 |
| 63 | 231.7 | 203 | 56 | 45 | 60 | 87 |
| 64 | 224.5 | 195 | 51 | 45 | 60 | 84 |
| 65 | 224 | 272 | 96 | 79 | 52 | 124 |
| 66 | 227.3 | 222 | 92 | 81 | 35 | 95 |
| 67 | 208.4 | 98 | 37 | 32 | 18 | 43 |
| 68 | 158.3 | 40 | 18 | 18 | 8 | 14 |
| 69 | 121.7 | 49 | 13 | 13 | 11 | 25 |
| 70 | 114.5 | 37 | 14 | 13 | 11 | 12 |
| 71 | 104.8 | 25 | 10 | 9 | 4 | 11 |
| 82 | 52.4 | 18 | 0 | 0 | 18 | 0 |
| 92 | 54.3 | 10 | 0 | 0 | 10 | 0 |
| 102 | 65.6 | 107 | 2 | 2 | 105 | 0 |
| 112 | 33.6 | 45 | 4 | 3 | 41 | 0 |
| 122 | 34 | 57 | 5 | 5 | 52 | 0 |
| 131 | 41.09 | 1624 | 1525 | 809 | 2 | 97 |
| 132 | 38.41 | 1954 | 1837 | 930 | 0 | 117 |
| 133 | 65 | 786 | 702 | 361 | 25 | 59 |
| 134 | 54.06 | 1219 | 1121 | 605 | 23 | 75 |
| 135 | 135.1 | 1913 | 1707 | 934 | 47 | 159 |
| 136 | 68.76 | 1744 | 1696 | 896 | 48 | 0 |
| 137 | 38.37 | 2993 | 2934 | 1604 | 59 | 0 |

( Figure X11) Image of a sand wedge from an unrelated storm layer (core on right).

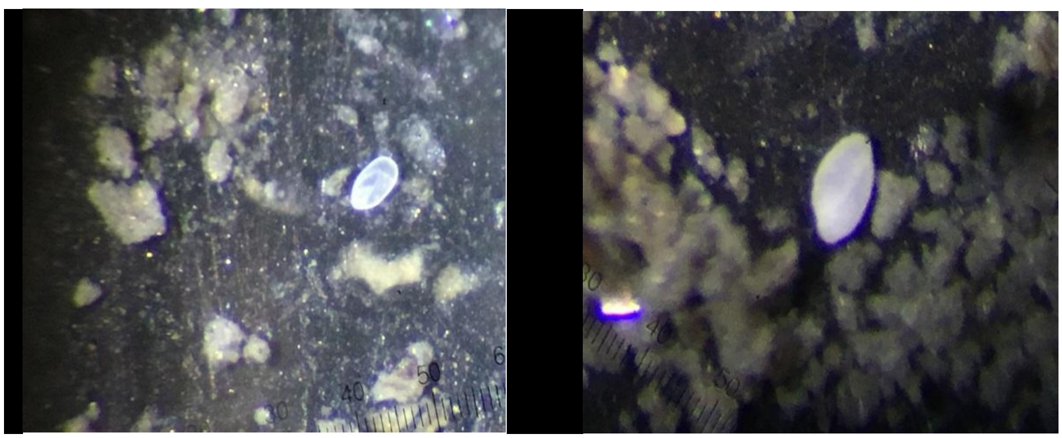
(Figure X12) Image of storm layer continuity for the younger sand lens.



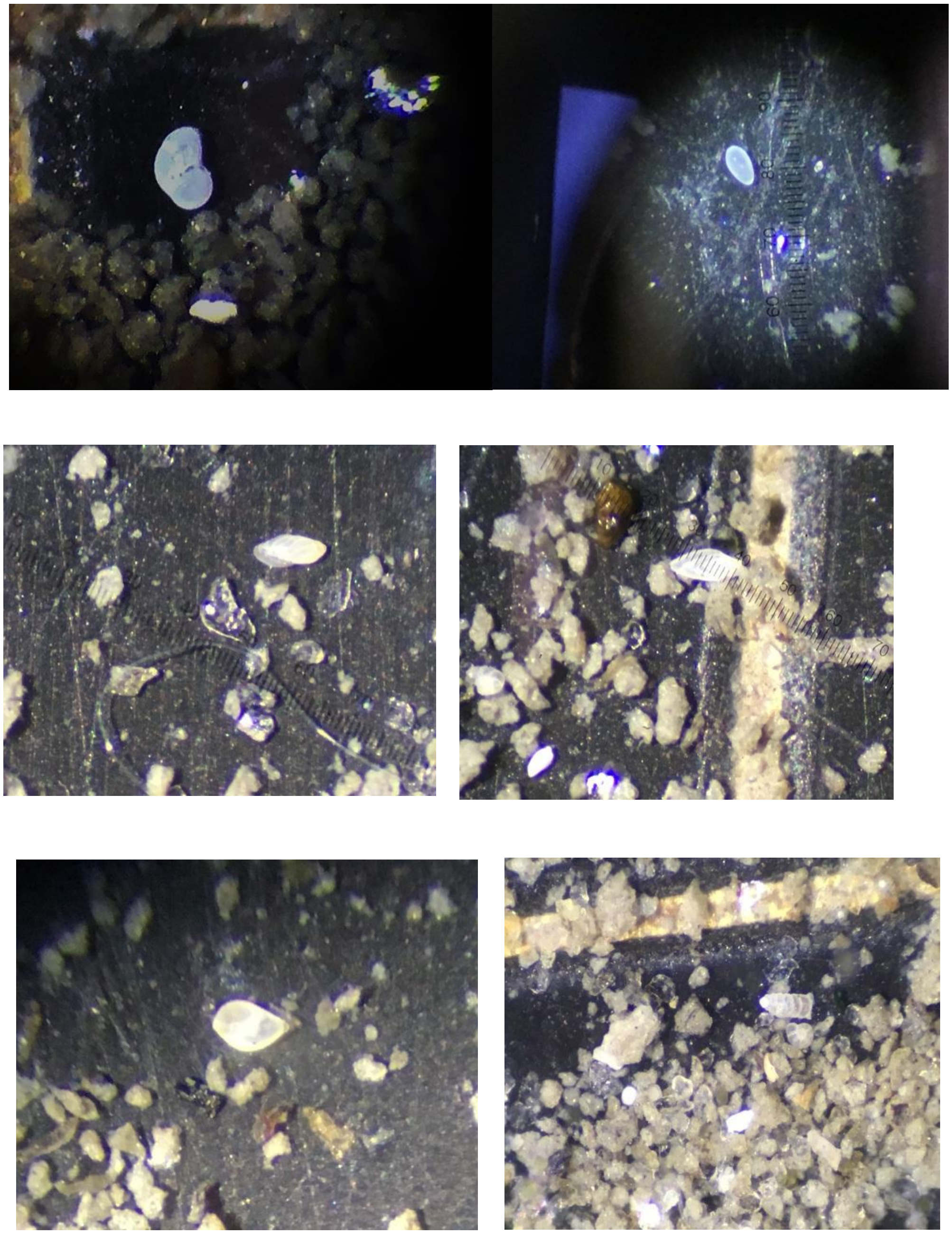
(Figure X13) Images of the older storm layer.

(Figure X14) Image of *Stilostomella* spp. This extinct Oligo-Miocene species indicates reworking from a strong storm (older layer).

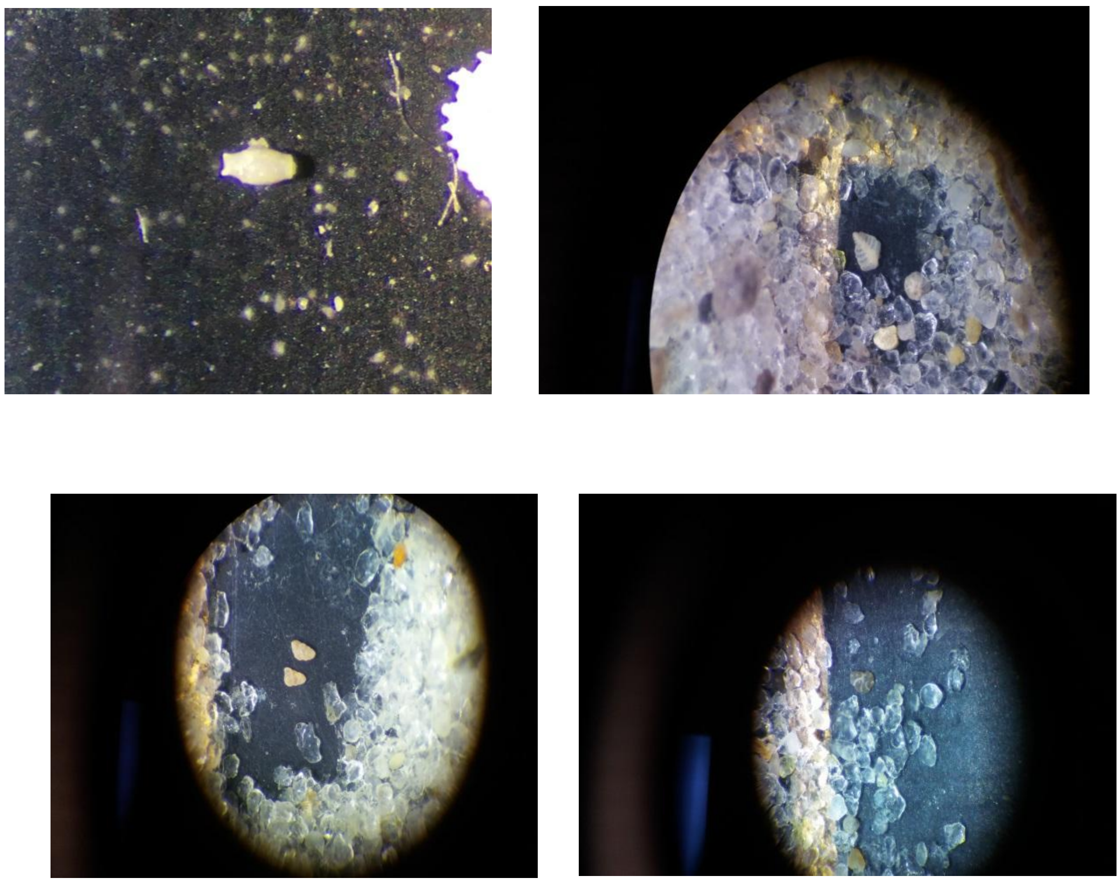
(Figure X15) Other deep ocean foraminiferal taxa indicating sediment transport from a strong hurricane (*Globobulimina* spp. left and *Triloculina* spp. right).



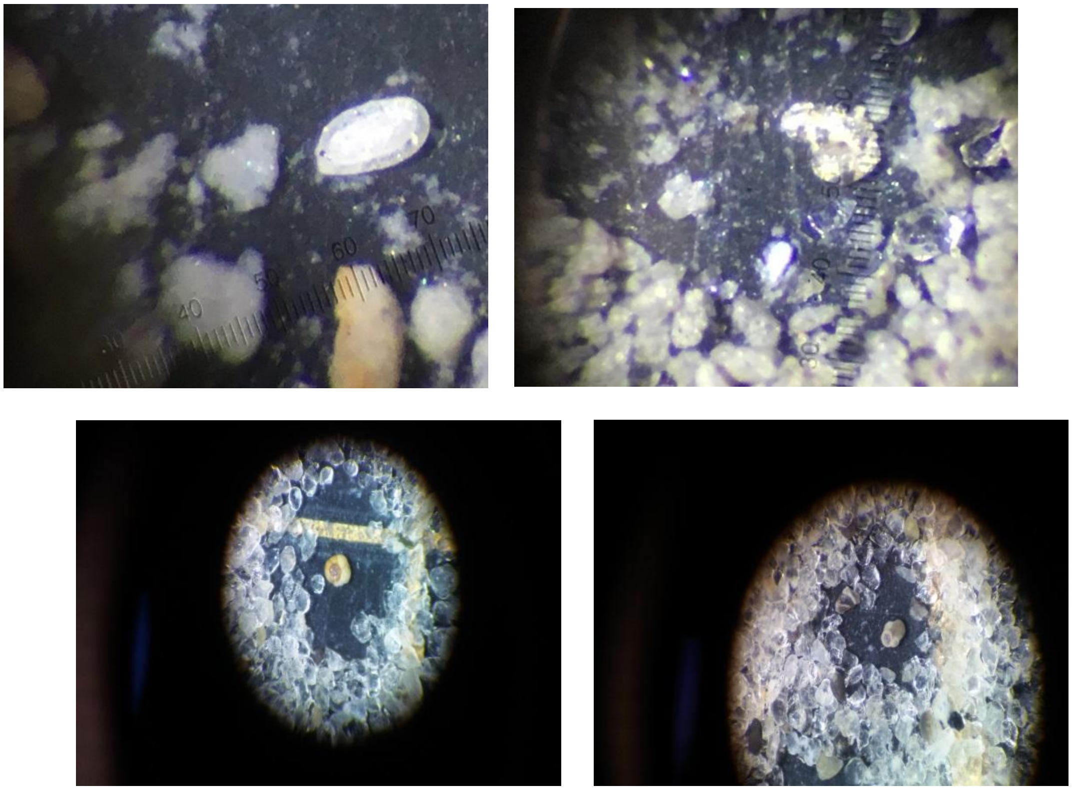
(Figure X15 continued) *Valvulineria* spp. top left and *Pyrgo* spp. top right. Middle left *Astacolus* spp. and middle right *Planularia* spp. Bottom left *Globobulimina* spp., bottom right *Bolivina* spp.



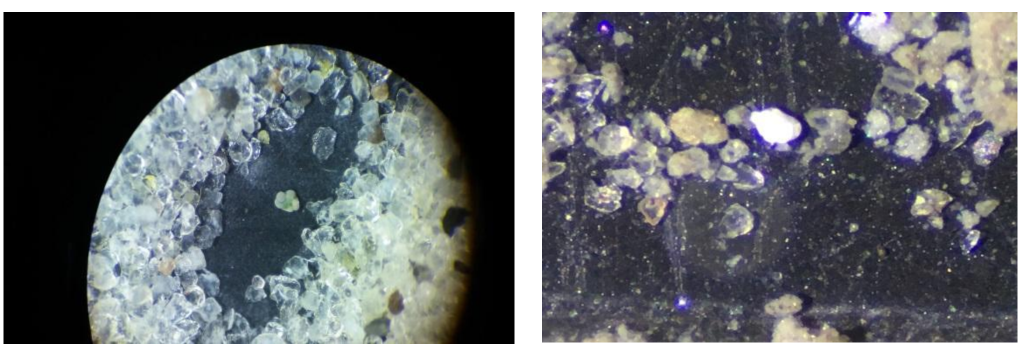
(Figure X16) Offshore-indicative assemblages transported by a hurricane.  Top left *Lagenina* spp., top right *Planularia* spp., bottom left *Uvigerina* spp., bottom right *Cibicides* spp.



(Figure X17) Agglutinated foraminiferal taxa typical in marsh facies. *Miliamina* fusca top left, *Ammonia* salsum top right, *Jadamina* macrescens bottom left, *Trochamina* inflata bottom right.




(Figure X18) Planktic foraminiferal taxa. *Globigerina* spp. left *Hopkinsina* spp. right.



(Figure X19) Two samples were retrieved for every section analyzed. One sample was used for foraminiferal analysis and the other for grain size analysis**.**