Fall 12-2016

Sedimentology of a Small Estuarine Marsh Along East (Pensacola) Bay, Florida

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SEDIMENTOLOGY OF A SMALL ESTUARINE MARSH ALONG EAST (PENSACOLA) BAY, FLORIDA

by

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A Thesis
Submitted to the Honors College of
The University of Southern Mississippi
in Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Science
in the Department of Geography and Geology

December 2016

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Abstract

Sediment samples from a marsh along East (Pensacola) Bay were analyzed using various laboratory techniques. The color, magnetic susceptibility, organic content, carbonate content, and sediment size distribution of each sample was measured to attain an overall profile of the sedimentary characteristics of the area. Using the GPS coordinates of each collection site, samples were categorized into sub-environments based on their position within the marsh. The trends within the study area and sub-environments were evaluated and interpreted. The data indicate that this marsh is a siliciclastic, fining-inland area that is frequently inundated with tidal fluctuations and storm surges. These storm surges transport large amounts of coarse-grained sediment into the marsh. There were also similarities in the fluvial channel sediments and samples taken near the mouth of the river, but not along the frontbar. This indicates that the depositional extent of the fluvial system in the study area ended at the outlet. Additional interpretations and statistical comparisons are discussed within this study.

Acknowledgements

First, I would like to thank my family and friends, who have been a never-ending source of support for the duration of this project and throughout my undergraduate career.

I appreciate the guidance of my thesis advisor, Dr. Franklin Heitmuller, who made this research possible. He provided the samples and equipment necessary to complete this project. He also had a stalwart supply of patience that withstood a storm of questions on a weekly basis. His input throughout the entirety of this project was invaluable.

I would also like to thank James Thompson and Malitha Rathnayake, two of the graduate students at The University of Southern Mississippi. Their guidance during the lab analyses was pivotal in my success throughout this project.

Lastly, I am grateful to the Department of Geography and Geology for allowing me to conduct an undergraduate thesis. It has served as an invaluable experience in research and problem solving that will stay with me throughout my career.

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Chapter 1: Introduction

Sediment and soil surveys provide a plethora of information for agricultural applications, conservation efforts, or to evaluate soil strength (Thom, 2000). The samples in this research project were tested to ascertain the organic content, sediment size distribution, carbonate content, and magnetic properties of surficial sediments throughout the study area. These findings, along with GPS coordinates of the collection sites, allow interpretations to be made on localized sedimentology and any gradational changes within the study area.

Coastal marshes are often viewed as transition zones between fluvial and marine systems, since they receive sediments from both riverine and offshore sources (Fleming, 2013). In Florida, these coastal estuaries are unique environments that are typically present in coastal inlets of low energy and small tidal fluctuations. They are a type of wetland, which, by definition, means that they are characterized by wetland hydrology, hydric soils, and more than 50% hydrophytic vegetation (Osmond, 1995). The Environmental Protection Agency describes marshes as wetlands that are repeatedly immersed with water, and possess soft-stemmed flora that is acclimated to those inundated conditions (Environmental Protection Agency, 2016).

Despite the ecological importance and wide extent of these ecosystems, there are still many unknown factors in the sedimentology of coastal marshes. The purpose of this study is to evaluate depositional sub-environments of a small microtidal marsh along East (Pensacola) Bay, Florida. By studying this wetland, the overall understanding of marsh sedimentology can be expanded on both a local and regional scope. This information can help researchers in the future to better understand the mechanics of coastal marsh sedimentology and enhance wetland rehabilitation efforts.

The goals of this study are as follows:

1. To evaluate any sedimentological trends within the study area.
2. To construct sub-environments within the study area that can be used to compare different sections of the marsh.
3. To determine the depositional extent of the fluvio-tidal system within the study area.

1.1 Location

While coastal marshes are present throughout the United States, over 60 percent of them exist in Florida. For this study, salt marshes in the Florida Panhandle are dominated by microtidal conditions. This region has a humid/temperate climate with an average of 62 inches of rainfall per year. The soils of the Panhandle are very diverse, and typically consist of siliciclastic sandy or clayey sediments overlying a limestone base. The marshes there support a wide variety of flora and fauna that are acclimated to brackish conditions (University of Florida, 2016).

Figure 1: Beachfront view of the study area along East Bay, Florida (Courtesy of FT Heitmuller).

The East Bay area is located at the boundary of Escambia and Santa Rosa counties, the westernmost counties in the Florida Panhandle. It contains a plethora of brackish, tidal marshes along the inner shoreline. The bay spans 15 miles east to west along the shoreline, and reaches 10 miles inland from the Gulf of Mexico.

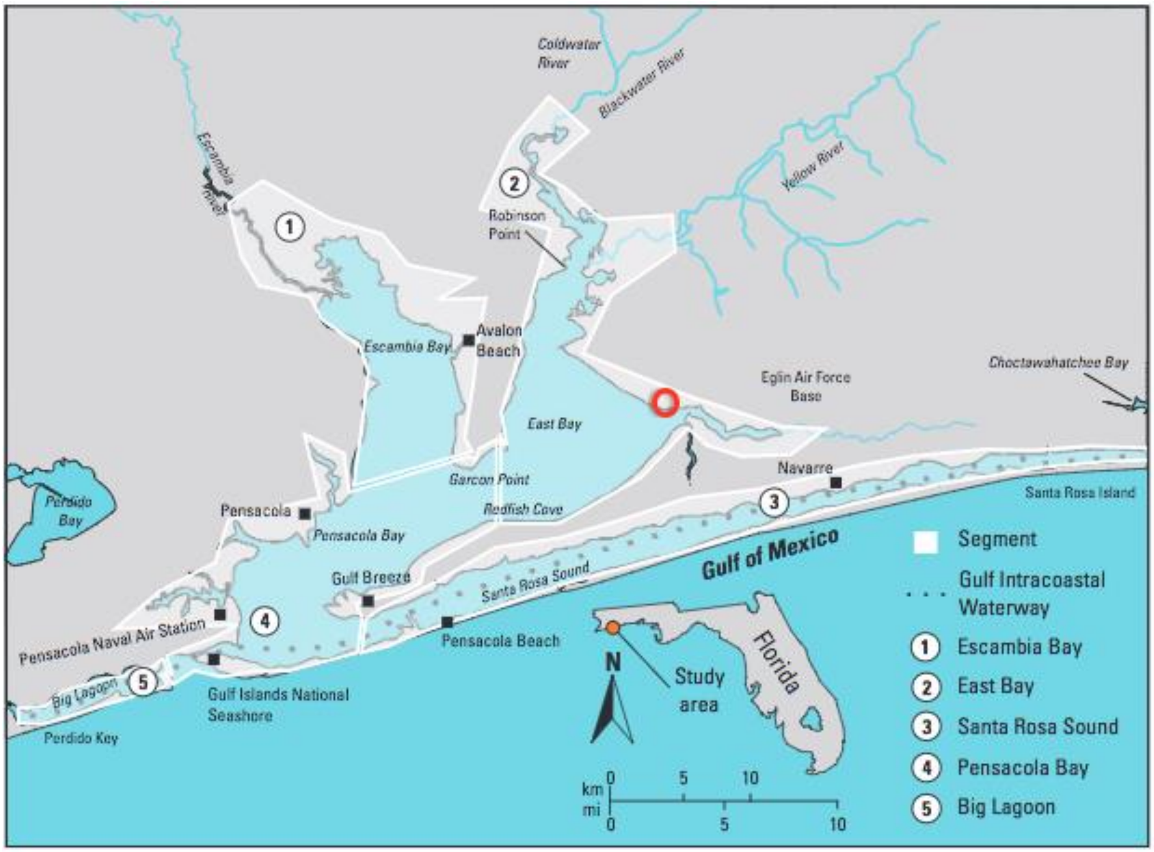

Figure 2: An image depicting the Pensacola Bay area. The Escambia Bay and East Bay flow into the Pensacola Bay, which contains brackish waters. The Santa Rosa Barrier Island is displayed at the bottom of the image, and serves as a boundary between the bay and the Gulf of Mexico. The red marker indicates the study area (modified from Handley et al., 2007).

This bay is one of the largest natural harbors in the country, and is protected from high-energy waters by Santa Rosa Island, a barrier island composed primarily of sand dunes that reach up to 5 meters above sea level. Both Escambia and Santa Rosa counties reside in the Coastal Plain Province. This physiographic region encompasses most of the East Coast, and is characterized by beds of clay, silt, sand, and limestone that dip southeast towards the sea. These beds range from Cretaceous age to modern deposits and are typically unconsolidated (Marsh, 1966).

Chapter 2: Literature Review

2.1 Salt Marsh Sedimentology

Coastal salt marshes typically form high in the intertidal zone, between mean sea level and the level of highest inundation. Surficially, they consist of muddy substrate and exist in the low energy waters of embayments or estuaries. The salinity of these marshes is based on the supplies of salt and fresh water and typically vary anywhere from 5-20%. The growth of algae and soft-stemmed plants is very important to the sedimentary structure of the marsh. Algae growing on the muddy floor of marshes stabilizes the substrate, preventing wave and current erosion. Also, thick aquatic vegetation serves to dampen the flow of water and accrete sediment from suspension (Luternauer, 1995).

The U.S. Army Corps of Engineers has developed a classification system for marshes based on their geomorphology, water source, and hydrodynamics. The geomorphology of salt marshes is typically that of a fringe basin. This geomorphic setting is characterized by frequent drydowns, a low water table, and is located on a topographic high with only surficial outlets. Tidal movements and precipitation are the primary salinity control mechanisms and sources of inundation. The supply of freshwater from tidal flushing is the main source of sediment for most salt marshes, which accumulates at the slopes of marsh deposits lining the perimeter of the wetland (Brinson, 1993).

There are multiple sources from which coastal marshes receive their sediment. One source of deposition originates from rivers and brackish creeks that transport terrestrial sediment into the marsh. Deposition from these fluvial systems can become point bars or natural levees at the mouth of the marsh if sediment is transported rapidly enough. Another type of sedimentation occurs in flooded marsh platforms when water flows over vegetated areas that baffle or impede the flow of the moving water column. This reduction in water velocity results in localized deposition, since the water does not have enough energy to keep the sediments in suspension. The third type of sedimentation occurs at the borders of salt marshes when sediment-laden tidal inundations flow into the marsh and deposit sediment. This boundary is where coarser particles settle out, and often accounts for the majority of the sediment deposited throughout the salt marsh (Davis & Dalrymple, 2012).

As mentioned above, coastal salt marshes receive large amounts of their sediment from the tidal fluctuations of larger, deeper marine environments. This deposition occurs when sediment-laden water flows into the marsh inlet. The velocity of this water decreases progressively as the water travels further into the protected waters of the estuary. This velocity decrease reduces the water's ability to suspend sediment, and its coarsest sediments are deposited. As the velocity of water progressively decreases, finer silt- and clay-sized particles drop out of suspension. As a result, deposited sediment size typically decreases with increasing distance into the salt marsh. Sediment is dispersed over the marsh until the tidal velocity reaches zero, and the water begins to flow in the opposite direction (Haslett, 2010).

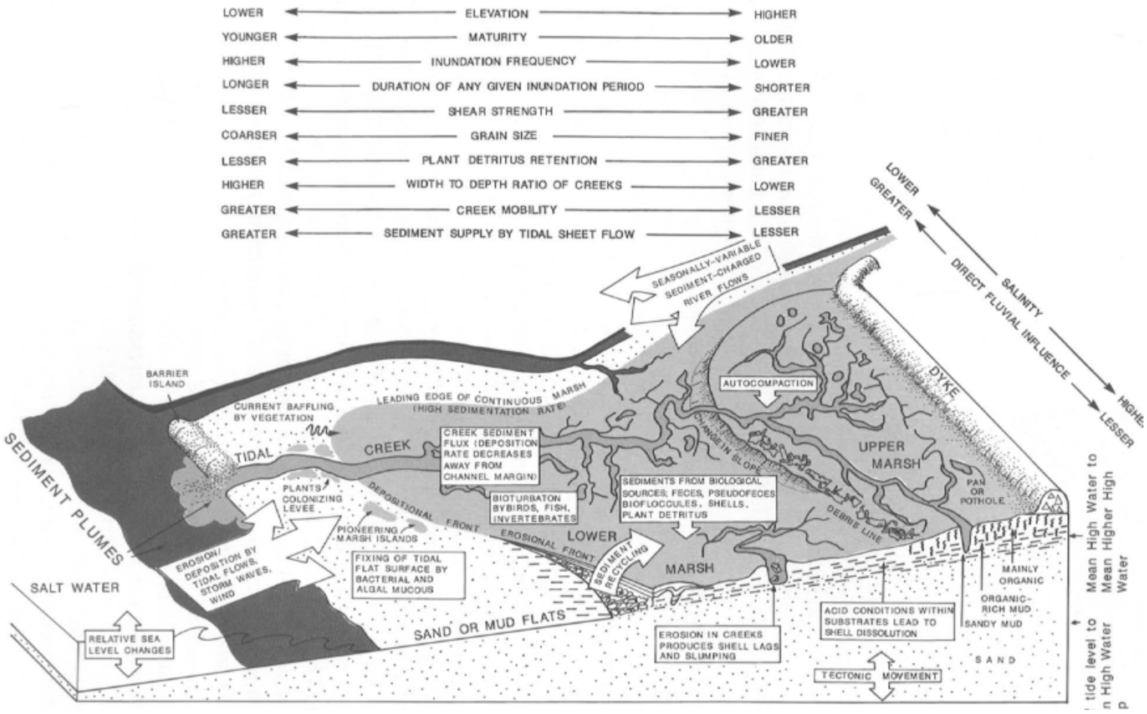

Figure 3: Diagram depicting the primary features and processes of a brackish marsh. Above the diagram are trends in elevation, grain size, hydrology, etc. of the marsh based on horizontal distance from the sea (Luternauer, 1995).

Another important source of sediment, especially for coastal wetlands, are storm deposits. For coastal environments, hurricanes and tropical storms are the most influential storms in coastal sedimentology. Strong winds and storm surges can deliver large blankets of coarser sediment deep within the marsh, which disrupts the typical fining-inland sequence that most marshes exhibit (Fleming, 2013). A study of a coastal marsh in St. Louis Bay, Mississippi, investigated the impact of storm deposits in coastal estuaries. Researchers discovered that two hurricane events were single-handedly responsible for a quarter of the sediment deposition in a 50-year period. In many coastal marshes, these periods of rapid sediment deposition are a main factor in marsh sustainability (Febo et al, 2003).

While storm events often sustain coastal wetlands by supplying large amounts of sediment, some can conversely cause significant damage. In 2004, Hurricane Ivan barreled into the Florida coastline, washing out a significant portion of Santa Rosa Island, which is located at the mouth of Pensacola Bay. This can lead to a substantial reduction of wetland volume if the barrier island is not maintained. Damage dealt by large storms over a course of hours or days could necessitate decades for a full recovery of barrier islands and wetlands. A recent study found that it took four years for the Santa Rosa Island to begin recovery towards its pre-storm geomorphology. It is estimated that it will take another seven years before the island's original vegetation, dune height, and dune volume is completely restored (Houser et al., 2015).

Figure 4: A breach of the Santa Rosa Barrier Island after the impact of Hurricane Ivan (NOAA).

Coastal marshes are also strongly influenced by tidal cycles. These daily inundations can cause the shoreline of a salt marsh to advance or retreat, depending on the tidal conditions. Fluctuations in water level cause minor transgression-regression sequences, which produce plateaus of terraced morphostratigraphic units. During periods of rising water level, called onlap periods, finer marine sediment facies are deposited on top of coarser terrestrial layers in a transgressive sequence. Lowering tides are called offlap periods, which results in coarser sediments being deposited more seaward. This causes terrestrial sediments to be deposited on top of marine sediments, which produces a regressive sequence. These repeated conditions cause sediment to be deposited in step-like terraces that undergo an erosion-accretion cycle once every ten to one hundred years (Haslett, 2010).

There have been multiple studies of wetlands in the same region as East Bay. Florida's Waccasassa Bay, at the eastern edge of the Florida Panhandle, is a microtidal wetland that has similar features to the study area. The Waccasassa Bay marsh is heavily influenced by tidal fluctuations in adjacent creeks, and relies heavily on this inflow of sediment-laden water. This area has been researched to determine the homogeneity of sediments in the marsh and the surrounding dendritic streams. The sediment accumulation rates of this area were calculated at multiple points throughout the marsh with sediment traps. It was found that there are higher deposition rates at the edges of the estuary, where tidal energy begins to decline. Also, an inverse relationship was observed between inundation frequency and the amount of deposition per inundation. This suggests that that short-term, frequent water inundations result in more deposition than long-term tidal rises (Wood & Hine, 2007).

Erosional processes in marsh environments can outperform sediment input sources and can lead to significant reduction in wetland volume. The primary factors in coastal marsh erosion are rising sea levels, subsidence, and wave motion. Sea level rise and subsidence cause part of the wetland to become submerged, facilitating internal marsh erosion. Wave energy can also gradually work away at the perimeter of the salt marsh by dislodging sediment (McLoughlin et al., 2013).

The unconsolidated materials that make up coastal wetlands are very prone to horizontal (wave) erosion, and it has been observed that the perimeters of marshes exposed to high-energy wind and waves will recede rapidly. Brackish marshes exposed to substantial wave energy on the Virginia coast were recorded to lose 0.2-0.5 meters per year. Marshes that interacted with high-energy waves were eroded into a linear bar parallel to the flow direction. Lower energy environments caused the marsh boundaries to become jagged, due to variable erosion and localized wave action. It was also found that the most erosion resistant coastal marshes consisted of sediments of various sizes. This distribution allows finer particles to be eroded, leaving behind more consolidated layers of coarse sediment that can protect the marsh from further damage (Leonardi, 2014).

Florida's coastal wetlands harbor an abundance of plant and animal life. In the Florida Panhandle, there are generally three trophic levels in coastal wetlands. The first tier consists of aquatic plants and seagrass. The second group is made up of macroinvertebrates, such as diatoms and varieties of algae. These organisms serve as an ecological link between primary producers and larger vertebrate animals. The highest trophic tier includes larger vertebrates, such as fish, amphibians, or birds (Lee et al., 2009).

2.2 Munsell Color Rating

Accurately measuring a quality such as sediment color can be a challenging task, since everyone perceives colors differently. How could a scientist determine that a sample is light yellowish brown? How could one communicate their findings, and would other scientists understand what exact color he or she is referring to? To mitigate this confusion and provide a universal color classification system, the Munsell Color System was created. This system consists of books with pages of colored squares. Figure 5 displays an example of one of the Munsell color pages.

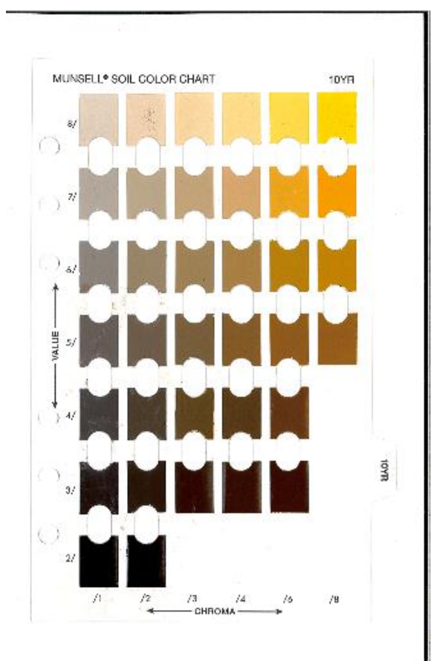

Figure 5: An example of a Munsell color chart sheet. This spectrum in particular (10 YR) was used extensively in this study, as it contained most of the color values of the East Bay samples (VCSU, 2016).

This system allows scientists to accurately determine a sample's color in the field or in a lab by visually matching the soil's color to the colored squares. The pages in the book are organized according to hue, which distinguishes base colors, such as red and yellow. Horizontal rows of colors on each page represent the value, which describes how light or dark the color is. The vertical rows display a transition in chroma, or the intensity of the color. These three color measurements are combined to create a notation that pinpoints the sample's exact color. The notation system has the following format: Hue, value/chroma. For instance, the Munsell rating of 10YR 2/2 indicates a soil color of "Very Dark Brown" (USDA, 2016).

Although color measurements may not be the most sophisticated testing method, they can provide convenient, qualitative information about a sediment sample. Darker sediments often indicate a high organic content, while reddish soils denote a higher concentration of oxidized iron.

2.3 Magnetic Susceptibility

Everything on our planet, whether man-made or natural, has specific magnetic properties. While magnetism is often perceived within the limited scope of magnetic metals, people rarely stop to consider the magnetic properties of earth materials, such as rocks or soil. Measuring the magnetic susceptibility (the tendency of a material to become magnetized) of a rock or sediment sample allows researchers to better understand the mineralogy of the specimen. A higher magnetic reading indicates the presence of iron bearing minerals, or other elements that are more easily magnetized (Dearing, 1999).

The physical definition of magnetic susceptibility is the tendency of a material to become magnetized while exposed to an external magnetic field. It is denoted by the Greek symbol phi (χ), and is a ratio between the external magnetic field and the degree of magnetization. The derivation of magnetic susceptibility measurements is expressed in the following formula:

$$M=\chi H,$$

where M is the vector of the induced magnetization (measured in amperes/meter), H is the intensity of the external magnetic field (also units of A/m), and χ represents magnetic susceptibility, which is a dimensionless unit.

The use of this formula enables magnetic susceptibility to be calculated if the intensity of the external magnetic field and induced magnetization are known. Susceptibility sensors utilize this principle by acquiring both of these values and computing their ratio (Hrouda et al., 2009).

Due to atomic influences on magnetism, not all materials will respond in the same way to an external magnetic field. There are three main categories of magnetic behavior that all materials are categorized into. These classes of magnetic susceptibility each have specific reactions to a magnetic field that vary depending on the individual material's atomic structure.

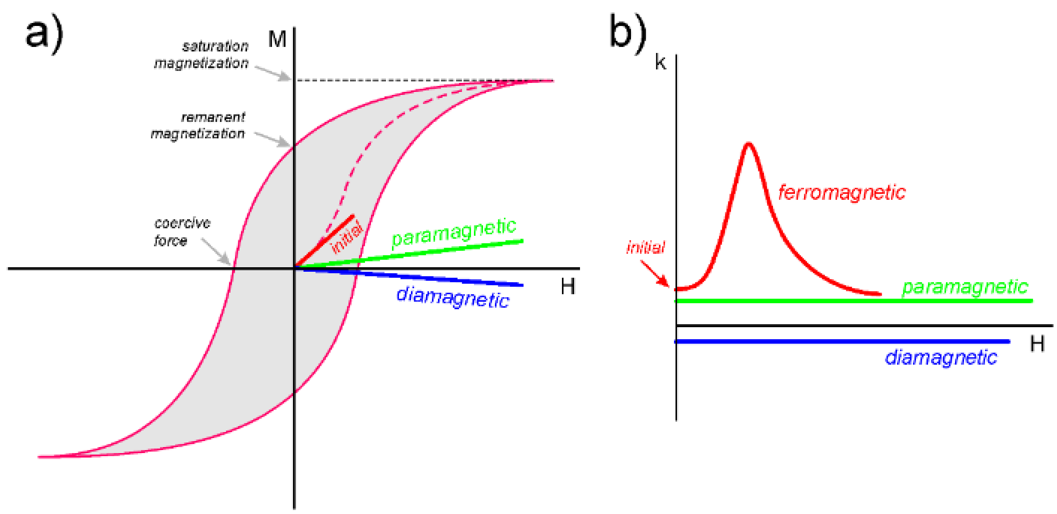

Figure 6: The right graph displays the magnetic reactions of all three types of magnetic materials when exposed to an external magnetic field. In this graph, the horizontal axis represents the external magnetic field, while the vertical axis shows the magnitude and polarity of the resulting magnetization. The left graph emphasizes ferromagnetism and how it reaches a peak magnetism, known as magnetic saturation (Hrouda et al., 2009).

The first two categories have very weak magnetization, and are typically considered "nonmagnetic." The first category is known as diamagnetic materials. These materials are not collectively magnetic and have no magnetic ordering. These materials cannot retain an internal magnetic field after the external field has been removed. A unique property of this group is that they produce a negative magnetization while subjected to a magnetic field. As a result, the magnetic susceptibility of these materials will nearly always be negative with a low absolute value (Moskowitz, 1991). Common mineral examples are quartz, plagioclase, calcite, and apatite. The second category is paramagnetism, which produces a weak positive magnetic susceptibility value. Paramagnetic materials have some unpaired electrons in unfilled orbitals, which results in an overall positive magnetic moment. This magnetic moment is typically a small, positively charged field that disappears once the external field is removed. The third category consists of ferromagnetic materials. These are the substances that are typically thought of as "magnetic." These substances retain their magnetic field as long as they are below a certain temperature, known as the Curie Temperature, that is specific to each ferromagnetic material. Notable geological examples include iron-bearing minerals, such as magnetite, hematite, ilmenite, and pyrrhotite (Nelson, 2013).

Magnetic susceptibility measurements are used widely in environmental studies, likely due to the ease and convenience of recording them. Susceptibility measurements can be recorded using lab equipment, or out in the field directly on rock faces using portable sensors called kappameters. With minimal effort, multiple detailed measurements can be taken that provide valuable insights into the geochemistry and mineralogy of each sample (Hrouda et al., 2009).

2.4 Sedimentary Organic Matter

Soil organic matter (SOM) is a major constituent of sediments in areas of high biological productivity. This is especially true in coastal estuaries, which support an abundance of plant and animal species. SOM also is a reservoir for natural carbon sequestration and is the main source of mineral nutrients necessary for plant growth. There are three principal categories of organic matter that exist in surficial sediments. The first group consists of plant residue and small living microbial organisms. The second category includes all organic matter that is presently decomposing, which is also known as the "active fraction". The active fraction makes up the majority of SOM. The last category is comprised of stable organic matter, and is often referred to as humus. This material has been completely decomposed, and is the most conducive organic matter for plant growth (USDA, 2014).

In a process known as the carbon cycle, all organic carbon on our planet is transferred and recycled. Coastal marshes play a large part in this cycle by storing vast quantities of organic carbon. Environmental carbon sequestration is a highly researched topic, since high concentrations of carbon-rich gases in the atmosphere have been shown to increase global warming. Wetland ecosystems mitigate the effect of greenhouse gasses by storing away carbon in its sediments and within biomass. Decomposing organic matter is stored away in the sediments of marshes, while wetland vegetation removes carbon dioxide from the atmosphere through photosynthesis. It is estimated that coastal salt marshes worldwide remove 4.8 to 8.7 million metric tons of carbon from the atmosphere annually. The preservation of these valuable carbon reservoirs is crucial to ensure that atmospheric carbon levels remain as low as possible (Quintana-Alcantara, 2014).

The organic carbon cycle within coastal wetlands can be evaluated based on the various methods of carbon storage and transfer within the ecosystem.

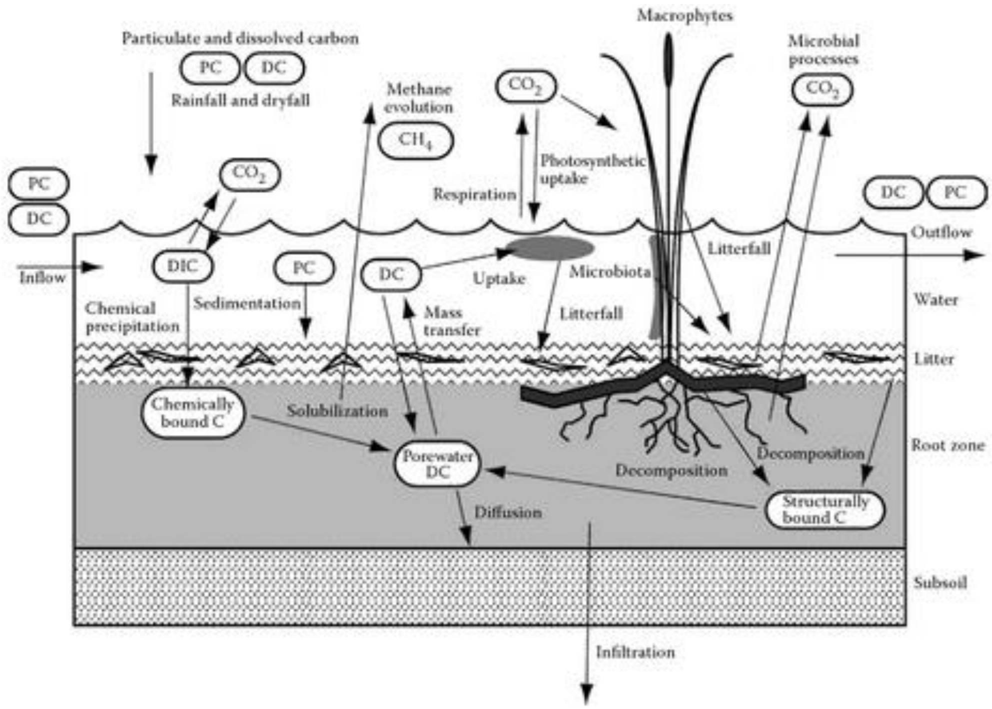

Figure 7: Diagram depicting the various transfers and stores of organic carbon within a typical wetland environment (Kadlec & Wallace, 2009).

The rate and amount of decomposing material within the area is the main input of organic carbon into sediments, water, and growth of vegetative biomass. Surficial wetland vegetation is capable of removing additional carbon from the atmosphere, while submerged plant life can remove organic carbon from the water column. The primary output of carbon from wetland ecosystems includes methane evolution, the respiration of aquatic wildlife, and microbial processes. (Kadlec & Wallace, 2009).

2.5 Carbonate Minerals

Coastal wetlands are prime environments for the formation of carbonate minerals, which can eventually form limestones and dolostones. These minerals are primarily made of calcium carbonate, which comes from the shells and skeletons of various aquatic invertebrates. These invertebrates take in calcium from saline water to create these shells, which are left behind when the organism dies. In addition, calcite and aragonite particles can be produced by certain algae species within microtidal wetlands (Nichols, 2009).

A common way to evaluate carbonate composition involves the effervescence of calcium carbonate in hydrochloric acid in the following reaction:

$$CaCO_3 + 2HCL = Ca^{++} + 2Cl^{-} + H_2O + CO_2$$

In this reaction, the calcium carbonate and hydrochloric acid react to produce calcium cations, chlorine anions, water molecules, and carbon dioxide gas. The carbonate minerals are removed as carbon dioxide gas from the solution, which provides an accurate means for measuring the mass of the removed minerals.

2.6 Sediment Grain Size

In marine environments, sediment is deposited when the water column is no longer turbid enough to support the sediment grains. While gravity eventually pulls all sediment grains toward the riverbed/floor of the body of water, finer sediments, such as clays, can take days to settle in an undisturbed body of water. In flowing/disturbed waters, these finer sediments take even longer or never fall out of suspension. Due to tidal and fluvial influences, certain areas of coastal wetlands have more energetic waters than others. This means that certain sediment sizes will be deposited in certain locales within a marine system. This makes an analysis of sediment size distributions very useful in providing insights into a marine depositional environment, such as a microtidal wetland.

In this research, the sediment size distributions of various samples were examined to acquire an overall profile of depositional characteristics in the study area. Sediment size can be calculated using Stoke's Law, which dictates the amount of drag on a suspended particle within a viscous liquid.

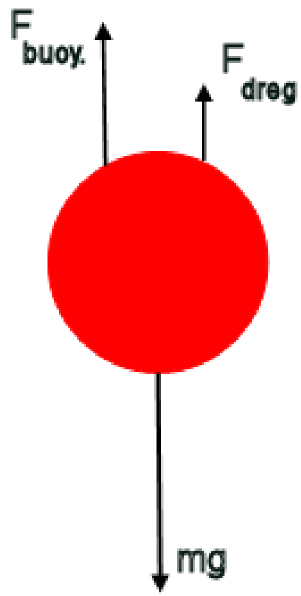

Figure 8: The forces acting on a spherical particle moving through a liquid. Gravitational force is the largest vector, which is equal to the mass of the particle times the rate of acceleration of gravity. Two smaller vectors work against gravity, which are buoyancy and drag. As the speed of the particle increases, the force of drag increases, causing the particle to reach a terminal velocity (UTK Physics).

Assuming that the sediment particle in question is perfectly spherical, there are three forces acting upon it. The force of gravity pulls downward on the sediment grain, forcing it towards the bottom of the water column. There is a drag force and, if applicable, a buoyant force that resists the gravitational force, slowing the descent of the sediment grain. In coarser sediments, the mass of the particle is greater, which increases the gravitational force and the rate of settling. The opposite is true for fine-grained sediments. If the amount of suspended sediment is measured at frequent intervals, a sediment size distribution can be constructed, which details all size elements within a sediment sample (UTK Physics).

Chapter 3: Methodology

For this experiment, 40 samples were collected in the study area and evaluated based on their color, magnetic susceptibility, organic content, carbonate content, and sediment size distribution. These tests allowed conclusions to be made on the composition and depositional environment in the East Bay area. This sedimentological data yielded in this experiment were analyzed to gain a generalized overview of the collection site, as well as a comparison of different zones of the marsh.

3.1 Sample Collection/Preparation

In this analysis, forty samples were collected at various points along the shoreline and in the upland portion of the marsh. With the exception of samples 17 and 18, all samples were collected surficially using a small shovel or trowel to collect the uppermost layer of sediment. Samples 17 and 18 were collected from a depth of one meter using an auger.

Figure 9: Sample collection at the study area (Courtesy of FT Heitmuller).

The samples were stored and labeled in separate Nasco Whirlpack collection bags, and the GPS coordinates of the collection site were recorded using a Trimble portable GPS unit with an accuracy of approximately 3 meters. The samples were then stored away in an ice chest to reduce changes in temperature, humidity, and coloration until testing. These samples were collected on June 25, 2010, and were analyzed throughout the summer and fall of 2016.

3.2 Laboratory Techniques

The first step in this experiment was to record the Munsell color values for each of the 40 samples. These were recorded first so that the color values would closely represent the samples while in situ. All of the following procedures in this experiment would have altered the original coloration of the samples. Next, all of the samples were heated in a drying oven at 100^0 C overnight. Due to the removal of moisture, many of the more organic samples hardened into tough amalgamations of sediment. Each of these samples was thoroughly disaggregated with a mortar and pestle before further tests were conducted.

The next test that was conducted was a magnetic susceptibility analysis. These measurements were taken before the other tests because the other analyses could have influenced the magnetic properties of the sediment samples. Measurements were recorded using Bartington MS2B unit connected to a desktop computer, which was running compatible Bartsoft processing software. The magnetic susceptibility unit that was used had been calibrated to measure the susceptibility of 10 grams of sediment, so that was the target mass for each analysis.

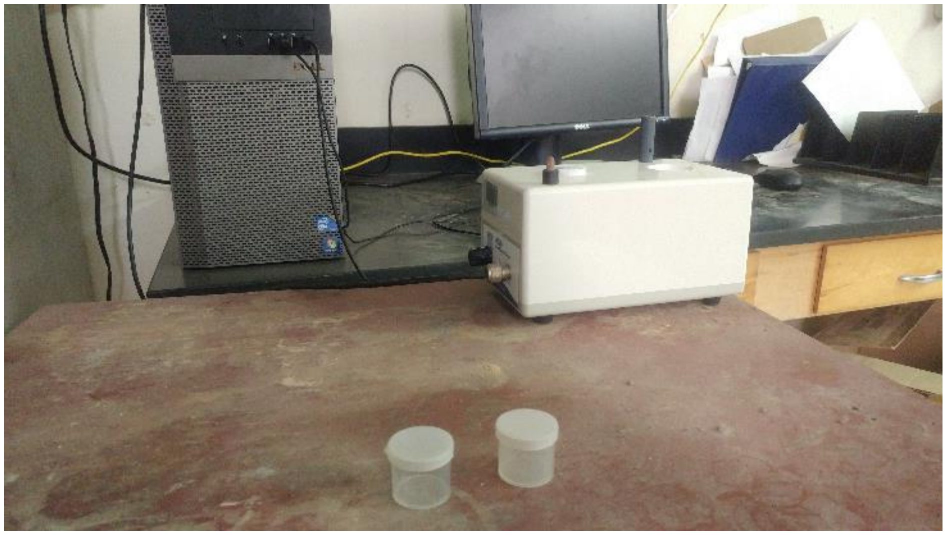

Figure 10: Image of the MS2B susceptibility unit, plastic vials, and desktop computer used in the magnetic susceptibility measurements.

Each mass measurement in this project was recorded using a digital scale with an accuracy of 0.014 grams. Using this scale, 10 grams of each sample was measured and placed in a plastic, cylindrical vial with a cap on top. Each sample was tested six times: three low frequency measurements and three high frequency measurements. Before each of the six readings, the machine was zeroed out, and the measurement time was set to 1 minute to ensure consistency. The three low frequency measurements were averaged together, as well as the three high frequency values. This removed any variances in the readings, ensuring a higher degree of accuracy. This susceptibility test does not alter the sediments in a way that would influence the following tests, so the 10 grams of sediment evaluated in each magnetic susceptibility test was re-combined with the rest of the sample.

With the magnetic susceptibility tests completed, the next test performed was an organic content analysis. One way to perform this test is to add hydrogen peroxide (H_2O_2), which removes the organic content in sediment. This can be done by first emptying a known mass of sample into a weighed 1000 mL beaker. Then, 30% H_2O_2 is added very slowly, causing the sample to effervesce. Placing the beaker on a hot plate while adding peroxide speeds the reaction considerably. Peroxide is added until the sample stops fizzing, which means that there is no organic matter left to react with. The sample is then dried and measured, and any loss of mass is recorded as the removed organic material. While this is an excellent method for measuring organic matter, it comes with quite a few sources of error and is time-consuming. Using too much peroxide on a sample results in extremely violent effervescence, which ejects some of the sample from the flask. Also, it can be difficult trying to determine whether or not a sample is done reacting with the peroxide. Due to these inaccuracies, the organic percentage of each sample was instead measured with the loss-on-ignition test.

Figure 11: Image of muffle furnace and crucibles used in the loss-on ignition test.

This test involved heating 5-10 grams of sediment in a pre-weighed crucible inside of a muffle furnace at 550^0 C for four to five hours. After heating, the sample was re-weighed to find the mass of any burned off organic material. The equation $\frac{Removed\ organics}{sample\ mass\ (before\ ignition)} \times 100$ was used to obtain very accurate organic percentages for each sample. The sediment used in this test had to be discarded, since the intense heat fused some sediment grains together and would have provided erroneous readings in the sediment size analysis. Hydrogen peroxide was then used to remove the organics from the remainder of the sample. Organic material would have had an adverse effect on the sediment size analysis, since it often acts as an adhesive that holds particles together. Removing all of the organic material ensured that the sediment size analyses had the smallest degree of error possible. Since the organic percentage was already found using loss-on-ignition, organic material could be removed without the worries of previously mentioned sources of error. Due to a shortage of hydrogen peroxide in the laboratory, the organic material in samples 26-40 were not completely removed. This could have resulted in a small degree of error in the aforementioned samples' sediment size analyses.

The next experiment performed was a gravimetric carbonate analysis described by Allison and Moodie in *Soil Sampling and Methods of Analysis.* First, a mixture of 400 mL 1mol Hydrochloric acid (HCL) and 3 grams of ferrous chloride ($FeCl_2 \bullet 4H_2O$) reagent was stirred until the ferrous chloride dissolved. This reagent was added to the HCL to prevent any calcium carbonate from re-precipitating as other minerals, which would alter the amount of mass lost. The HCL solution was then divvied up into eight labeled 250 mL Erlenmeyer flasks, each one with 50 mL of the solution. Each beaker with HCL was weighed to find the mass of the beaker and solution. Then, 5 to 10 grams of each sediment sample were added to their respective flasks. After reweighing the flask with sediment and HCL inside, a rubber stopper with a small hole or tube was securely fitted onto the opening to reduce evaporation, while still allowing carbon dioxide gas to escape. The samples were stored away for up to two hours, which is the maximum time necessary for the reaction to complete. After the two hours had elapsed, each beaker was reweighed with the stopper removed. Any loss of mass was recorded and the carbonate percentage of each sample was calculated.

The final test conducted on each sample was a sediment size analysis. For this analysis, a 1000 mL Bouyoucos tube, a hydrometer, distilled water, 5% hexametaphosphate ($(NaPO^3)^6$) solution, a milk-shake mixer, and a set of wet sieves are necessary.

Figure 12: Image of Bouyoucos tubes and a hydrometer being used in sediment size analyses.

First, 50 grams of the sample was placed in a 400 mL beaker. Then, 250 mL of distilled water and 100 mL of 5% hexametaphosphate solution (a clay deflocculant) were added. The deflocculant was produced by mixing one liter of distilled water with 50g of solid sodium hexametaphosphate on a hot plate while rigorously stirring until all of the ($(NaPO^3)^6$) crystals dissolved. This beaker was stored away overnight to ensure that the deflocculant disaggregated smaller clay particles thoroughly. Then, the solution was placed in a milk-shake mixer for five minutes to ensure that the sample is entirely disaggregated. After that, the earthy-tasting milkshake was poured into the Bouyoucos tube, and distilled water was added up to the 1000mL marker. A control tube was prepared by filling a separate tube with only distilled water and deflocculant, which provided the control specific gravity and temperature readings. A stopper was placed on the opening of the tube containing the sediment, and carefully shaken for 1 minute. Immediately after placing the Bouyoucos tube upright, a timer was started. A hydrometer was gently lowered into the tube, and specific gravity measurements were taken at the following intervals: 40 seconds, 1 min., 1.5 min., 3 min., 5 min., 10 min., 15 min., 30 min., 45 min., 1 hour, 2 hours, 4 hours, 6 hours, 1 day, 2 days, and lastly 3 days. If it was necessary to take a hydrometer reading later or earlier than its intended sampling period, the time at which the measurement was taken was noted and incorporated into the calculations.

The next portion of the sediment size analysis involved the use of wet sieves to analyze the coarser grains in the sediment. The sieves sizes used were the 2 mm (-1 phi), 1 mm (0 phi), 0.5 mm (1 phi), 0.25 mm (2 phi), 0.125 mm (3 phi), and 0.06 mm (4 phi) sieves. They were stacked on top of each other with the coarsest (2mm) on top and the finest (0.06 mm) on the bottom. The Bouyoucos tube was poured in through the top sieve, and tap water was used to push the sediment grains into their respective sieves. Six pre weighed 100 mL beakers were labeled with the sample number and grain size. Using a squeeze bottle, the sediment in each sieve was transferred into the beakers, which were dried overnight at 100 ^{0}C. The beakers were then weighed to calculate the mass of sediment caught by each sieve. These figures were then used to analyze the sand fractionalization of the sediment sample. These data were entered into an Excel spreadsheet that was pre-programmed with Stoke's Law equations that calculated the D16, D50, D84, and sorting coefficient for each sample.

Chapter 4: Results and Discussion

The 40 collection sites in this research project were categorized into distinct sub-environments. This allows for comparison between and within each sub-environment.

Figure 13: Image depicting the sub-environment zones. Fluvial sediments are marked with blue indicators. In order to avoid zooming out too far to see the sub-environments, two fluvial collection sites to the north are not shown in this image.

The samples were placed into sub-environments based on a consideration of both their geographic location and the structure from which each sample was collected (such as sandbars, marsh edge, etc.) The term "Spartina Ridge" refers to a species of grass that is prevalent in this sub-environment. The term "Juncus Marsh" also originates from the type of vegetation growing in that area, which is a plant colloquially known as "needlerush."

It is also necessary to know which sediment samples make up each sub-environment. The Western Frontbar sub-environment was comprised of samples 1, 2, 5, and 6. The Central Frontbar/Marsh Edge sub-environment contained samples 3, 4, 7, 8, 9, and 10. The Spartina Ridge group included samples 22, 23, 26, 29, 30, 38, 39, and 40. The Juncus Marsh sub-environment consisted of sample numbers 24, 25, 27, 28, 31, 32, 33, 34, 35, and 37. Sediments collected from the fluvial bed include samples 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 36.

The following table displays the results of the color, magnetic susceptibility, organic content, carbonate content, and sediment size analyses for each sample:

Table 1: Compilation of collected data from all analyses.
*After the removal of organics, samples 14 and 15 did not have sufficient sediment remaining to perform a precise sediment size analysis.

Sample #	Color	Magnetic Susceptibility (Low Frequency)	Magnetic Susceptibility (High Frequency)	Organic Content (%)	Carbonate Content (%)	d16	d50	d84	Sorting Coefficient
1	2.5Y 7/2 (Light Gray)	$4.3270 * 10^{-6}$	$5.5445 * 10^{-6}$	0.71	0	0.158719	0.258065	0.446957	1.4680
2	10YR 8/2 (White)	$5.9383 * 10^{-6}$	$7.3109 * 10^{-6}$	0.29	0.21	0.267307	0.365053	0.462799	1.2208
3	10YR 6/3 (Pale Brown)	$-5.3027 * 10^{-6}$	$-4.6249* 10^{-6}$	0.27	0.32	0.277189	0.376164	0.475140	1.2165
4	10YR 8/3 (Very Pale Brown)	$-8.5995 * 10^{-6}$	$-8.6426 * 10^{-6}$	0.17	0.37	0.273441	0.373066	0.472691	1.2201
5	5YR 2.5/2 (Dark Reddish Brown)	$2.6322 * 10^{-6}$	$3.3188 * 10^{-6}$	15.96	0.18	0.139335	0.298410	0.450250	1.4996
6	5YR 2.5/2 (Dark Reddish Brown)	$18.4972 * 10^{-6}$	$18.5318 * 10^{-6}$	23.55	0	0.001478	0.017248	0.173392	4.4795
7	5YR 2.5/2 (Dark Reddish Brown)	$-5.3423 * 10^{-6}$	$-2.6003 * 10^{-6}$	10.58	0.44	0.253612	0.387092	0.634497	1.2959
8	5YR 2.5/1 (Black)	$28.4488 * 10^{-6}$	$30.4189 * 10^{-6}$	15.50	0.22	0.001502	0.015223	0.061587	2.5259

9	5YR 2.5/1 (Black)	$15.2399 * 10^{-6}$	$15.2113 * 10^{-6}$	10.91	0.38	0.000958	0.129999	0.238741	7.8876
10	5YR 2.5/1 (Black)	$32.4117 * 10^{-6}$	$37.6579 * 10^{-6}$	17.93	0	0.001074	0.018208	0.058010	1.4540
11	10YR 7/3 (Very Pale Brown)	$-5.9708 * 10^{-6}$	$-1.3467 * 10^{-6}$	0.46	0.78	0.305621	0.448670	0.814484	1.4118
12	10YR 5/3 (Brown)	$-9.2636 * 10^{-6}$	$-7.3109 * 10^{-6}$	0.61	0.28	0.297486	0.418880	0.540274	1.2416
13	10YR 2/2 (Very Dark Brown)	$24.4520 * 10^{-6}$	$25.7624 * 10^{-6}$	13.68	0	0.000971	0.071353	0.335472	10.3045
14*	10YR 2/2 (Very Dark Brown)	$-4.6063 * 10^{-6}$	$-3.2793 * 10^{-6}$	70.41	0.33	N/A	N/A	N/A	N/A
15*	10YR 2/1 (Black)	$2.6405 * 10^{-6}$	$5.9426 * 10^{-6}$	40.74	0	N/A	N/A	N/A	N/A
16	10YR 2/2 (Very Dark Brown)	$35.0712 * 10^{-6}$	$43.5948 * 10^{-6}$	22.21	0.47	0.011293	0.018558	0.083463	3.0760
17	10YR 5/4 (Yellowish Brown)	$-7.3348 * 10^{-6}$	$-6.6165 * 10^{-6}$	10.41	0.7	0.252470	0.420455	0.915506	1.3535
18	10YR 2/1 (Black)	$3.9573 * 10^{-6}$	$4.6627 * 10^{-6}$	55.67	0	0.000706	0.019190	0.213024	9.5481
19	10YR 2/2 (Very Dark Brown)	$2.0041 * 10^{-6}$	$1.3046 * 10^{-6}$	7.14	0.18	0.018727	0.366802	0.490133	1.2872
20	10YR 3/2 (Very Dark Grayish Brown)	$27.8087 * 10^{-6}$	$29.7756 * 10^{-6}$	17.34	0.55	0.001966	0.087726	0.238417	4.1007

21	10YR 2/2 (Very Dark Brown)	$39.6303 * 10^{-6}$	$27.1181 * 10^{-6}$	13.62	0.3	0.001494	0.074558	0.246029	4.1250
22	10YR 8/2 (White)	$-9.2308 * 10^{-6}$	$-5.6443* 10^{-6}$	0.12	0.41	0.286610	0.395417	0.538551	1.2277
23	10YR 5/3 (Brown)	$2.0191* 10^{-6}$	$1.9630* 10^{-6}$	10.59	0.72	0.270682	0.373787	0.476892	1.2284
24	10YR 3/3 (Dark Brown)	$-3.2634* 10^{-6}$	$-3.3067* 10^{-6}$	3.24	0.41	0.266968	0.387161	0.559770	1.2616
25	10YR 2/2 (Very Dark Brown)	$29.7050* 10^{-6}$	$31.6965* 10^{-6}$	15.90	0	0.002982	0.139329	0.291988	3.7457
26	10YR 3/2 & 7/2 (Very Dark Grayish Brown)	$-10.2855* 10^{-6}$	$-11.2901* 10^{-6}$	1.57	0.43	0.269939	0.406070	0.703161	1.2862
27	10YR 2/1 (Black)	$9.9429* 10^{-6}$	$11.2445* 10^{-6}$	10.58	0	0.071580	0.223281	0.482955	1.6594
28	10YR 2/2 (Very Dark Brown)	$1.3341* 10^{-6}$	$2.6364* 10^{-6}$	2.35	0	0.077393	0.392626	0.714286	1.4128
29	10YR 2/1 (Black)	$20.5013* 10^{-6}$	$17.8533* 10^{-6}$	36.98	0.34	0.006297	0.101650	0.564690	3.7995
30	10YR 7/2 (Light Gray)	$-12.5933* 10^{-6}$	$-7.6195* 10^{-6}$	0.55	0	0.312500	0.488167	0.853916	1.4490
31	10YR 2/1 (Black)	$37.6824* 10^{-6}$	$37.6846* 10^{-6}$	25.62	0.34	0.002118	0.063200	0.208059	3.1475
32	10YR 2/2 (Very Dark Brown)	$35.0772* 10^{-6}$	$36.3168* 10^{-6}$	30.66	0.31	0.001612	0.041657	0.105640	3.5356
33	10YR 2/2 (Very Dark Brown)	$-2.6456* 10^{-6}$	$-1.9469* 10^{-6}$	9.99	0	0.054733	0.380101	0.724482	1.5902

34	10YR 2/2 (Very Dark Brown)	$25.1267 * 10^{-6}$	$23.8205 * 10^{-6}$	12.89	0	0.007743	0.251583	0.453430	4.2488
35	10YR 3/2 (Very Dark Grayish Brown)	$-2.6711 * 10^{-6}$	$-2.6394 * 10^{-6}$	9.57	0.6	0.140084	0.239476	0.499836	1.5998
36	10YR 2/2 (Very Dark Brown)	$33.0636 * 10^{-6}$	$32.4145 * 10^{-6}$	24.48	0.24	0.001486	0.063256	0.148869	3.1482
37	10YR 2/1 (Black)	$3.9873 * 10^{-6}$	$5.2727 * 10^{-6}$	4.00	0.31	0.067066	0.224231	0.482539	1.8633
38	10YR 6/2 (Light Brownish Gray)	$-6.6314 * 10^{-6}$	$-6.5984 * 10^{-6}$	0.40	0	0.318547	0.515101	0.871644	1.4519
39	10YR 3/4 (Dark Yellowish Brown)	$5.9555 * 10^{-6}$	$5.9401 * 10^{-6}$	6.93	0.62	0.069241	0.473655	0.828696	1.5648
40	10YR 7/2 (Light Gray)	$-5.9614 * 10^{-6}$	$-6.5954 * 10^{-6}$	0.44	0	0.283601	0.401134	0.633796	1.2447
		$8.5928 * 10^{-6}$	$9.4752 * 10^{-6}$	13.776	0.26	0.123841	0.244810	0.44140	2.7306

While magnetic susceptibility measurements are not optimal for deducing the detailed mineralogy of samples, observing the overall distribution of susceptibility values can yield many interpretive results. Overall, the magnetic susceptibility measurements were fairly consistent. They were all on the 10^{-6} scale, and all measurements were indicative of paramagnetic and diamagnetic minerals. A few of the samples had significantly higher susceptibility measurements, indicating miniscule amounts of ferromagnetic materials, such as ilmenite. In the western frontbar sub-environment, the samples were exclusively composed of paramagnetic minerals. The central frontbar/marsh edge sub-environment was predominantly diamagnetic, with negative susceptibility values. This was likely due to the presence of the most common diamagnetic mineral, quartz, in the form of quartz-rich sand. The only measurements in this sub-environment that weren't diamagnetic were two positive susceptibility readings of samples taken near the fluvial outlet. Considering that the samples taken from the channel bed were some of the highest positive values in the study area, the paramagnetic minerals in these samples likely originated from a terrestrial source upstream and were transported downstream to the channel mouth. The samples from the Spartina Ridge sub-environment were predominantly diamagnetic, which is indicative of quartz. The seaward position of the ridge and sediment size analysis support the claim that this sub-environment is dominated by quartz-rich sand. The Juncus Marsh sub-environment samples alternated from paramagnetic readings to diamagnetic readings, without any consistent trends. As mentioned earlier, the samples from the fluvio-tidal channel were dominated with paramagnetic minerals that likely eroded from an upstream source rock.

The organic percentage readings were highly variable, ranging from 70 percent to less than one percent.

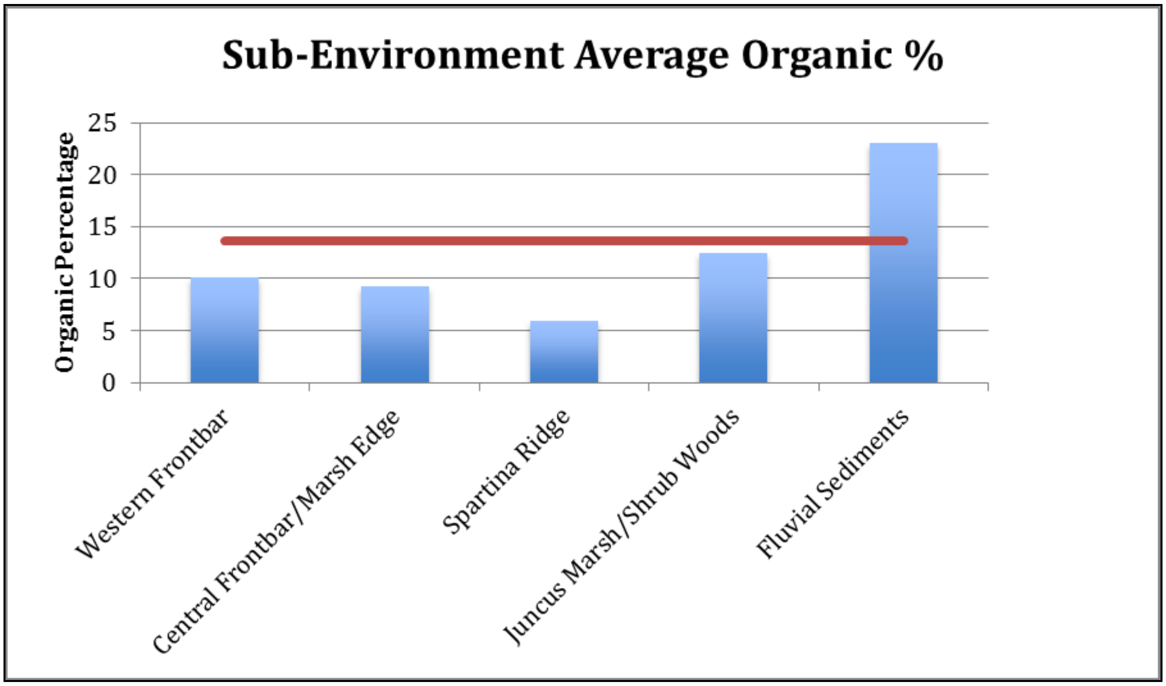

Figure 14: The average organic percentages within each sub environment. The red line displays the average of all 40 samples.

The sediment samples in this study followed the general trend of higher organic content with increasing distance from the shoreline. As expected, the lighter colored, beachfront sediments exhibited an overall lower organic percentage than the finer grained, darker colored sediments. The Western Frontbar, Central Frontbar, and Spartina Ridge sub-environments made up the seaward portion of the marsh and had the lowest average organic percentages in the study area. The Juncus Marsh and Fluvial samples had a significantly higher organic percentage, indicating a higher level of biological productivity in the marsh uplands. Near the mouth of the river, there are elevated organic percentages in samples 9, 10, and 23. The organic component of these samples was much higher than their sub-environment's average, and suggests the delivery of organic components to the bay via the fluvio-tidal channel.

Concerning carbonate content, all of the samples contained less than one percent $CaCO_3$. This indicates that the study area is predominantly made up of siliciclastic terrigenous material, and that biological calcium carbonate production is not very high in the area.

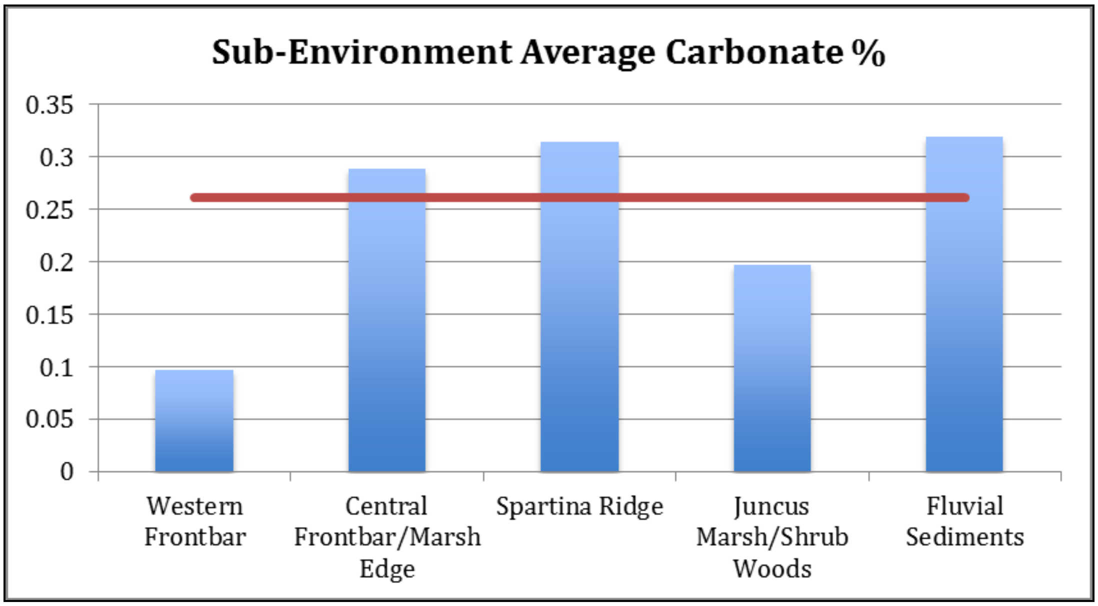

Figure 15: The average carbonate percentages of each sub-environment. The red line marks the average for all 40 samples.

The highest average carbonate percentages were recorded in the Central Frontbar, Spartina Ridge, and Fluvial sub-environments. The Juncus Marsh and Western Frontbar sub-environments had relatively lower organic percentages. It is worth noting again that the electric scale used to measure the loss of mass in this test was accurate within 0.014 g. Many of the samples only lost 0.01 g of mass in the carbonate test, meaning that the loss of mass on some samples could be attributed to the scale's margin of error. Due to this concern, the samples were closely monitored to see if any visible effervescence was occurring in any of the samples. In samples 11, 17, and 39, which displayed some of the highest carbonate percentages, it was noted that there was a small degree of visible effervescence coming from small particles of shell-like material.

The trends in the sediment size analyses displayed an overall fining of sediments in the marsh with increased distance from the bay. The samples collected from the Frontbars and Spartina Ridge sub-environments were almost exclusively well-sorted sand. Samples that were collected further from the shore chiefly consisted of moderately to poorly sorted sandy loam.

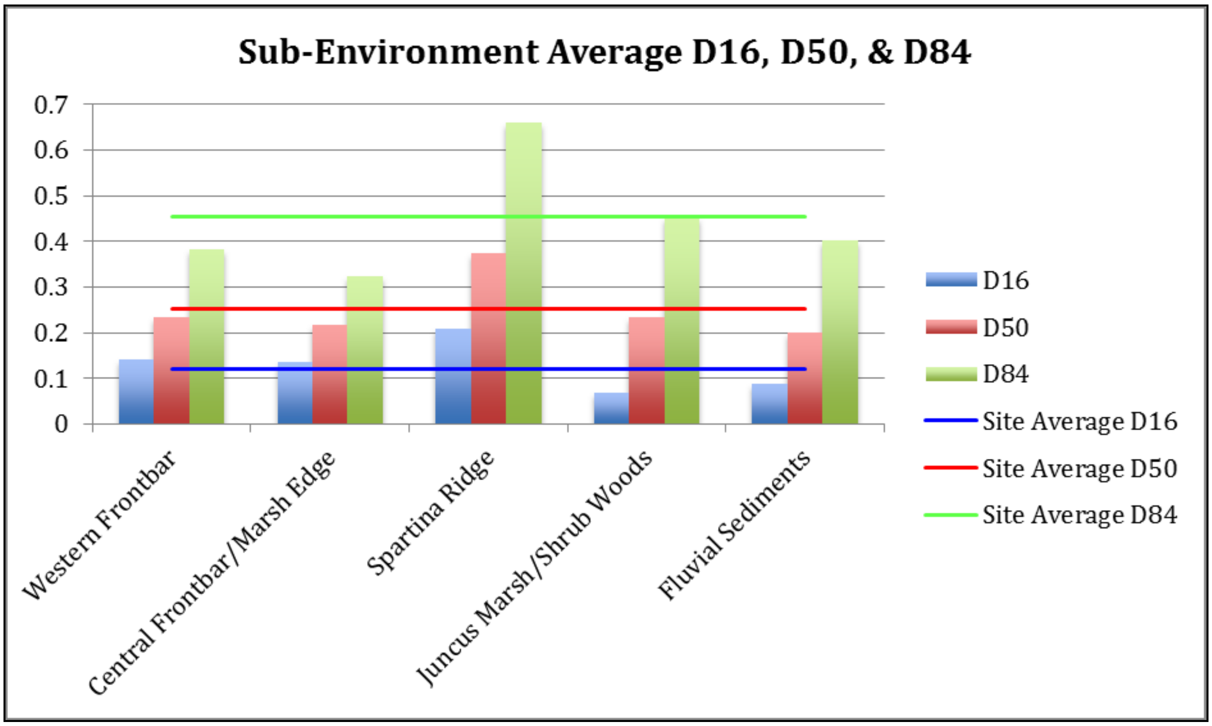

Figure 16: The average D16, D50, and D84 values within each sub-environment. The blue, red, and green lines mark the average sediment size values for all 40 samples in the study area.

On average, the western frontbar samples had higher sediment size values than the central frontbar samples. This is due to the location of the collection sites within each of the two sub-environments. The central frontbar is closer to the fluvio-tidal outlet, which acts as a source of finer grained sediment. In addition, half of the samples within the central frontbar sub-environment are finer grained samples from the marsh edge, which lower the average sediment sizes for the entire group. The Spartina ridge sub-environment had the highest average D16, D50, and D84 values within the study area. Due to the exposed location of the ridge, high-energy waters prevent finer grained sediments from being deposited there. The cordgrass that is the namesake of this sub-environment likely impedes the movement of the water column enough for coarser sand particles to fall out of suspension, creating a well-sorted layer of deposited sand. It was expected that the inland Juncus Marsh/Shrub Woods sub-environment would have the finest grained sediments in the study area. It had the lowest D16 value, but displayed relatively high D50 and D84 values. In fact, many of the inland samples contained an unexpected amount of sand-sized sediment, which is likely due to flooding or storms transporting these coarser grains deeper into the marsh. As mentioned in the literature review, storm events can rapidly deposit these sand-sized sediments deep within coastal marshes. They have also caused breaches in the Santa Rosa Barrier Island, which relocated sandy sediment from the island into these estuarine environments. These samples were collected roughly five years after Hurricane Katrina, which had one of the most powerful storm surges in gulf coast history. Studies of Bay St. Louis marshes by Febo et al. (2003) show that storm deposits from smaller hurricanes can have profound effects on marsh sediment size for decades, making it very plausible that the elevated sand fraction of surficial sediments within the marsh is a result of a major storm or storm-like event. The sediments collected from the fluvio-tidal channel had the lowest D50 value, and intermediate D16 and D84 readings. These analyses imply that the channel receives some coarse grained sediments through storm deposits, but not to the extent of the Juncus Marsh sub-environment.

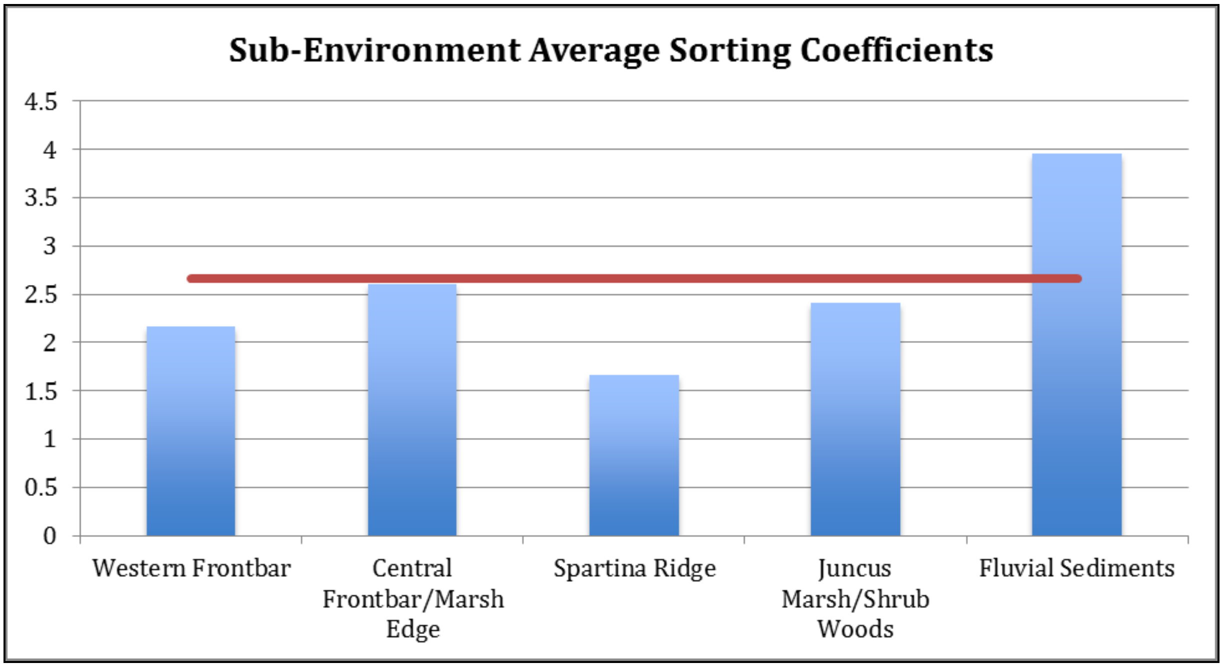

Figure 17: Average sorting coefficients for the samples in each sub-environment. The red line marks the average sorting coefficient of all 40 samples throughout the study area.

The spartina ridge sediments were the most well-sorted in the study area. This is likely due to the higher amounts of wave and wind energy that this sub-environment is exposed to, which would mainly allow coarser sands to be deposited. The sorting coefficient of the western frontbar was relatively low, indicating that these sediments are moderately well-sorted sands. The central Frontbar and Juncus Marsh sub-environments have sorting environments that coincide with the site averages. The fluvio-tidal channel samples were the most poorly sorted in the study area. This partially due to extremely high sorting coefficients in samples 13 and 18. This could be due to collection errors, or a local anomaly in the channel. It is also due to the extreme difference in sediment size between the fine-grained channel sediment and the coarser sands introduced during tidal fluctuations and storm events.

Chapter 5: Conclusions

In this experiment, samples from a small estuarine marsh along East Bay were collected, analyzed, and interpreted to gain an overview of sedimentological processes and trends. The data in this study has led to multiple interpretations and conclusions about the depositional environment within the study area:

- Trends in experimental data revealed that this marsh generally contained more organic, finer grained sediments with increasing distance from the shore.
- The magnetic susceptibility and organic content tests showed similarities between channel bed sediments and sediment samples near the fluvio-tidal channel outlet. Samples 9, 10, and 23 were the most affected. These samples in the Central Frontbar and Spartina Ridge sub-environments were supplied sedimentary materials from the fluvial system, and define the magnitude and area of deposition that the system is capable of. The paramagnetic minerals and elevated organic percentages noted at the mouth of the channel were not observed at the point of the spartina ridge nor anywhere else in the central frontbar. These samples also had significantly lower sediment size readings that were more similar to the fluvio-tidal channel. This means that the channel's sediment load is not sufficient to influence sub environments past the mouth to East Bay. Past the outlet, the fluvial sediments are suspended within the energetic waters of the bay, and are not primarily deposited along the shoreline within the study area.

- The Spartina Ridge sub-environment was the most sedimentologically homogeneous section in the study area. It was predominantly composed of very well-sorted coarse sand due to its location, where it was exposed to high energy waters and received the majority of its sandy sediment from the bay. It contained diamagnetic minerals throughout the ridge, which was likely due to quartz minerals in the sandy sediment.
- There was a surprisingly high sand fraction in the Juncus Marsh sub-environment, which appeared to be fine-grained organic sediment. This is likely due to storm deposits, which are a dominant factor in coastal wetland sedimentology. The wind, waves, and storm surges from hurricanes can deposit large amounts of sediment in a very short period of time. Considering the time at which the samples were collected, Hurricane Ivan or Katrina could be responsible for the deposited sand.

While the highest degree of accuracy was strived for in every single measurement, there were still multiple sources of error. The first source of error in this experiment was the incomplete organic removal of sediment samples #26-40. This was mainly due to a shortage of hydrogen peroxide in the lab during the allowed time for testing. While the majority of the organic matter was removed in these samples, it probably introduced a relatively small amount of error in the sediment size analyses. The digital scale also introduced a small degree of error (0.014g) in the mass readings. The digital scale's margin of error was more problematic with the carbonate analysis, since miniscule amounts of carbonate minerals were being lost. In retrospect, I would have liked additional samples from the northwestern section of the marsh, and more samples around the channel outlet.

There are many additional studies that could be conducted in the area. A very interesting topic of future research would be a study of subsurface storm related deposits in the East Bay area. Samples would be collected using an auger to look at the sequences of storm deposits throughout the bay, and also analyze any transgressive/regressive sequences or other subsurface structures. Another potential study could investigate the dynamics of Santa Rosa Island, how it affects East Bay, and impacts of storm events on the barrier island.

This project evaluated the sedimentology of a coastal wetland in order to gain a better understanding of the processes that occur there. A thorough understanding of coastal wetlands is very important, since the preservation of these ecosystems are beneficial to both humans and the environment. Coastal marshes are important because they serve as a buffer zone for pollutants between marine environments and terrestrial uplands. These environments also support a myriad of ecologically important animal and plant species (University of Florida Extension, 2016). Additionally, these wetlands serve as a barrier that protects coastal communities from the full impact of storm waves. Finally, coastal marshes provide locations for recreational activities, such as swimming, fishing, and boating (Luternauer, 1995).

Despite their importance, the territory of salt marshes has been repeatedly encroached. These coastal marshes are often built upon, utilized for agriculture, or polluted by industrial activities. Modifications to the hydrology of the area, such as the damming or dredging of rivers can cause sediment starvation in coastal marshes. River training is another practice that can degrade wetlands, since modified rivers can deliver higher energy water that facilitates erosion. Some mechanisms of erosion stem from natural origins rather than human-induced. Rising global sea levels result in longer submergence periods and more erosion of marsh banks. Storms with large waves and winds also degrade coastal wetlands extensively. There are innumerable human and natural influences that pose a threat to these delicate ecosystems. Sedimentological studies like this increases the knowledge of coastal wetlands and improves our ability to sustain them (Luternauer, 1995).

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