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Spatial Correlation Between Framework Geology And Shoreline Morphology In Grand Bay, Mississippi

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By

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Spatial correlation between framework geology and shoreline morphology in Grand Bay, Mississippi

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The Grand Bay National Estuarine Research Reserve (GBNERR) adjoins two costal embayments in the eastern Mississippi Sound, Grand Bay and Point Aux Chenes Bay, which encompass a late Pleistocene/ Holocene delta of the Pascagoula-Escatawpa fluvial system. Historical maps and aerial imagery indicate that the GBNERR shoreline has experienced long-term retreat at spatially variable rates. The research presented here investigates the relationship between the coastal geomorphological evolution of GBNERR and the underlying geological framework. Coastal morphology and stratigraphy were characterized by analyzing 85 km of chirp sonar sub-bottom seismic profiles and 45 sediment cores. Shoreline retreat rates were determined through geospatial regression analysis of 11 historical shorelines surveyed between 1850 and 2015. Results indicate that Pleistocene paleochannels in the underlying fluvial distributary ravinement surfaces are spatially correlated with shoreline segments that exhibit elevated retreat rates and should be accounted for in future models of local as well as regional coastal evolution.

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CHAPTER I

INTRODUCTION

Study area and issues addressed

The Grand Bay National Estuarine Research Reserve (NERR) rests upon a relic deltaic headland that is fronted by the Mississippi Sound (Figure 1.1) (Morse et al., 1944; Harvey et al., 1965; Kramer, 1990; Eleuterius and Criss, 1991; Peterson et al., 2007). The deltaic headland built seaward prior two thousand years ago, and sediment from the delta formed the Grand Batture Islands that once fronted the headland (Figure 2.1) (Peterson et al., 2007). Rapid deterioration and ultimate drowning of the Grand Batture Islands occurred from 1890 to present (Figure 1.2) (Kramer, 1990; Eleuterius and Criss, 1991; Meyer-arendt et al., 1991; McBride and Byrnes, 1997; O'Sullivan and Criss, 1998; Schmid, 2000; Morton et al., 2000; Otvos, 2001, 2011; Otvos and Giardino, 2004; McBride et al., 2007; Peterson et al., 2007; Service, 2008; Rosati and Stone, 2009; Gilmer et al., 2012; Ennis et al., 2013; Twichell et al., 2013; Moore et al., 2014; Penland et al., 2014; Passeri et al., 2015). An investigation was conducted to better understand shoreline change of this area. Recent researchers have investigated the correlation between shoreline morphology and anticendent geology (Belknap and Kraft, 1985; McNinch, 2004; Browder and McNinch, 2006; Rosati and Stone, 2009; Rosati et al., 2010; Twichell et al., 2013). Drawing on the ideas and findings of previous research, two objectives were defined for the current research. The first objective was to better understand the local deposional history of the study area, and the second was to spacially corrolate paleochannel deposits to variation in shoreline change and shoreline morphology. The results of the study suggest that spacial correlation exhists between paleochannel deposits of late Pleistocene age and regions where shoreline retreat rates are elevated. These findings will aid in detecting areas prone to high shoreline retreate rates in the future, both within this study area and other areas of similar environmental conditions.

Statement of hypothesis

It has been suggested that antecedent geology can influence coastal and benthic surfaces (Belknap and Kraft, 1985; McNinch, 2004; Browder and McNinch, 2006; Rosati and Stone, 2009; Rosati et al., 2010; Twichell et al., 2013). Through the analysis of 33 chirp seismic surveys, 45 sediment cores, and numerous historical maps, this study was designed to investigate spatial relationships between paleo-bathometry and recent coastal morphology. Specifically, this research attempted to explore correlation among paleochannel deposits and variations in shoreline change rates along the study area's coast.

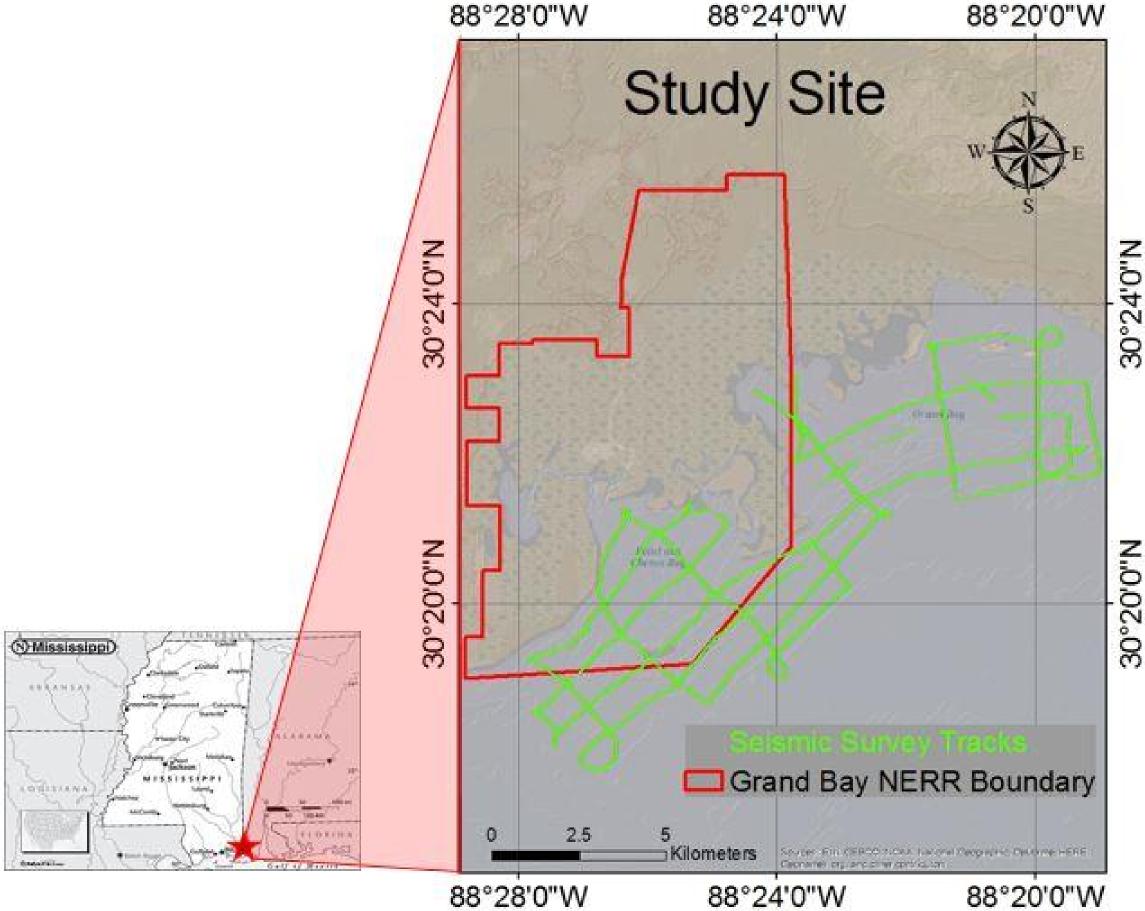


Figure 1.1 Study Area

The image depicts the Grand Bay National Estuarine Research Reserve, MS (red) and the seismic survey grid path (green).

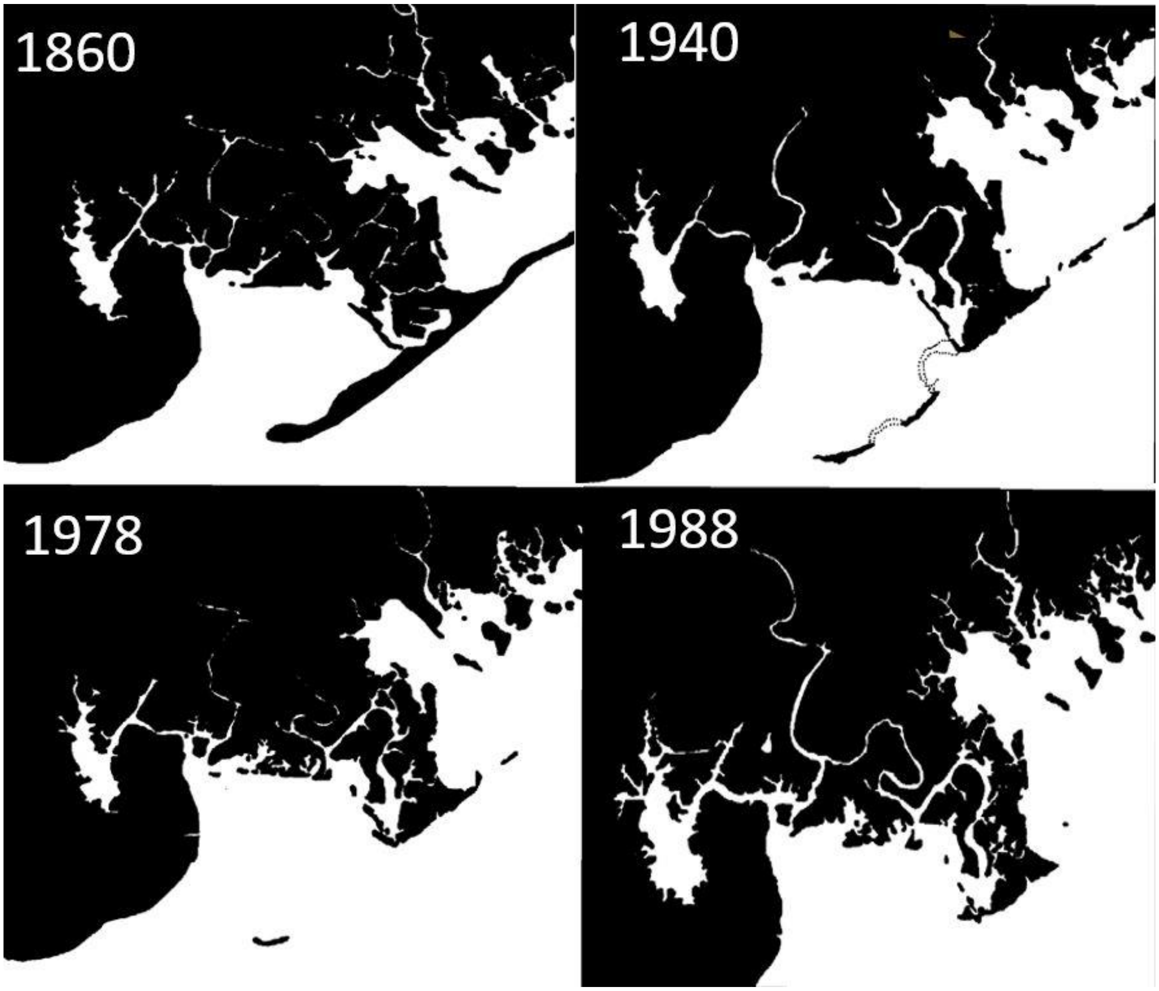


Figure 1.2 Historical Maps 1860-1988

Image depicts deterioration of the Grande Batture Islands over a period of 128 years.

Sea level change

Sea level change controls shoreline positions through time. Sea level can also influence the type of sediment that is deposited. For instance, sands accumulate nearshore whereas clays tend to accumulate in more distal environments. Therefore, if sea levels rise sufficiently, it is expected that clays will overlie previously deposited sands. Much research has been focused on sea level fluctuations from the Paleogene through the Quaternary in order to understand past deposition and predict future changes to coastlines along the northern Gulf of Mexico (Blum and Carter, 2002; Morton et al., 2000; Reed, 2002; Otvos, 2004; Törnqvist et al., 2004; Simms et al., 2007; Milliken et al., 2008; Donoghue, 2011; Gilmer et al., 2012; Moore et al., 2014). Glaciation has contributed to changes in the sea level of the Gulf of Mexico through the geologic past. The mid-Pliocene was an interglacial period, when sea levels may have exceeded present levels by 20 m (Masson-Delmotte, V. et al., 2013). By the late Pliocene, however, sea level had fallen to near present elevation (Donoghue, 2011). The last interglacial period 120 ka marked another rise in eustatic sea level approximately 6 m above present levels (Masson-Delmotte, V. et al., 2013). The last glacial maximum occurred ~20 ka, and sea levels fell to approximately 120 m below present levels (Simms et al., 2007; Donoghue, 2011; Troiani et al., 2011; Masson-Delmotte, V. et al., 2013). Studies indicate that sea level rise was rapid before 7 ka but then slowed to approximately 1.5 mm/yr where shorelines reached near present levels (Törnqvist et al., 2004).

Since the late 1800's, the rate of sea level rise has increased. Sea level rise in the Gulf of Mexico currently averages between 2-5 mm/y, whereas historically (over the past 4000 yrs) it has averaged 0.4-0.6 mm/yr. (Anderson et al., 2010; Milliken et al., 2008). Past research indicates sea level rise rates have increased over the last century. FitzGerald et al., (2008) found that sea level rose 195 mm from 1870-2004, averaging a rate of 1.7 mm/yr. Additionally, FitzGerald et al., (2008) noted two periods of increased sea level rise rate, the first in 1915 at a rate of 1.7 mm/yr and the second in 1993 at a rate of 3 mm/yr.

In addition to increased rates of sea level rise contributing to land loss, studies have shown that sea level rise and climate change can increase the storm surge recurrence interval, which likewise increases inundation (FitzGerald et al., 2008). Further research regarding changes in climate and sea level has predicted that storm intensity may increase as sea surface temperatures increase and sea levels rise (Easterling et al., 2000; Walsh, 2004; Emanuel, 2005; Houser et al., 2008; Pries et al., 2008; Bender et al., 2010). The recent increase in rate of sea level rise has contributed to erosion and submergence of coastlines along the Gulf of Mexico and within the study area. Therefore, understanding additional controls on coastal morphology will allow investigators to better predict regional coastal change as it relates to increased storm frequency and intensity.

Marsh fronting barriers

Across the world, coastal marshes are fronted by protective barriers (Beets and Van Der Spek, 2000; A. Cooper et al., 2007; J. A. G. Cooper et al., 2007; J. et al., 2010). Examples of coastal barriers include spits, beach ridge plains, barrier islands, and shoals. Barriers are found on passive margins and account for ~10% of earth's coastlines (A. Cooper et al., 2007; Pilkey et al., 2009; Otvos, 2012). The study site at Grand Bay and Pointe Aux Chenes Bay is also characterized by submerged shoals that are remnants of the Grande Batture Barrier Islands. The Grande Batture Islands extended in a thin island chain parallel to shore, and were formed from sediment deposited in a deltaic, low energy environment (Figures 1.2 and 2.1). Based on their formation and morphology, the Grande Batture Islands could have been classified as a Mississippi type barrier island and are similar to barrier islands of the Mississippi, Lena, and Po River deltas (Stutz and Pilkey, 2002). The Grande Batture Islands could also have been classified as Marsh Fringing Fetch Limited Barrier Islands because they formed in low-energy, minimal fetch environments (A. Cooper et al., 2007; J. A. G. Cooper et al., 2007; Otvos, 2010; Pilkey et al., 2009; Cooper, 2013). Other islands across the United States share similar characteristics with the submerged Grande Batture Islands, specifically in eastern Louisiana and other low energy environments such as the Chesapeake Bay (McBride and Byrnes, 1997; Stutz and Pilkey, 2002; J. A. G. Cooper et al., 2007; Costanza et al., 2008; Pilkey et al., 2009; Rosati and Stone, 2009; Cooper, 2013;Twichell et al., 2013; Moore et al., 2014). This makes the Grande Batture shoals a good proxy for understanding future marsh front change in other areas of the world.

Coastline change and tropical storms

Coastal wetlands and marshes have declined in spatial extent over the past century due to both human and environmental factors (Mitsch and Gossilink, 2000; Reed, 2002; FitzGerald et al., 2008; Cowart et al., 2010; Ennis et al., 2013). Mitsch and Gossilink, (2000) summarize both the environmental and the socioeconomic value of wetlands. A key point of their work states that a wetland's value is dependent on its ability to benefit humanity. They assert that a wetland is economically valuable if it is large enough to function properly and is located near a populated area. Therefore, it is a topic of serious concern that Kraft et al., (1992) predicts 10000 km^2 of vegetated marsh to be lost by 2100. The Grand Bay coastline alone has experienced an average shoreline loss of 2 m/yr due to wave erosion (O'Sullivan and Criss, 1998). Because coastal marshes filter contaminants, provide shelter for many aquatic species, and buffer storm surge it is important to understand the mechanisms that control coastal erosion and wetland loss. Accordingly, the proposed research will provide insight into how erosional processes affect the Grand Bay marsh.

Two and a half meters of coastline backing Pointe Aux Chenes Bay and Grand Bay are lost annually due to erosive forces caused by wave action associated with rising sea level (Schmid, 2000). A dramatic example of shoreline change within the study area is when the Grande Batture Islands underwent rapid subsidence from 1900 through the early 1970's, at which point they were reduced to submerged shoals.

In addition to sea level rise, increased rates of storminess may have contributed to land loss in the study area (Otvos and Carter, 2013). The Grand Bay marsh has experienced numerous tropical cyclones over the last century. A hurricane that made landfall in 1740 incised Dauphin Island and created an inlet between Dauphin and what is now Petit Bois Island (Otvos and Carter, 2013). The inlet allowed higher energy waves to pass through and attack the marsh fronting Grande Batture Island, attributing to its deterioration and rapid submergence. Eleuterius and Criss, (1991) documented 23 hurricanes occurring near or over Grand Bay from 1870-1921. They attribute Grand Bay's erosion primarily to hurricane related events. Results drawn from the research of Eleuterius and Criss, (1991) suggest that hurricanes caused overwash events, which first led to northwestern migration of the islands and, subsequently, decreased the height and width of the islands. Eventually, continual wave action coupled with storm events segmented the Grande Batture Islands. Further erosion caused them to become completely submerged and left the marsh behind the island exposed to greater wave fetch and enhanced erosive forces (Eleuterius and Criss, 1991).

Further inundation of sea water in the Grand Bay marsh is expected as sea levels continue to rise. Previous computer-generated inundation models of Grand Bay have only shown elevation as the primary factor for flood prone areas (Ennis et al., 2013).

However, underlying geologic features have been correlated to areas subject to high erosion and accretion rates in other similar coastal environments (McNinch, 2004). If there is a correlation between rates of coastal change and subsurface geologic structures, then such factors should be added to inundation models so that the model better reflects natural processes.

The current research has aided in identifying areas prone to erosion and has allowed researchers to identify links between zones of high retreat rates in Grand Bay and preexisting geologic features. A goal set forth for this research was to locate areas more susceptible to erosion based on antecedent geology, for the purpose of predicting areas prone to inundation beyond using elevation alone as a proxy for inundation models. Sea level rise in concert with increased storm frequency has clearly attributed to salt marsh loss and the reshaping of the coastal landscape; however, it is still difficult to predict in a spatial framework where erosion will occur and to what extent. The purpose of this research was to understand the underlying geology with the hopes of better predicting locations prone to high erosion rates within the study area.

Study application and importance

Marsh front barriers are important morphologic features that contribute to the sustainability of the marsh itself. These barriers can take many forms including spits, barrier islands, and shoals. Oertel (1985) defines barrier islands as narrow elongate landforms resting parallel to shore and consisting of unconsolidated material. Numerous environmental factors contribute to the morphological development of barrier islands including, but not limited to, island genesis, sea level rise, tides and waves, storm frequency, and antecedent geology. When barrier islands change, lagoon and marsh morphology are also affected (Oertel et al., 1992).

The Grande Batture shoals in Grand Bay NERR are former barrier islands that fronted the Grand Bay marsh and are protected from high energy wave attack by the Petit Bois and Dauphin islands. The islands formed at a delta front which was supplied by either the Escatawpa or Pascagoula rivers (Meyer-arendt et al., 1991; Peterson et al., 2007). The river began building the delta when transgression slowed approximately 5-7 ka (Blum and Carter, 2002; Donoghue, 2011; FitzGerald et al., 2008; “Kramer1.pdf,” n.d.; Peterson et al., 2007). Native American artifacts found in the area indicate that the delta has existed at least 3 ka (Peterson et al., 2007). The Grande Batture islands formed from sediment deposited at the delta front. The islands grew to their full extent and existed through the late 1800’s; however, they experienced considerable rates of erosion in the early to mid-1900’s, and underwent rapid decline from 1900 until they were reduced to submerged shoals by the early 1970’s (Eleuterius and Criss, 1991).

Barrier islands have been classified based on morphology which is influenced by environmental factors. A classification of the former Grande Batture Islands has been determined because it is pertinent for relating the current study to areas sharing similar geomorphologic features and environments. The Grande Batture shoals are distinctive because they are former marsh fringing fetch limited barrier islands (FLBIs) that front the Grand Bay marsh. Nearly a decade ago, J. A. G. Cooper et al., (2007) used advancements in technology to identify and locate a previously overlooked landform. J. A. G. Cooper et al., (2007) described these landforms as sheltered islands having low wave energy. Further research found that FLBIs could be classified into eight groupings: classic, two-sided, backbarrier parallel, deltaic, fjord-head, marsh fringe, inlet, and thermokarst (Pilkey et al., 2009). Of these groupings, the Grande Batture shoals share characteristics with both deltaic and marsh fringe FLBI's. Fetch limited barrier islands are important because they have not been extensively studied, and over 15000 of these islands occur worldwide (A. Cooper et al., 2007; J. A. G. Cooper et al., 2007; Pilkey et al., 2009). However, of the 15000 FLBI's only 584 are of the marsh fringing type (Pilkey et al., 2009). Another classification that the Grande Batture Islands could fall under is the Mississippi Delta Lobe type described by (Stutz and Pilkey, 2002), yet, the Mississippi type barrier islands tend to be larger and subject to greater fetch than the Grande Batture Islands. Therefore, marsh fringe FLBI's seems to be the most appropriate classification for the Grande Batture Islands. Because FLBI's tend to be affected by sea level rise to a greater extent than other barrier islands, due to their smaller sediment volume and overall size (Pilkey et al., 2009), and the Grande Batture shoals have already experienced submergence due to sea level rise, the Grande Batture shoals may be an exceptional proxy for long-term morphologic trends of extant marsh fringe FLBI's and Mississippi type barrier islands.

Geologic investigation

Extensive research has been conducted on the biology and ecology of Grand Bay (NERR). However, research concerning the geology of the area is limited. Understanding the geological processes acting in the estuary will allow decision makers to develop better management plans. Well informed management practices are essential since the Grand Bay estuary provides habitat to a diverse range of species, recreation, and protection to local communities against storms. Additionally, geological processes, specifically sediment transport and erosion rates, will directly affect coastal development in Mississippi. For instance, in recent years coastal communities have promoted tourism (e.g. Biloxi encourage the development of casinos) to help bolster local economies. Being able to predict areas prone to erosion and sediment loss will aid in coastal development projects. Investigating the geology of this region with tools and software previously unused as well as conceptual models developed recently allowed us to establish an improved understanding of how underlying coastal geology influences rates of shoreline retreat in in response to sea level rise and increased storminess.

Several conceptual models have been created to explain processes of barrier island evolution; although, the evolution of the Grande Batture islands does not appear to be fully explained by any one of these traditional models. For example, Johnson (1919) describes barrier island evolution controlled by sea level in which the barrier system, including the lagoon, will migrate continuously landward with sea level change through a process known as "rollover." Another model of barrier evolution proposes that rapid sea level rise coupled with low sediment supply can cause drowning and overstepping of barrier islands (Rampino and Sanders, 1980). Computer generated numerical models have found that barrier islands can experience rollover, drowning, and fluctuation of migration in a continuously rising sea (Jorge Lorenzo-Trueba, 2014). Additionally, a model has been created to explain island migration and subsidence over a compressible substrate (Rosati et al., 2010). Each model may illustrate part of the processes contributing to the retreat and submergences of the Grande Batture Islands; however, neither model fully explain observed evolution of these islands.

This research has utilized chirp seismic data to identify depositional layering and stratigraphic features in the subsurface that could not have been previously identified with sediment core data alone. The use of high frequency seismic tools allows for the collection of higher resolution data both in the vertical and horizontal than sediment coring alone can yield. Therefore, features previously missed have been identified and a more detailed story of deposition has been produced.

Research goals

The first objective of this research was to investigate the stratigraphy of Grand Bay in order to determine if underlying geology has potentially exerted control on the evolution of the Grande Batture Islands. To achieve this goal, shallow seismic data were collected and previously compiled sediment core were utilized. The samples and data have been analyzed to generate multiple maps and cross sections of the study site's subsurface. The maps have been used to identify stratigraphic layers and sedimentary features that underlie Grand Bay and Point Aux Chenes Bay. The maps and cross sections have been used in conjunction with pre-existing core data to interpret the depositional history of Grand Bay.

Additionally, maps of paleochannel deposits, identified by the seismic data, were used to correlate paleochannels with surface morphology and shoreline change rates. Researching the features that relate spatially to the Grande Batture shoal morphology will further an understanding of coastal processes in estuarine environments. The Grande Batture Islands have become submerged, leaving the coastline behind the island unprotected from wave attack, which has intensified coastline erosion (Schmid, 2000). The data gathered and analyzed in this research has linked subsurface geology to erosion prone areas. This knowledge will aid estuarine management by providing governing officials with updated information regarding Grand Bay's coastal processes.

Sediment core and chirp shallow seismic data have been utilized to map the subsurface of Grand Bay. Previous researchers exclusively used sediment core to produce interpreted cross sections of areas in Grand Bay. However, chirp technology used to produce sub-bottom profiles of the area had not been utilized to its full potential. The ability to obtain continuous "images" of shallow strata has provided much more detailed spatial resolution of Grand Bay. Additionally, Kingdom software donated by the IHS software company was used to attain depth maps, isopach maps, and cross-section interpretations of the sea floor. This software has the ability to produce continuous cross-sections and interpolate those cross-sections to produce surficial maps at depth. Past grain size distribution maps of the area do not have the resolution that can presently be obtained. This data has been collected for the purpose of correlating subaqueous geology to areas prone to high erosion rates. Finally, industry software has been utilized to produce more accurate and detailed maps and cross sections than were previously available.

CHAPTER II

BACKGROUND

General research

The Grande Batture Islands are unusual because they do not appear to follow the widely accepted models of barrier island retreat. The most widely accepted model of barrier retreat is that of continuous retrogradation with sea level rise. As the sea rises, wave energy on the barrier island becomes greater. Overwash events become more frequent and transport sediment from the barrier coastline to the back barrier, forcing the island to migrate landward (Johnson, 1919; Leatherman, 1982; McBride et al., 1995; Jorge Lorenzo-Trueba, 2014). The process of barrier island retrogradation can be referred to as barrier island rollover. Island rollover accompanied by lateral movement, breakup, and retreat are the most common geomorphic responses of islands along Louisiana's delta front (McBride et al., 1995). This is significant because, like the Louisiana islands, the Grande Batture Islands developed from relic deltaic lobes. Unlike the Louisiana islands, however, the Grande Batture Islands are not migrating landward but sinking in place.

The conceptual model that may be most relevant to Grand Bay research addresses barrier island retreat over a compressible substrate. This model describes deltaic barrier islands in Louisiana. The model suggests that as the islands roll over, they move out of sandy deposits and onto organic-rich deposits. Over time, sand accumulates and local subsidence occurs, leading to drowning and breaking up of the islands (Rosati et al., 2010). The model proposed by Rosati et al., (2010) shows how underlying geology prompts changes in island morphology and rates of erosion. The same process could be acting on the Grande Batture Islands because they are located seaward of compressible sediment.

Rampino and Sanders (1980) present another model illustrating how a reduction in sediment input coupled with rapid sea level rise cause barrier islands to drown in place and the shoreline to overstep the islands landward. Subsequently, a new barrier island is built by two processes: (1) spit elongation and (2) sediment transport from the relic barrier to the new shoreface (Rampino and Sanders, 1980). Leatherman (1982) refutes Rampino and Sanders (1980), and suggests their observations could be explained by continuous migration. If sediment input were to increase, the island would cease landward migration and accrete vertically as sea level rises. Later, if the rate of sea level rise were to outpace sediment input, the island would begin retreating again. Therefore, continuous migration would produce the same sediment deposits described by Rampino and Sanders (1980). Numerical models indicate that both the continuous model and the stepwise model can occur in nature given the right environmental conditions. Additionally, numerical models reveal that barrier islands can drown both vertically and horizontally. Vertical drowning can occur if overwash is insufficient to move the island landward, whereas horizontal drowning can occur during rapid or large overwash events; the landward migration occurs more rapidly than sediment can be supplied landward so the islands thin and denigrate (Lorenzo-Trueba, 2014). The Grande Batture Islands have drown during a time of sea level rise, thus it is possible that Rampino and Sanders'(1980) scenario could help explain the islands' submergence. However, new barrier islands do not appear to be forming nearer shore as predicted by Rampino and Sanders (1980) or the stepwise model of barrier island evolution.

Another unique trait of the Grand Batture Islands is that they are protected by Dauphin and Petit Bois islands. Islands that occur in areas that are sheltered by adjacent topography, are dominated by wind induced waves, and generally have fetch distances of 50km or less have been classified as fetch-limited barrier islands (Carrasco et al., 2008; Cooper et al., 2007; Cooper, 2013; J. et al., 2010; Pilkey et al., 2009; Smith et al., 2010). Using satellite imagery and aerial photography researchers were able to define a once overlooked landform they termed FLBIs (Cooper et al., 2007). They subdivided FLBI's into eight types based on location and morphology. The Grand Batture Islands can be best classified as the marsh fringe type of FLBI. Marsh fringe FLBI's tend to form chains of small, irregularly shaped islands separated by very thin, inoperative inlets (Pilkey et al., 2009). Moreover, marsh fringe FLBI's evolution is controlled primarily by storm events (Pilkey et al., 2009). Marsh fringe barrier islands have been reported to form from spit elongation in the Chesapeake Bay area (Cooper, 2013). These islands ultimately thin and breach where the islands either continue to migrate landward or become submerged. Additionally, researchers found that the sand which comprises the Chesapeake Bay marsh fringe FLBIs is maintained by rollover associated with high energy events, whereas the islands' morphologies are controlled by the underlying marsh substrate (Cooper, 2013). Similarly, to the Chesapeake Bay islands the Grande Batture Islands could have been two elongate spits that fronted the marsh headland (Figure 1.2). Also the Grande Batture Islands likewise have thinned breached and become submerged;

however, unlike the Chesapeake Bay islands rollover has been relatively insignificant. Accordingly, the research herein is focused on determining if a spatial relationship exists between geologic features underlying the marshy substrate, such as paleochannels, and the coastal morphodynamics of the Grande Batture Islands as well as their backing marsh.

Numerous researchers have considered how geologic controls influence barrier island change. Their studies link grain size, sediment volume, and antecedent geologic features to rates and locations of shoreline change (Browder and McNinch, 2006; McNinch, 2004; Miselis and McNinch, 2006; Miselis et al., 2014; Schupp et al., 2006; Twichell et al., 2013). Scientists have found that St. Gorge Island, Ship Island, and the Chandeleur Islands, in the Gulf of Mexico, have experienced different relative sea level rise rates because of differences in geologic controls such as the islands' genesis and mean grain size (Twichell et al., 2013). Additionally, (Twichell et al., 2013) found sediment volume is inversely proportional to shoreline change, and finer grained sands erode more rapidly than larger coarser grained sands. Otvos and Carter, (2013) take this observation a step further and use sediment size and island formation to predict barrier islands' lifespans. They found that islands formed by deltaic lobes have finer grain size than non-deltaic barriers. Thus, non-deltaic islands experience slower shoreline change and slower erosion rates than islands formed by deltaic lobes. Twichell et al. (2013) found, in addition to grain size and volume controls, paleochannels could play a role in shoreline change. Their work found that paleochannels tend to occur in conjunction with greater island change rates. Erosional hotspots and shore oblique bars have both been found to correlate spatially with gravely pre-modern channel outcrops (McNinch, 2004).

Additional work by Browder and McNinch, (2006) found that gravely deposits and "bathometric anomalies" can be correlated with areas of shore elevated shoreline variability. They hypothesize that high-energy events strip away modern overlying strata, exposing gravely channel deposits. The exposed gravel produces an area of bathometric roughness, causing turbulence in the water above the gravel deposits. The turbulence removes fine-grained sediment and establishes a positive feedback loop leading to locally amplified erosion and accretion (Browder and McNinch, 2006). Applying the ideas gathered from the aforementioned research, shallow seismic data coupled with geologic data will be used to determine if spatial correlation exists between subsurface paleochannel deposits and shoreline variability within the study area.

Regional research

The Grand Bay (NERR) is located approximately 15 km southeast of Pascagoula, Mississippi. The Reserve encompasses a coastal salt marsh that is protected from open ocean waves by Petit Bois and Dauphin Barrier Islands and is fronted by the Grande Batture shoals. Coastal marshes are one of the most biologically productive areas in the world, making them an excellent sink for contaminants. The abundance of plants and bacteria in marshes contribute to nitrogen assimilation and denitrification which prevents excess nutrients from entering the ocean and causing eutrophication (Arndt et al., 2009; Seitzinger, 1988). Additionally, through the process of phytostabilization, heavy metals are immobilized and stored either within the roots or in sediment bound by the roots of estuarine plants (Weis and Weis, 2004).

Furthermore, commercially and recreationally fished species including shrimp, red drum, speckled trout, blue crabs, and oysters use the Grand Bay marsh as a nursery

(Peterson et al., 2007), which adds to the marsh's economic value. The Gulf Coast's shrimping industry boasts over $300 million of revenue annually, partially due to Grand Bay's rich resources (USA EPA, 2012).

Finally, the estuaries and marshlands of Grand Bay provide buffers from storm events associated with tropical cyclones, protecting the nearby towns of Moss Point and Pascagoula. Estuaries reduce storm surge by limiting fetch, decreasing waves, and increasing drag by maintaining shallow water depths (Costanza et al., 2008). Additionally, Costanza et al., (2008) found that coastal wetlands save Louisiana an average of $1700 per hectare of marshland per year. Coastal marshes are environmentally and economically significant; therefore, processes that alter the morphology of the marsh are important to understand. This research will study the antecedent geology underlying the study area to better understand changes in coastal morphology.

The study area's climate is classified as humid-temperate with average temperatures ranging from 27.6° C in the summer months to 12.0° C in the winter months (Kramer, 1990). Average precipitation in the area ranges from 94 cm to 246.4 cm annually (Peterson et al., 2007). The driest months of the year, October and November, coincide with the weakening of the Bermuda High which shift predominate wind origin from the southeast to continental pressures systems from the northeast during winter months (Eleuterius and Criss, 1991; Kramer, 1990). In April the Bermuda High again begins strengthening bringing with it warmer temperatures and evening thunderstorms that normally occur from June through August (Eleuterius and Criss, 1991; Peterson et al., 2007). A prevailing eastward wind direction during both seasons' results in westward longshore drift of sediment in the Grand Bay area, and has been observed by sediment piling on the eastward side of protruding storm drains along Highway 90 (Kramer, 1990). Additionally, ebb tidal currents have been shown to be stronger than flood tides in the study area which suggests suspended sediment will be transported off shore (Passeri et al., 2015). Another factor contributing to sediment movement within Grand Bay is tidal influence. Grand Bay has a mean high water of 4.75 m, a mean low water of 4.34 m, and a mean tide level of 4.55 m (NOAA). The Grand Bay experiences diurnal tides with a mean range of 0.485 m, placing Grand Bay in micro-tidal setting (NOAA). Overall Grand Bay can be considered a low-energy coast with the greatest influences on sediment movement being currents occurring near the shoreline and storm events.

Two hypotheses have been proposed to explain the formation of the study area's coastline. Both hypotheses propose the occurrence of a river that once flowed through what is now the Grand Bay NERR and built a delta in the location of present day Bayou Cumbest. The delta lobes supplied sediment which formed the Grand Batture Islands (Eleuterius and Criss, 1991). The first hypothesis proposes that the Pascagoula River or one of its distributaries merged with the Escatawpa River near Orange Grove, Mississippi, flowed southeast, emptied into Bayou Cumbest, and formed a petruding deltaic headland (eg., Harvey et al., 1965). The currently accepted hypothesis indicates that the Escatawpa River created the delta when it began flowing toward the location of present day Bayou Cumbest during the early to mid-Holocene. Later, the Escatawpa River was captured by a tributary of the Pascagoula River near Orange Grove, Mississippi and growth of the Grand Bay delta ended when sediment was no longer supplied by the Escatawpa River (Peterson et al., 2007) (Figure 2.1). After the capture of the Escatawpa River, sea level continued to rise. Finally, persistent sea level rise, local subsidence, and lack of sediment input into the system led to erosion of the marsh.

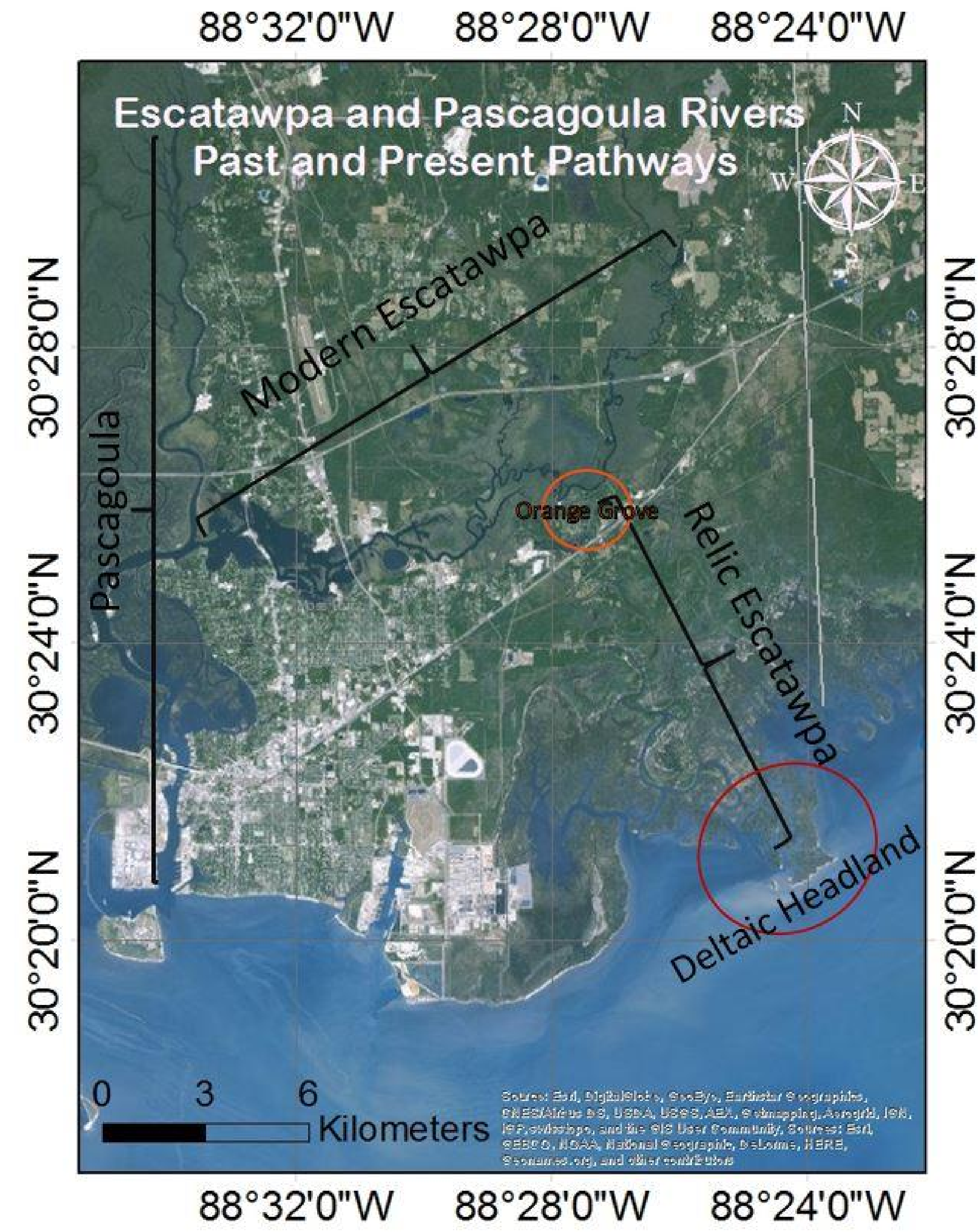


Figure 2.1 Pascagoula River and Escatawpa River Locations

Image illustrates the past and present locations of the Escatawpa River. The location where a tributary of the Pascagoula River captured the Escatawpa River (orange) and the location of the protruding deltaic headland built by the Pascagoula River (red) are also noted.

Tropical cyclones contribute greatly to coastal land loss along Grand Bay. Tropical cyclones usually occur from June to November with the greatest frequency between the months of August to October (Kramer, 1990). A total of 71 Tropical cyclones have been recorded 120 km or closer to the study area since 1852 (NOAA) During tropical storms, sediment from the shore face can be moved to the backshore marsh aiding in coastline erosion and rollover (Miner et al., 2009). During storm surge events vegetation can be eroded away and lost. This process can contribute to future erosion due to lack of roots to bind and hold sediment in place (Otvos and Carter, 2008; Pries et al., 2008). Additionally, hurricanes can split island and open tidal channels. One of the earliest recorded hurricanes, which occurred in 1740 made landfall near Grand Bay and has split a barrier island seaward of the study area into Petit Bois and Dauphin Islands (Otvos and Carter, 2008). The tidal channel grew, allowing waves of greater energy and fetch to reach the Grand Bay marsh which was exposed due to the loss of the Grande Batture Islands and the South Riggolets headland (O'Sullivan and Criss, 1998; Otvos and Carter, 2008) (Figure 2.2). Storm events and wave action continues reshaping the Grand Bay coastline. O'Sullivan and Criss (1998) found that wind generated waves contribute to marsh erosion within the study area. They created a conceptual model that illustrates two processes in which the waves erode the marsh headland. The first process of wave erosion occurs when waves break against the shallow marsh substrate. The waves first erode the base of the marsh then when they have undermined the underlying sediment the overburden is too great and the overlying sediment and vegetation fall into the sea. The second process occurs when waves are higher than the marsh. The water carries sediment that abrades marsh vegetation which leads to loss of vegetation, making the area more susceptible to erosion.

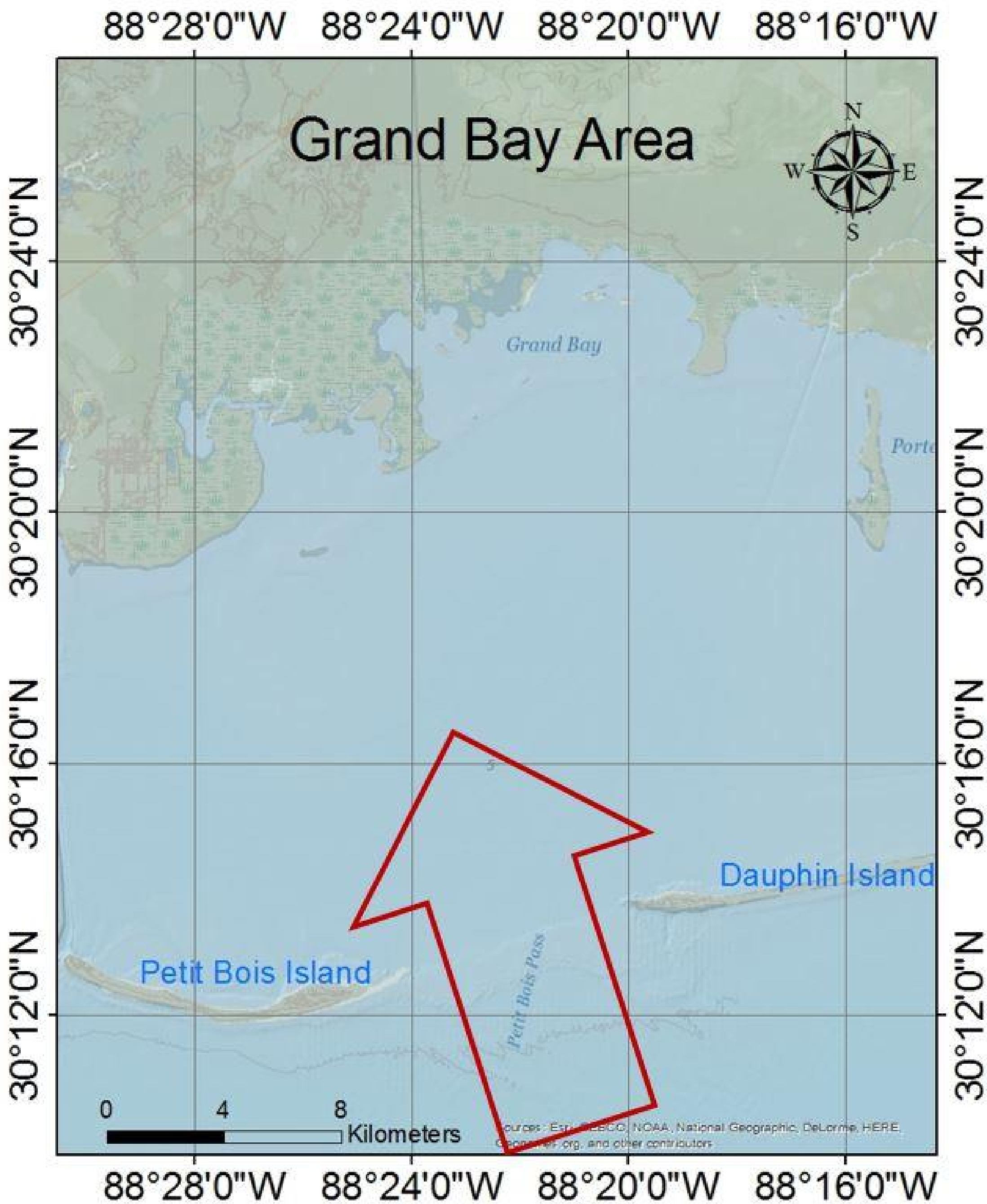


Figure 2.2 Mississippi Sound and Grand Bay

Image depicts location of Dauphin Island and Petit Bois Island with relation to the deltaic headland. Also Petit Bois Pass, which was opened by the 1740 hurricane, is highlighted by the red arrow.

Stratigraphy

Regional Units

Neogene

Undifferentiated Neogene

Underlying the Pleistocene units are 900-1500m thick Pliocene and Miocene units. They stretch the length of the Mississippi coast and are found at approximately 20 m depth along Belle Fontaine and Jackson County. This undifferentiated sequence consists of clay beds with sand to gravel beds spread throughout. These units tend to be more consolidated than those of the Pleistocene and Holocene age. The Undifferentiated Neogene unit may contain formations such as the Hattiesburg, Pascagoula, and the Graham Ferry formations. However, it is often unfeasible to stratigraphically distinguish these formations both in seismic and core data which has led researchers to group these units as Undifferentiated Neogene though some deposits are much younger in age. (Mississippi Department of Envronmental Quality, 1994; Otvos, 2001)

Pliocene

Citronelle Formation

The Citronelle is a 50 to 400 foot thick terrace deposit of non-marine clays, sand, and gravel (Mattson and Berry, 1916). The Citronelle is important to this research because it is the oldest formation (3-1.5 mya) to outcrop onshore in Grand Bay NERR, north of the study site, and was deposited during the onset of Pleistocene glaciation (Otvos, 1985; Otvos, 1988; Peterson et al., 2007) More recently the Citronelle has been described as wide spread fluvial deposits of braided streams in an estuarine environment

(Otvos, 2004b). The Citronelle Formation has been determined to be of late Pliocene age from age dating of pollen found within the formation.

Pleistocene

Biloxi Formation

The Biloxi Formation consists of transgressive deposits of very fine sand to clay nearshore to lagoonal brackish sediment. The Biloxi Formation was deposited in a period of higher sea during the last glacial maximum approximately 120ka. In the Belle Fontaine area the Biloxi Formation lies unconformably at depth of 2 to 13 meters. Additionally, the Biloxi Formation has been observed to be between 4 and 45 meters thick and thins landward as it interfingers with the Gulfport and Prairie formations. The Biloxi is approximately 8-10 m deep roughly 1km west of the study area. The Biloxi is laterally extensive across the Mississippi Sound and lies atop undifferentiated pre OIS 5e sediments. (Kramer, 1990; Mississippi Department of Envronmental Quality, 1994; Otvos, 1985, 2001)

Gulfport Formation

The Gulfport Formation is composed of 3.5-8 m thick fine to medium sands and is interpreted to be barrier ridge, dune, and beach deposits of a late Pleistocene high stand and has been dated to OIS 5e (Kramer, 1990; Otvos, 1985, 2001). The Gulfport represents progradation of the LIG aged shoreline over lagoonal and nearshore clay deposits of the Biloxi Formation (Mississippi Department of Envronmental Quality, 1994). The Gulfport has been identified both at the surface and 1.5m below overlying

Holocene deposits near Belle Fontaine; however, the Gulfport Formation has not been recorded to be present at proximal to the study area.

Prairie Formation

The pale yellow to olive green, silty to sandy grained, Prairie Formation has been interpreted as alluvial coastal plain deposits associated with OIS 5 aging 120 ka to 90 ka however luminescence dates indicate that the Prairie Formation coastal plain is present between 50 ka and 30 ka in parts of Louisiana (Kramer, 1990; Otvos, 1985, 2001). The deposits of Prairie Formation range 5-10 meters thick and extends laterally along the Mississippi shoreline. It is exposed at the surface inland near Belle Fontaine, Mississippi and dips seaward where Holocene sediment overlies it to depths 1m and greater (Mississippi Department of Envronmental Quality, 1994). Through analysis of core collected approximately 1km to the west of the study area, the Prairie Formation was interpreted to outcrop inland and dip seaward to depths of 5-8 m (Otvos, 1985). This indicates that the Prairie Formation is laterally extensive and relatively uniform across the Mississippi Sound and so is expected to reach similar depths within the study area.

Holocene

The sediment deposited during the Holocene, 11.7 ka through present, consists of mainland beach, barrier island, shoal, bay, estuarine, river channel, swamp, marsh and deltaic environments. Grains range from sand-sized to clay-sized particles and also include organic material and peat. The Holocene deposits have been observed to be unconsolidated and range from 5 to 10 meters in depth. Within Grand Bay, the Escatawpa River built a delta approximately 5ka; however, coastal processes have eroded the deltaic deposits since the capture of the Escatawpa by the Pascagoula River. (Kramer, 1990; Otvos, 1985)

Structure

Regionally the Pliocene through Holocene beds dip to the south and west. From previous analysis of sediment core sampling, an isopach map was created that indicates an overall thickening of Holocene sediments to the south and west and an overall thinning trend to the north and east (Kramer, 1990). Also to note, there is an area of thickening south and parallel to the Riggolets Island. Other work conducted near the area also indicates a general thickening and southward dipping of units seaward. Additionally, Holocene deposits immediately thicken at the coastline in the Bella Fontaine area (Mississippi Department of Envronmental Quality, 1994).

Local sea level change

The shaping of present day Grand Bay and the whole norther Gulf of Mexico has been greatly influenced by sea level change. The oldest geologic formation to outcrop near the Grand Bay area is the Citronelle Formation. The Citronelle is composed of sand and gravel fluvial deposits but also has floodplain and estuarine clays(Otvos, 1985; Kramer, 1990; Mississippi Department of Envronmental Quality, 1994). The Citronelle was deposited in the late Pliocene during a time of regression and regional uplift (Otvos, 2004b). Evidence of tectonic influence can be seen by the relatively steep 30° to 40° southwestward dip associated with the unit. Limited deposition occurred during the early Pleistocene.

The middle Pleistocene marked the beginning of the LIG highstand 128 to 82 ka. The Biloxi Formation is interpreted as inshore and nearshore environment and is indicative of transgression during the early LIG; however, the Biloxi estuarine and shallow marine clays continued to be deposited seaward well into the LIG highstand. The Gulfport and Prairie formations partially overly the Biloxi Formation and were deposited simultaneously. The Prairie Formation marks the landward coastal plain facies, while the Gulfport Formation marks the barrier complex further seaward. As sea level slowed the Prairie and Gulfport formations built seaward during the highstand. (Mississippi Department of Envronmental Quality, 1994; Otvos, 1985)

Wisconsinan glaciation followed the LIG highstand. The Wisconsinan has been associated predominately with erosional surfaces; however, in some inland areas of Mississippi and Louisiana loess deposits are quite common. The Wisconsinan marked a significant lowstand with sea levels 120 m below present levels (Donoghue, 2011; Masson-Delmotte et al., 2013; Simms et al., 2007; Troiani et al., 2011).

Two major hypotheses have been proposed regarding changes in sea level since 18 ka. The first hypothesis states there have been middle Holocene sea level high stands. The second states that there have been times of sea level standstills followed by rapid increases, but always below present sea level. Investigations using optical luminescent age dating and interpreting coastal barriers and high beach ridges along the coast of Texas suggest that sea levels were 2 meters higher than present at approximately 6.5 ka (Blum and Carter, 2002). Whereas studies utilizing ^{14}C in basal peat deposits indicate that sea level change rates have fluctuated greatly, but sea level has still remained below present level since 20 ka (Törnqvist et al., 2004; Milliken et al., 2008). An additional paper by (Morton et al., 2000) recognizes that differences in sea level histories are dependent on whether researchers are studying barrier landforms or peat deposits and hypothesizes that high beach ridges could have been produced by overwash events. Overall acceptance of Gulf of Mexico sea level suggests episodes of high SL rise rates in the past 20 ky followed by a slowing of sea level over the last 6000 years (Fairbanks, 1989; Lambeck et al., 2002; Donoghue, 2011).

CHAPTER III

METHODS

Seismic profiles

The primary source of data for this investigation were shallow seismic profiles collected with a chirp sonar. The Edge-Tech 216S sub-bottom profiler is a submersible sonar towfish that produces and receives acoustic signals directed approximately perpendicular to the seafloor as it is hauled behind a vessel. A transducer and receiver located within the towed sonar vehicle enable sound pulses to be emitted and received. The transducer produces an acoustic signal at a defined frequency. The transmitted signal either attenuates into the subsurface or is reflected back to the receiver. The ability for the signal or sound wave to reflect or attenuate is determined by the acoustic impedance of materials that the signal travels between and is dependent on a number of factors including angle of incidence, the change in density between medias, as well as the internal velocity of the medias as the wave propagates (in this case the seawater and the sediment below the seafloor) Lurton (2002). The reflected signal is then measured by the transceiver. If the acoustic impedance between layers is strong the received reflectance will be greater. The transceivers are a set of hydrophones that convert acoustic signals to electrical pulses which are then converted from analog to a digital display that can later be analyzed through the use of software designed for displaying seismic data (Schock and LeBlanc, n.d.; Schock, 2004, 1989; Rakotonarivo et al., 2011; Tseng et al., 2012).

Shallow seismic data were collected in Point Aux Chenes Bay and Grand Bay using the Edge-Tech 3100 sub bottom profiler system in conjunction with a 216S towfish on the dates of September 24-26, 2015. The towfish was attached to a davit extending from the port side of the research vessel and towed at a depth of approximately 0.5 m. The sonar operated at a frequency of 2-15 kHz. The pulse type used was FM with a pulse length of 20 ms. The vertical resolution achieved by the chirp system was approximately 10 cm, and penetrated depths of 20m. The speed of the vessel was held between 2 and 5 knots to insure optimal seismic quality. A total of 33 seismic surveys were collected which produced over 85 km of seismic profiles. The survey grid pattern was determined by fallowing a trajectory that traverses preexisting core locations (Figure 1.1), in order to obtain a more detailed cross section of the subsurface. Data files were converted from .jsf to .segy by code created by O'Brian (2004). Once files were converted to .segy they were imported into IHS Kingdom Suite software program for interpretation. IHS software is an energy industry standard software used to interpret 2D and 3D seismic lines, accurately digitize horizon lines, and produce subsurface maps. By utilizing the Kingdom software horizons were picked and cross sections, depth maps, and isopach maps were created. The maps have aided in identifying sedimentary structures, interpreting stratigraphy, and understanding geologic evolution of the area.

Sediment core

In 1990 Karen Kramer investigated the stratigraphy underlying Grand Bay and Point Aux Chenes Bay in a Mississippi State University thesis. Her research was centered on analysis of 50 core samples that ranged in depth from 0.5 m to 3 m (Figure 3.1). Kramer analyzed the core, identified 8 sediment facies, and produced 8 cross sections from the eight sediment layers she was able to differentiate. Kramer also noted one erosional unconformity that she correlated across her study area. She interpreted the unconformity as a boundary between Holocene and Pleistocene sediments. Her cross-sections indicate that the beds of sediment dip seaward in a southwestwardly direction (Figure 3.2). The sediment core and interpreted cross sections were beneficial for use in helping confirm a general dip direction for the beds in the area. Nevertheless, because this core penetrated only 3m into the subsurface it helped little in defining formation.

Sediment core data stored by the Mississippi Department of Environmental Quality (MDEQ) has been utilized for determining depths of formations within the study area. The sediment core collected by MDEQ is located 2 to 4 km due west of the study area (Figure 3.1). MDEQ core data consists of logged sediment core with noted changes in lithology and hand written interpretations of geologic formations. Interpretation of this core indicates the Holocene Pleistocene unconformity lies between 0 and 3 m at on-shore locations and dips seaward to depths of 5 m below the seafloor. The core data illustrates that the Prairie Formation thins and shallows landward until it outcrops onshore. The Biloxi Formation underlies the Prairie Formation and deepens seaward; however, the Biloxi Formation thins seaward and pinches out, or becomes undifferentiability from underlying sediment, seaward of the study area. Unconsolidated Neogene units dip seaward, underlie the Biloxi Formation, and are located from 10 to 15 m below the seafloor (Figure 3.3). The Holocene/Pleistocene boundary for the MDEQ cores is located at the top of the Prairie Formation. MDEQ interpreted the Prairie Formation reaching depths of 5 m below the seafloor suggests that core collected by Kramer did not penetrate deep enough to reach the Holocene/Pleistocene boundary.

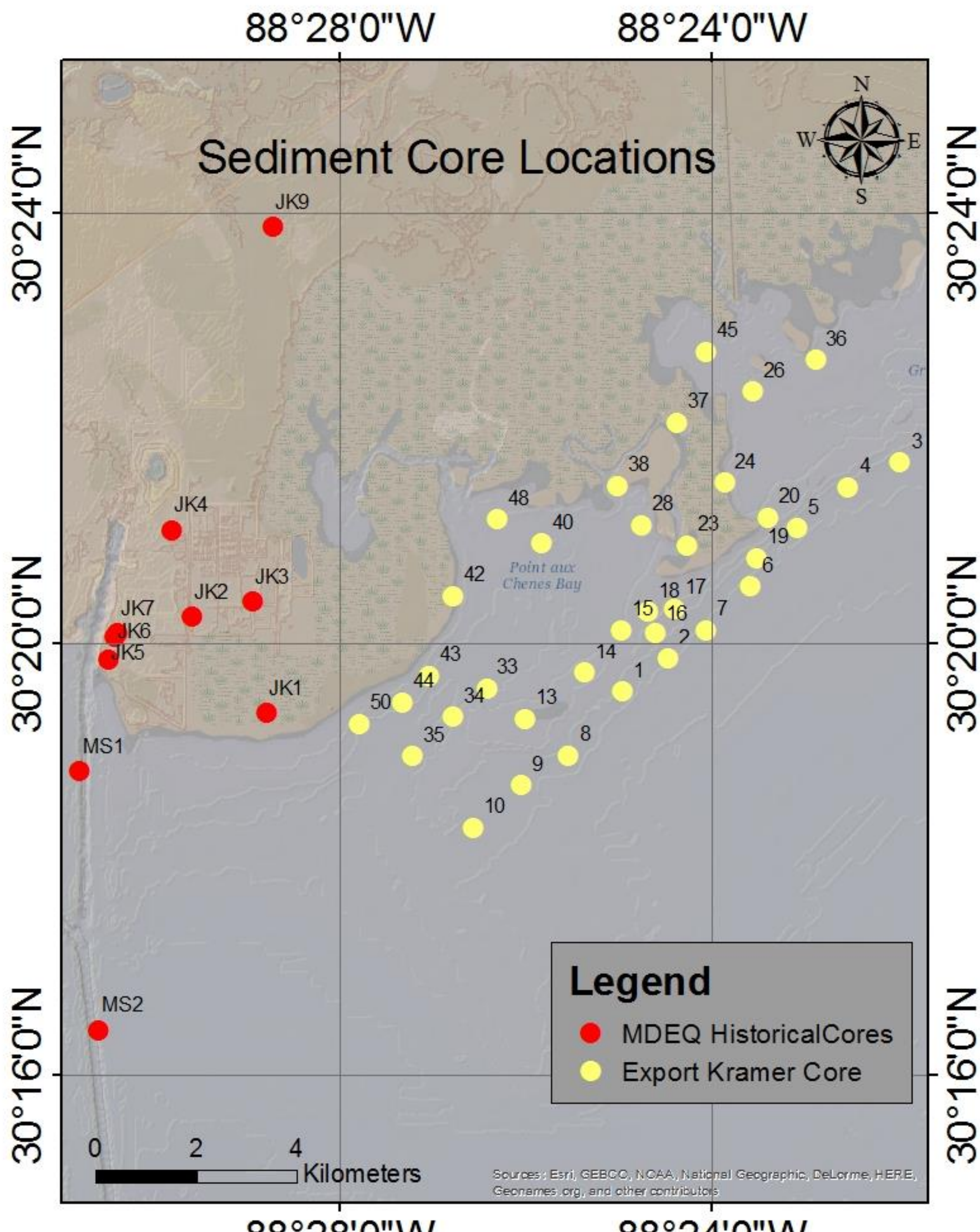


Figure 3.1 Core Location

Image depicts location of core utilized in this study. The red represents the location of core from the Mississippi Department of Environmental Quality, and the yellow represents the location of core from Kramer (1990).

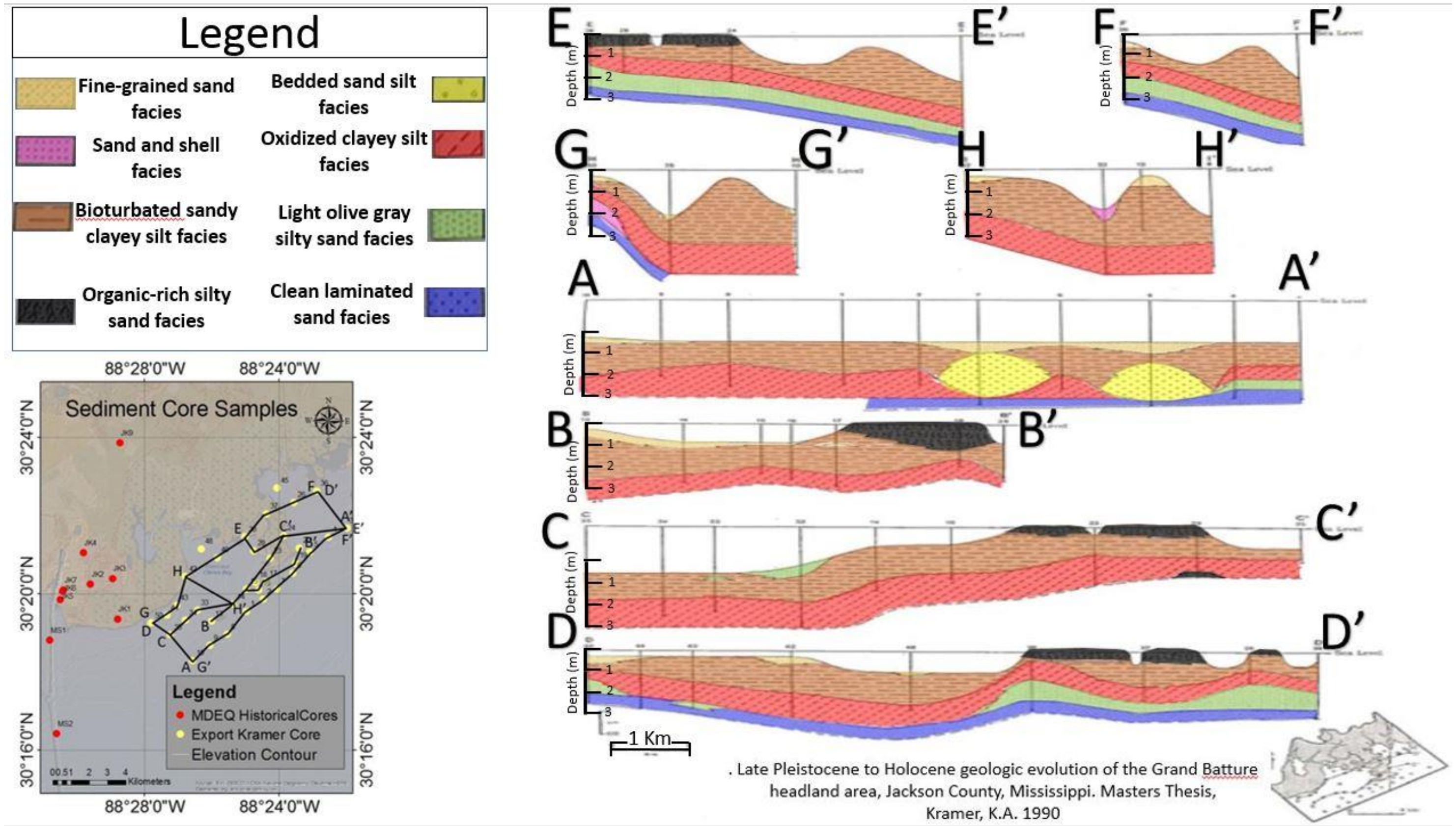


Figure 3.2 Modified from Kramer (1990) Core Locations and Cross Sections

Cross Sections interpreted by Kramer (1990) show 8 identified facies. The red facies had previously been interpreted as Pleistocene-Holocene boundary; however, never exceeds 3 m depth below subsurface.

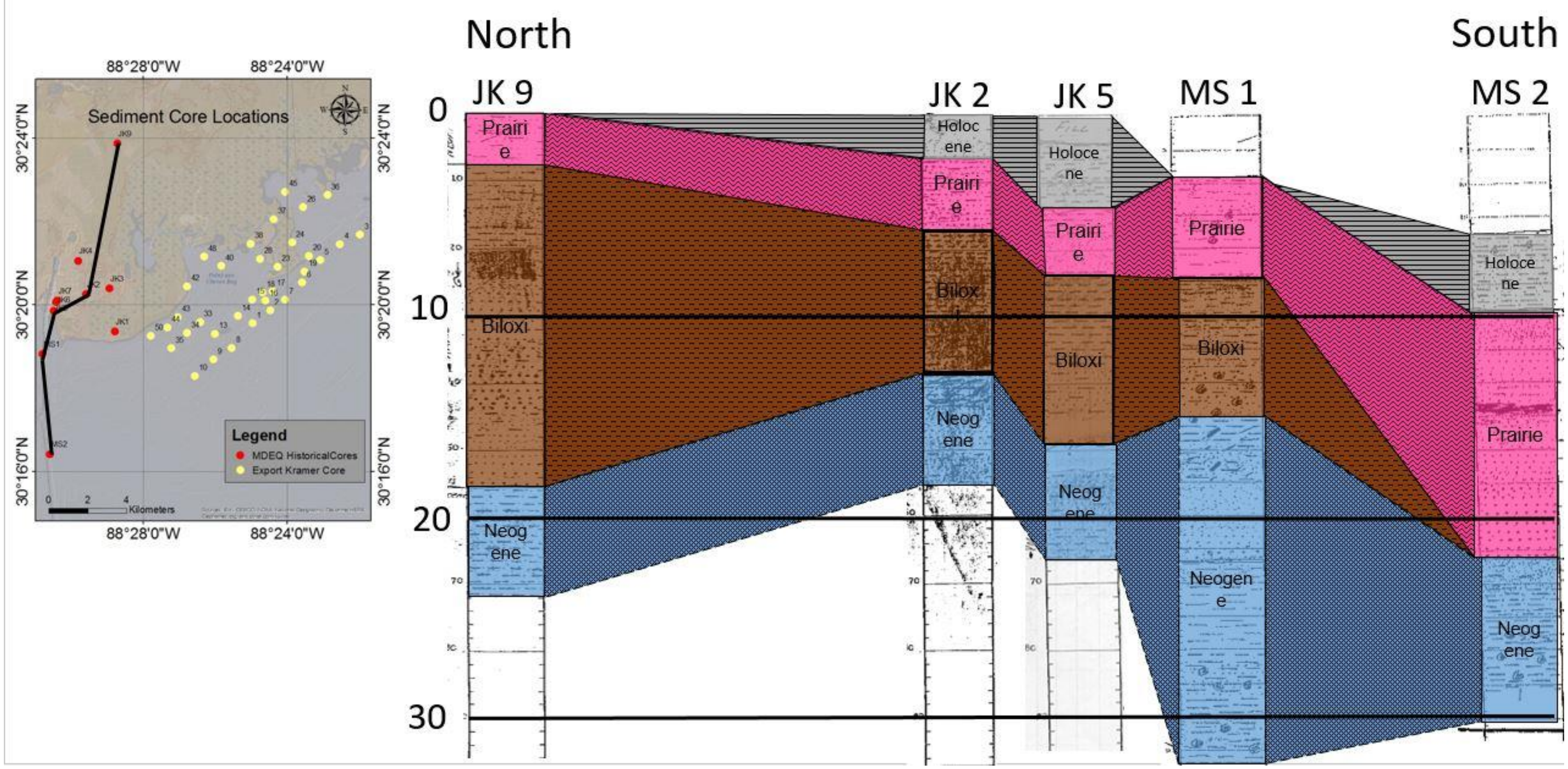


Figure 3.3 Mississippi Department of Environmental Quality core samples

Cross section is modified from MDEQ core logs. The cross section illustrates the Holocene-Pleistocene boundary ranging from 0 to 5 m below the subsurface.

Geologic interpretation

Seismic data collected from the study area was entered into IHS Kingdom Suite software for further analysis and interpretation. Kingdom software is designed to aid in interpretation of both 3D and 2D seismic data. This study sought to utilize the functions of the software to better interpret 2D shallow seismic data collected with a chirp sonar system. The first step in the process was to convert the seismic files that were saved as .jsf files to .sgy files so the files could be correctly imported into Kingdom. The "jsf2segy" code was used to convert the files O'Brien (2004). Once the files were converted to a .segy file type they were imported into Kingdom. Kingdom has four options for importing data. The "Import Multiple 2D SEG Y Files with Coordinates" option was used to import the initial seismic data. The .segy coordinates were in a coordinate system unrecognized by the Kingdom software; therefore, after the seismic surveys were imported into Kingdom each survey's location had to be properly georeferenced and manually entered into Kingdom. Steven Dutch's UTM to Latitude and Longitude excel converter was utilized to properly convert the unrecognized UTM coordinates of each survey into Latitude and Longitude which were later entered into Kingdom. After the seismic survey data was properly imported into the Kingdom Suite analysis of the subsurface began.

The analysis consisted of a three part process. The first step of the process involved converting two way travel time (TWT) into depth. The velocity of sound passing through the sediment at the study area was assumed to be 1500 m/s. Depth was found by multiplying the TWT by the assumed acoustic velocity. The second step entailed picking horizons. Areas of where seismic lines were laterally continuous and had distinct visual contrast were chosen as horizons. Adjusting the gain and the vertical and horizontal scales allowed for better image clarity when choosing horizons. Once a strong reflective surface was selected the surface was named, assigned a color code, and traced manually in each survey. Three predominate reflective surfaces are visible in nearly all of the seismic surveys (Figure 3.4). The sea floor is also visible in all the survey lines. The shallowest notable horizon, Horizon Three (indicated by blue line), is between 1 and 4 m depth and is present in 26 of 33 surveys. The next horizon, Horizon Two (indicated by brown line), is located between 5 and 10 m depth and is present in 28 of the surveys. Finally, the deepest horizon, Horizon One (indicated by a pink line), is located between the depths of 10 m and 20 m and is present in 26 of the 33 surveys. Other reflective surfaces fall above and below the picked horizons; however, none are as laterally extensive as the chosen horizons. Therefore, the less laterally extensive surfaces were not identified as horizons. Also, of note, there is a perceptible almost gradational change in reflective amplitude between the depths of 1 m and 2 m; however, because this did not appear to be a true reflective surface it was not chosen as a horizon line. After the horizons had been chosen structure maps for each horizon were generated.

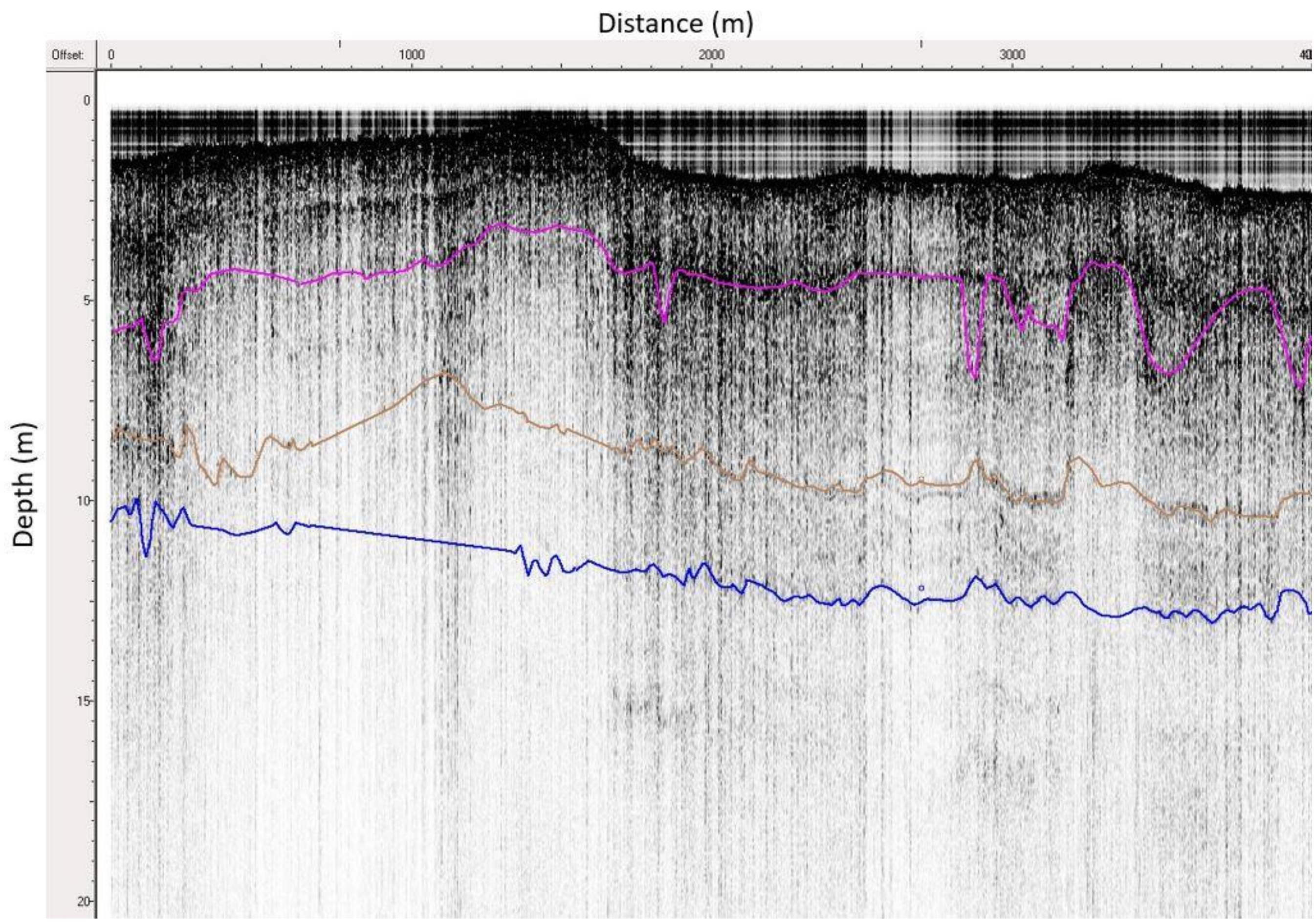


Figure 3.4 Seismic Survey

The seismic survey displays three horizons visible throughout the study area. They are indicated by color: Horizon One (blue), Horizon Two (brown), and Horizon Three (pink).

Structural maps

The first map created using the seismic data was a bathymetric map. The first and strongest reflector was interpreted as the seafloor. This sharp contact was traced, digitized, and named seafloor. Through the use of the Kingdoms contour mapping function, a basic contour map of the seafloor of Pointe Aux Chenes Bay and Grand Bay was produced. Using the same contour mapping function, maps illustrating the topographical surface of horizons One, Two, and Three were produced. The maps were created to help establish stratigraphic architecture and to better visualize the paleo-erosive surface morphology (Figures 3.5-3.8).

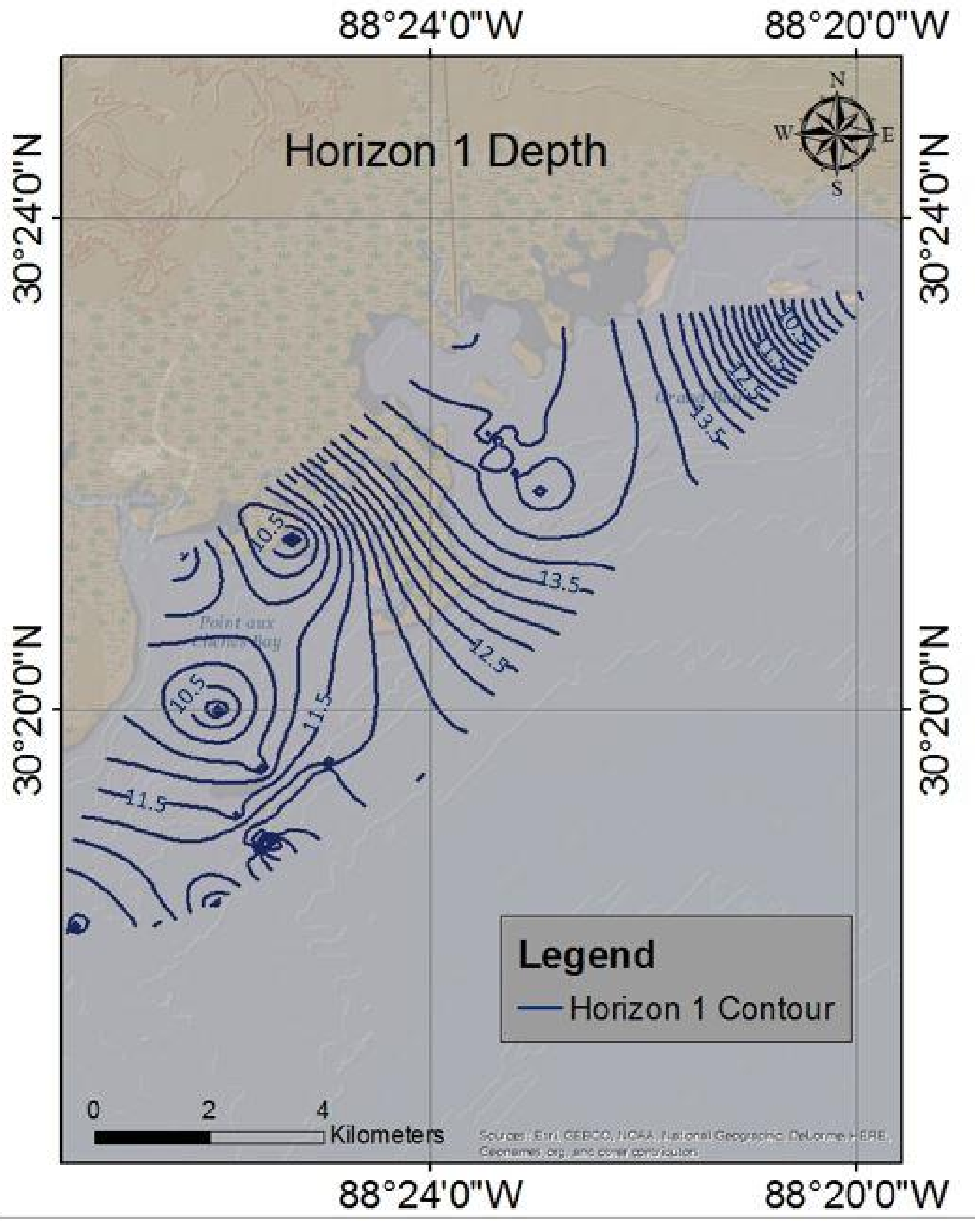


Figure 3.5 Horizon One depth map

Horizon One is interpreted as the top of the undifferentiated (pre-last glacial maximum) sediment.

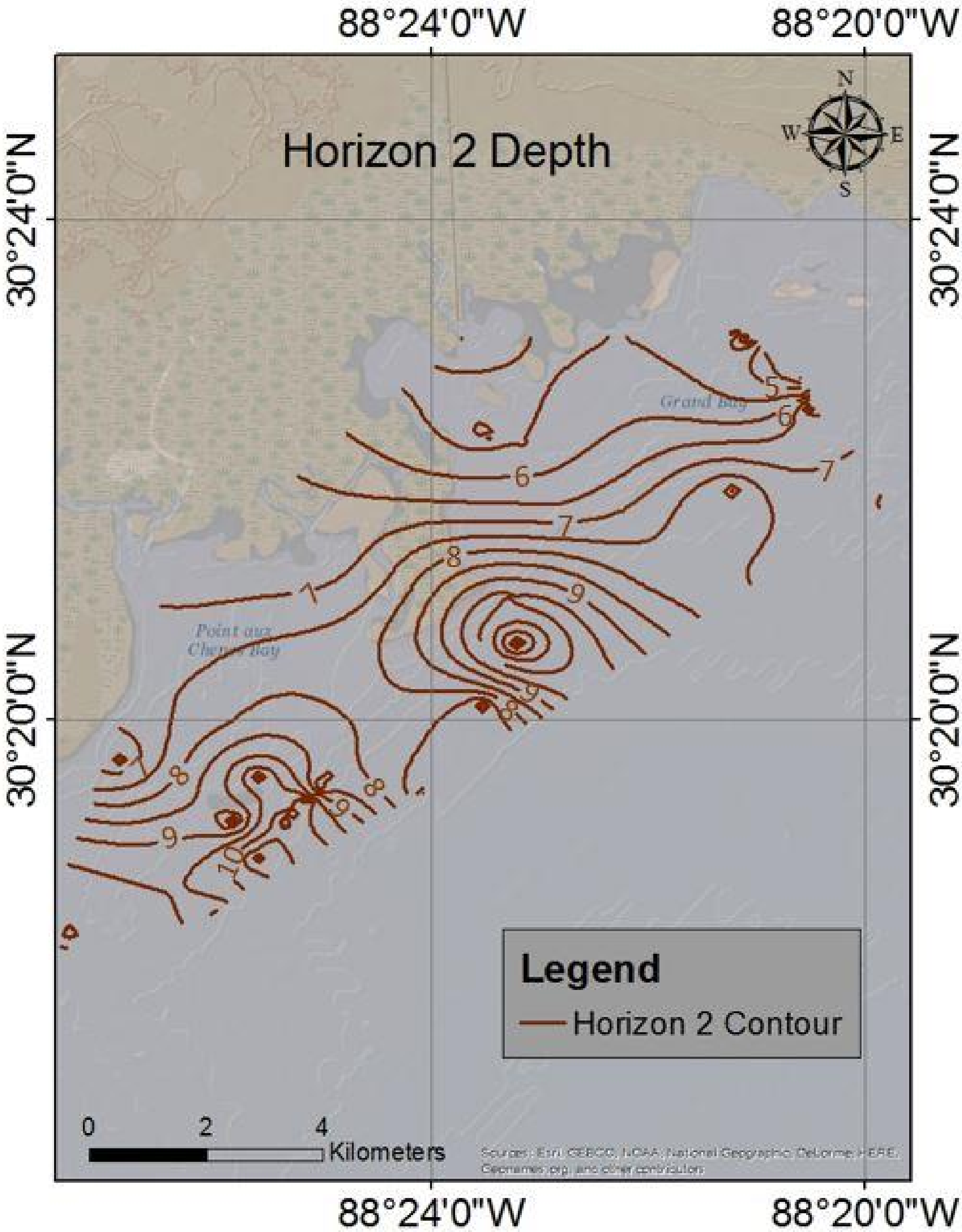


Figure 3.6 Horizon Two depth map

Horizon Two is interpreted as the top of the Biloxi Formation.

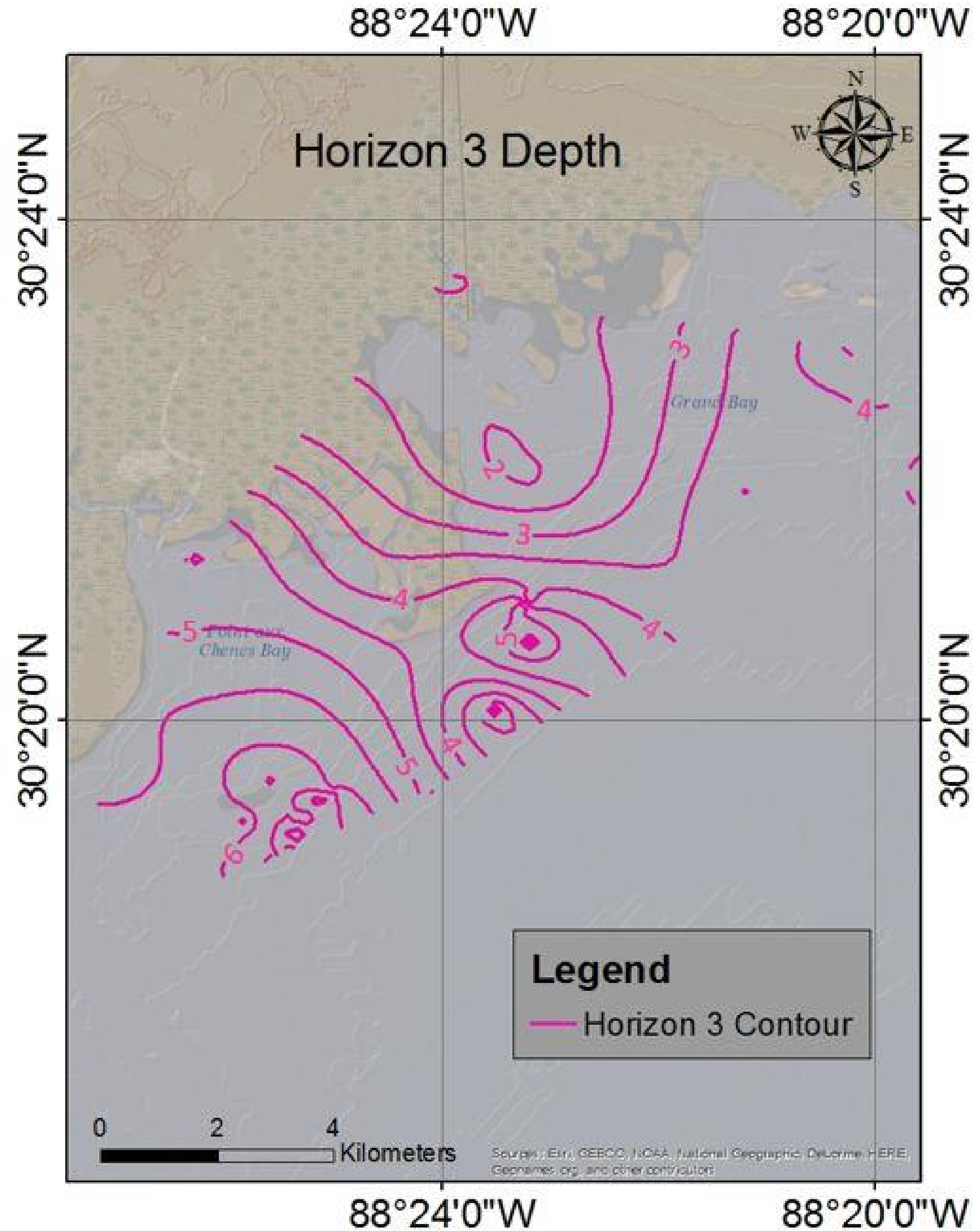


Figure 3.7 Horizon Three depth map

Horizon Three is interpreted as the top of the Prairie Formation.

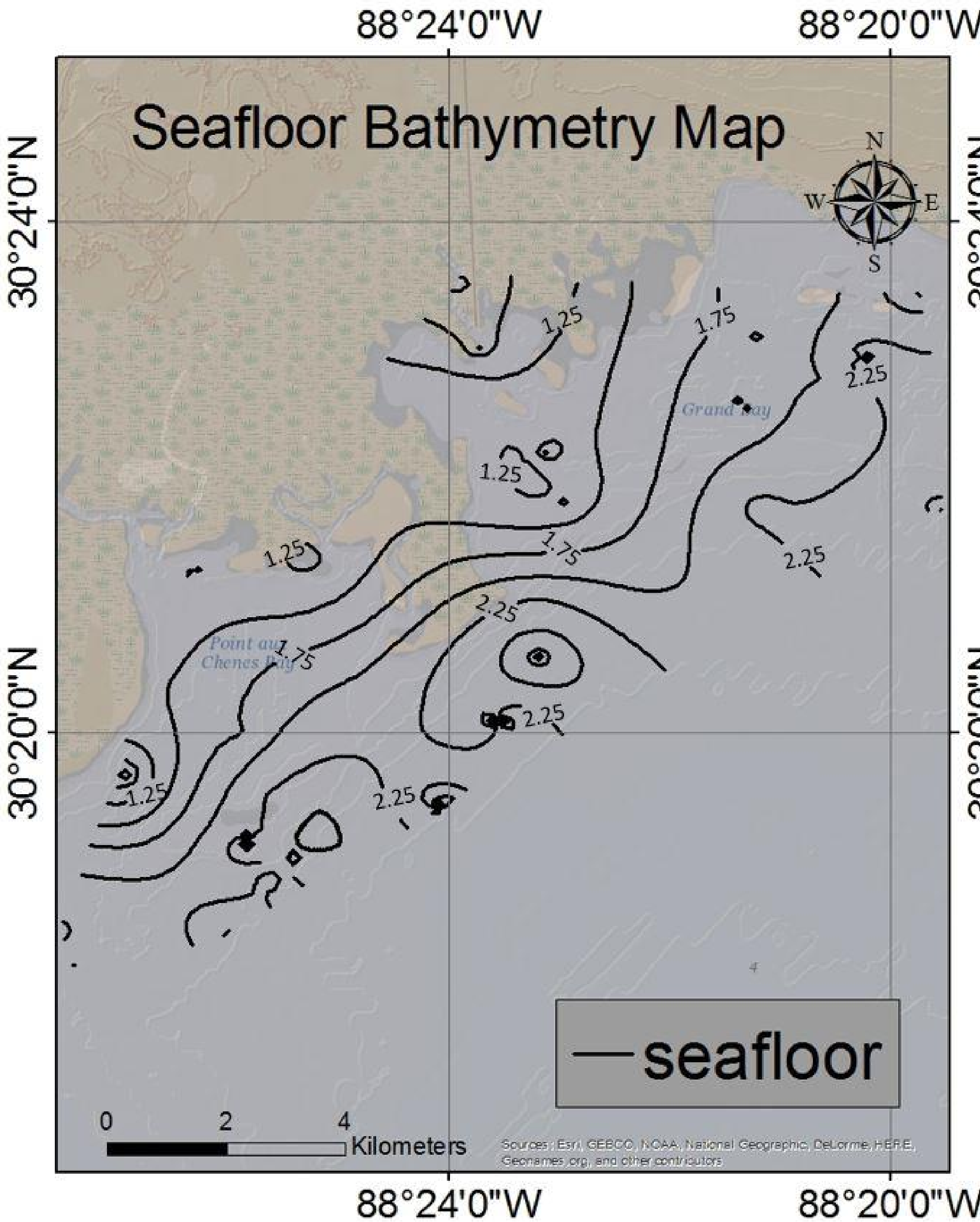


Figure 3.8 Bathymetry Map

Seismic lines were used to construct a bathymetric map of the study area.

Isopach maps

Isopach maps and depth below seafloor maps were created to help determine thickening and thinning trends of sediment between the picked horizons. Both the isopach maps and depth below seafloor maps were generated using a calculator function in Kingdom. The software compares two selected horizons and then subtracts the depth of the upper horizon from the depth of the lower horizon which provides a thickness value. This calculation is only applicable if both horizons are present any geographic point. If either horizon is not present a null value is assigned and the program will extrapolate to the nearest real value. The isopach maps were used to indicate the amount of sediment between each paleo-surface. Figures 3.9-3.13

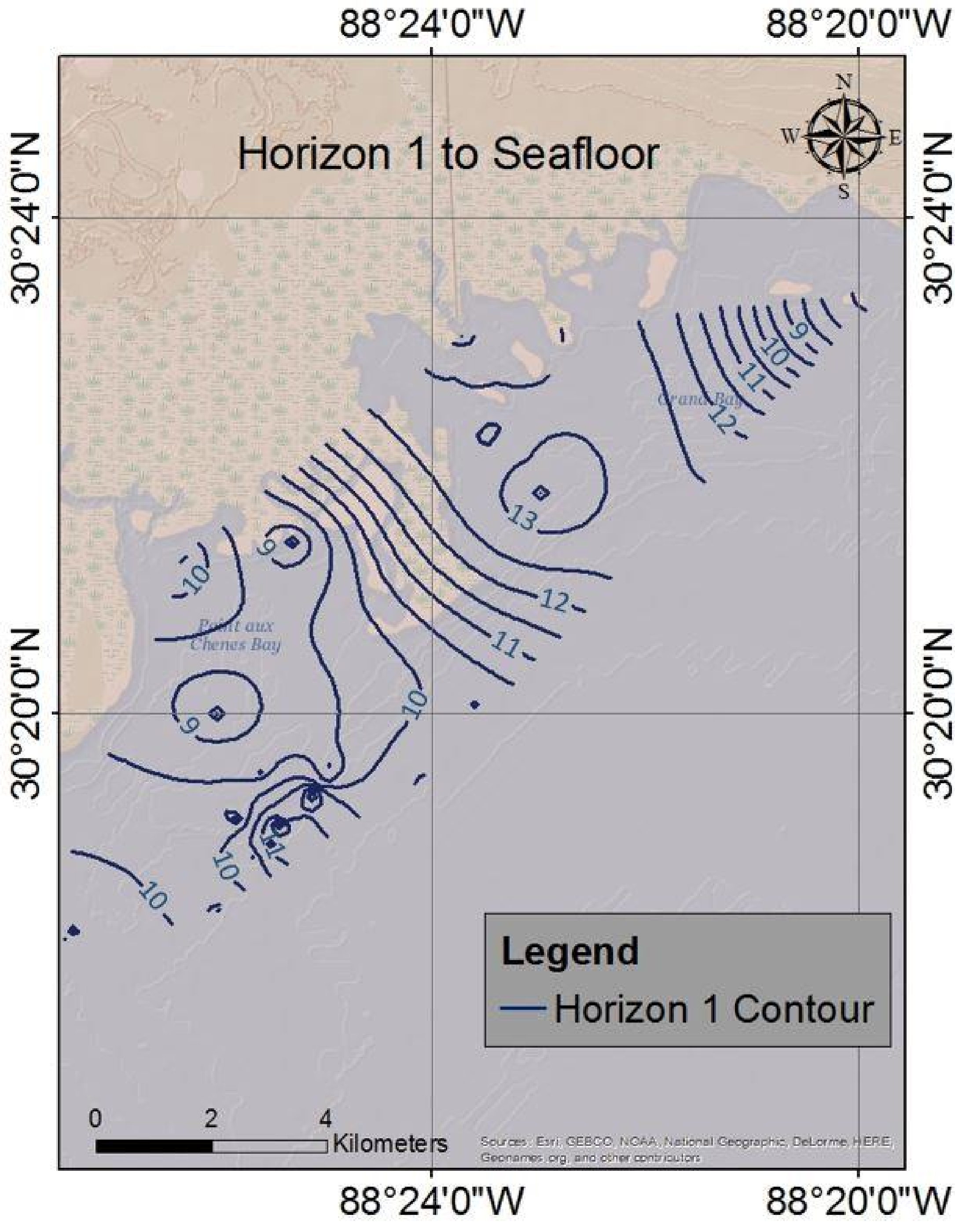


Figure 3.9 Horizon One depth to seafloor

The image indicates the depth from Horizon One (top of the undifferentiated sediment) to the seafloor.

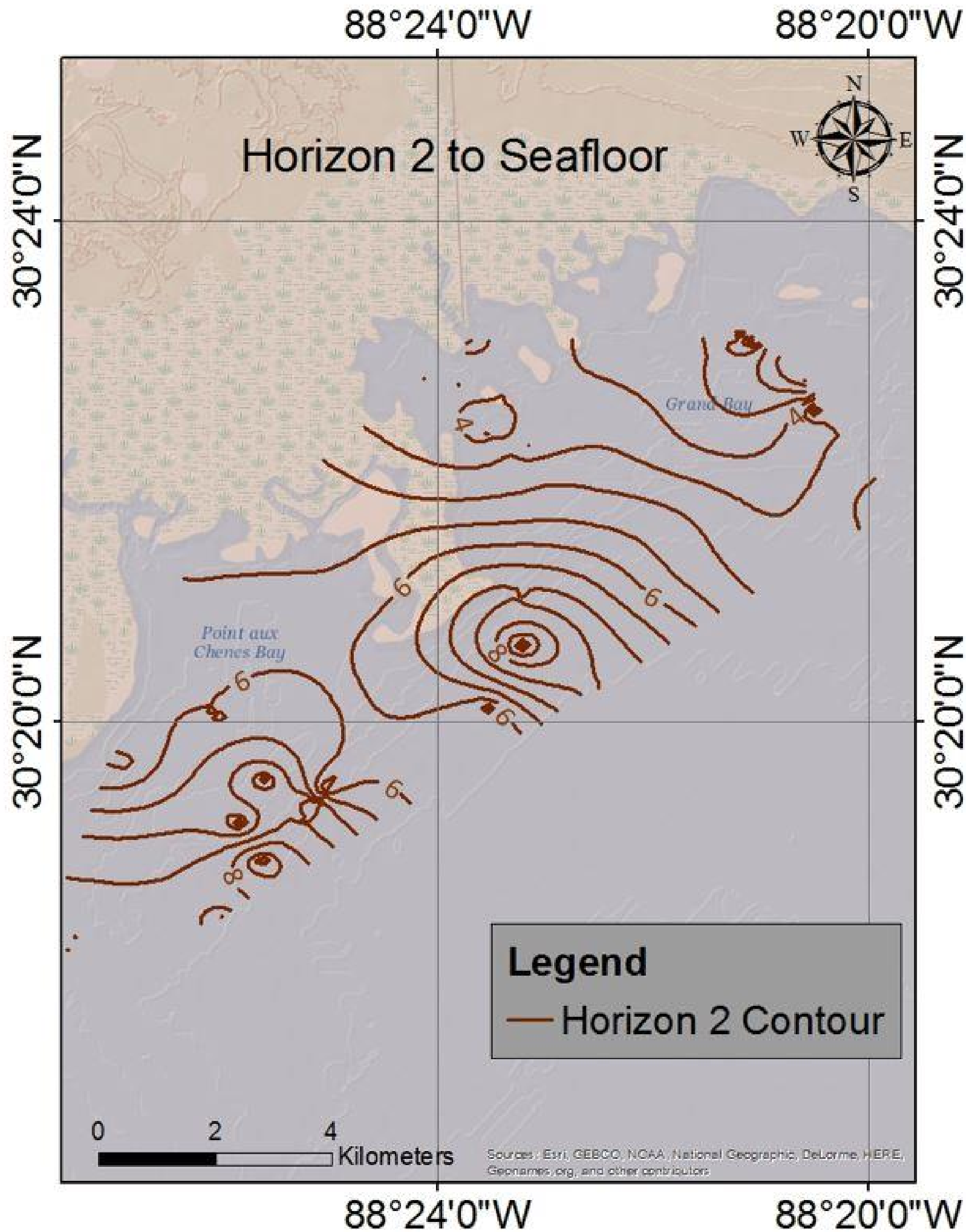


Figure 3.10 Horizon Two depth to seafloor

The image indicates the depth from Horizon Two (top of the Biloxi) to the seafloor.

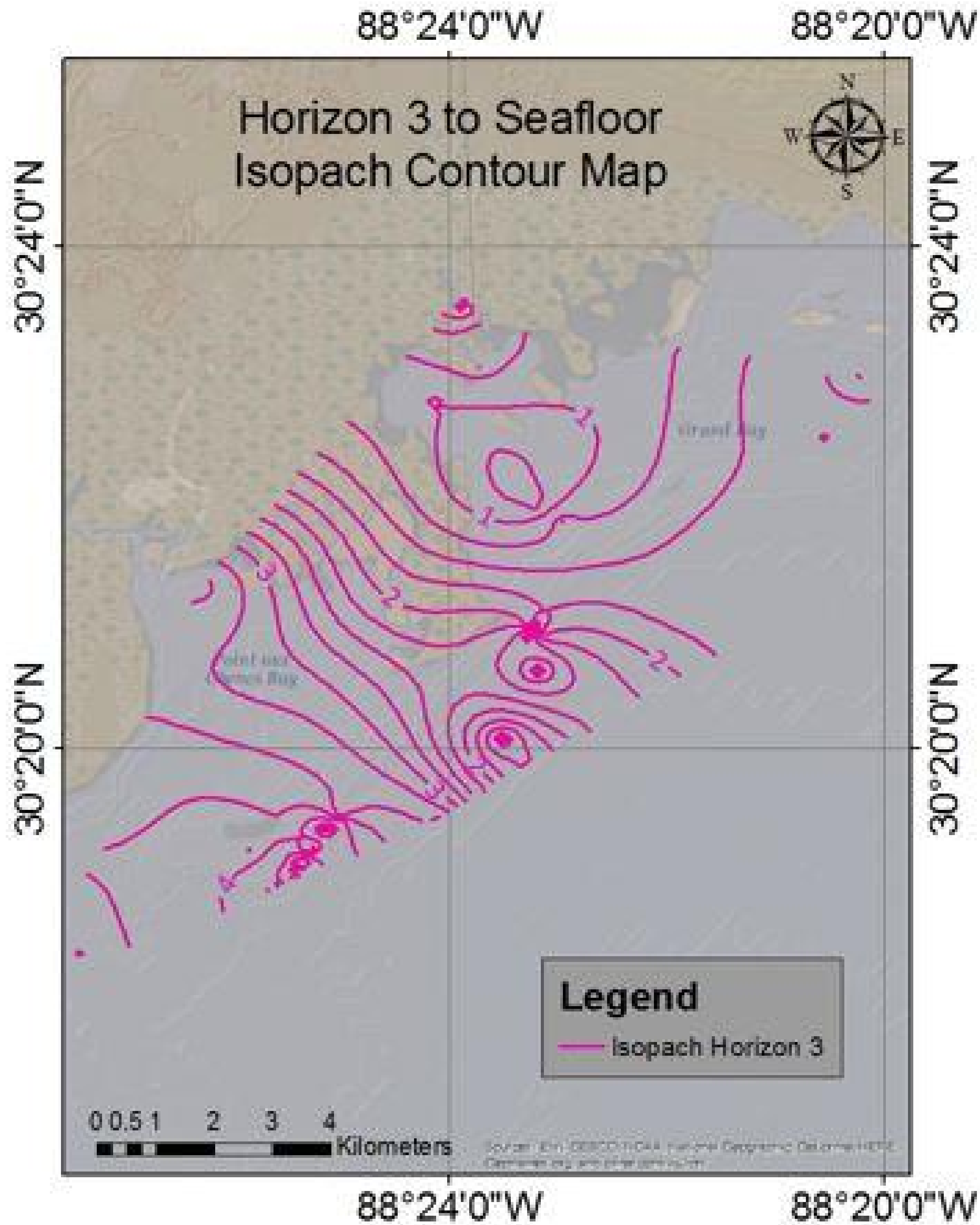


Figure 3.11 Horizon Three to seafloor isopach map

The image indicates the depth from Horizon Two (top of the Prairie) to the seafloor

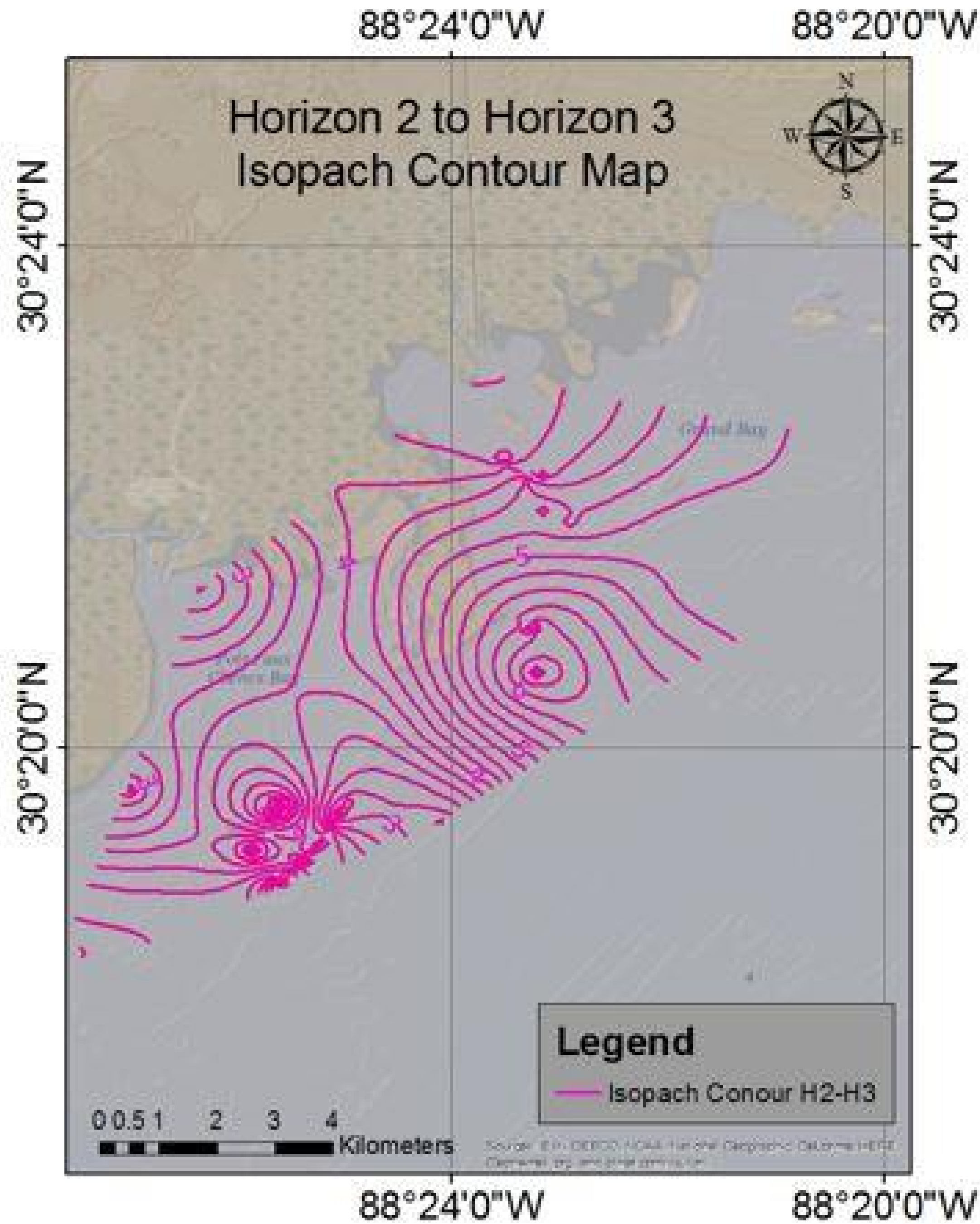


Figure 3.12 Horizon Two to Horizon Three isopach map

The image indicates the thickness of sediment (Prairie Formation) between Horizons Two and Three.

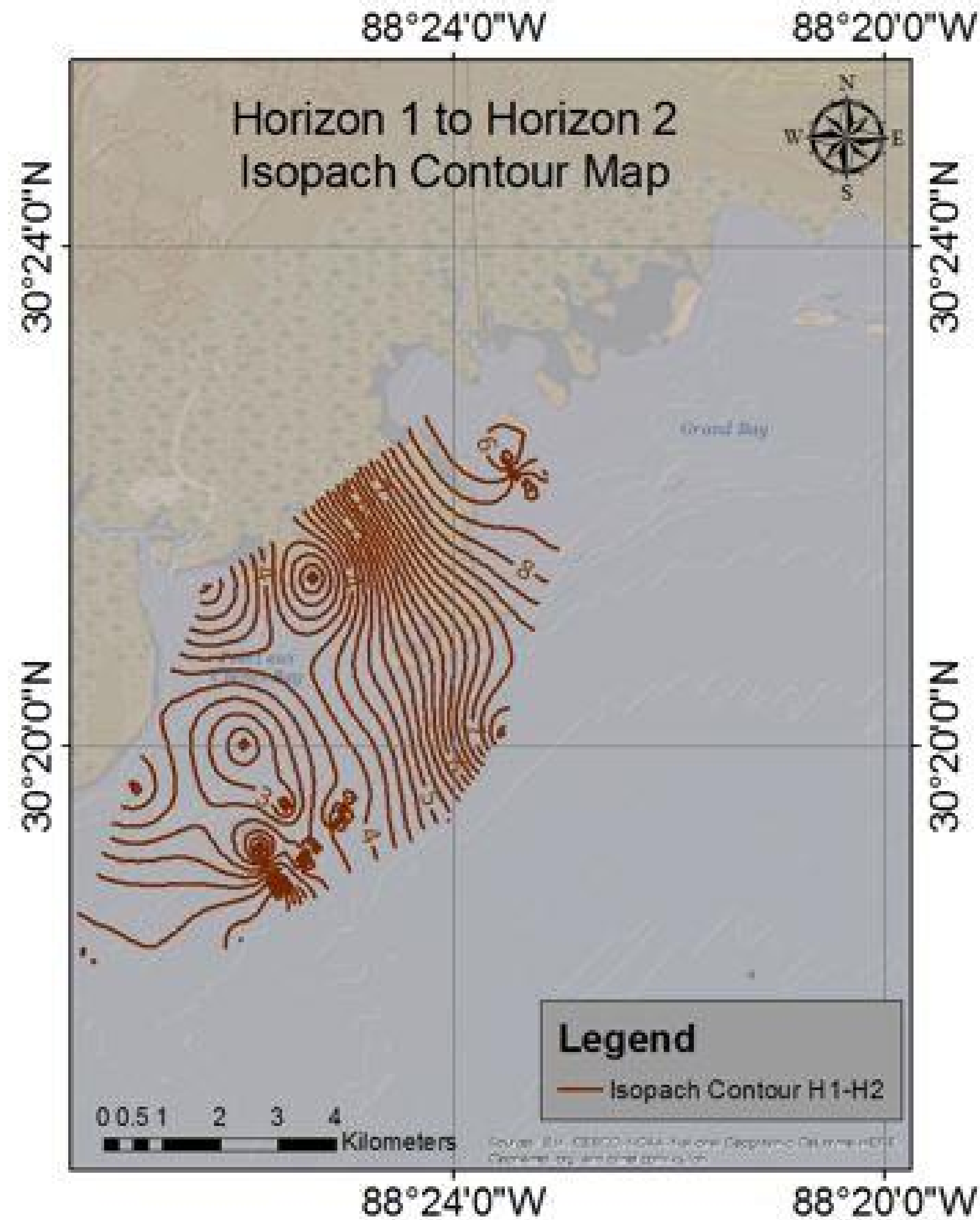


Figure 3.13 Horizon One to Horizon Two isopach map

The image indicates the thickness of sediment (Biloxi Formation) between Horizons One and Two.

Paleochannels

Paleochannel deposits were interpreted from seismic data. Each survey was analyzed by hand and the location of each paleochannel was entered into an excel spread sheet. The paleochannel deposits were grouped by where they were located in respect to each horizon. Paleochannel deposits that were located vertically between horizons One and Two were assigned the color blue. Paleochannel deposits located between horizons Two and Three were assigned the color Brown. Paleochannel deposits located between Horizon Three and the seafloor were assigned the color Pink. The paleochannels were additionally grouped by certainty. Figures 3.14 – 3.16 depict examples of each type of paleochannel with its given certainty. Paleochannel deposits that were easily recognizable, had distinct layers of infill, and point bar and cut bank deposits were assigned a confidence interval of 75-100%. Paleochannel deposits that were more difficult to determine but had distinct layering and infill were classified at a 50 to 75% confidence in. Paleochannel deposits given less than a 50% confidence had potential cut bank and point bar features however could not be positively identified. Once all the channels were identified and classified they were plotted in ArcMap as point data. One paleochannel depots map for each horizon interval was created. The confidence interval was depicted by shading the paleochannel points. The darker points represent higher confidence while the lighter points indicate lower confidence. The paleochannel deposits map was used to identify paleochannels and how they trended across the study area.

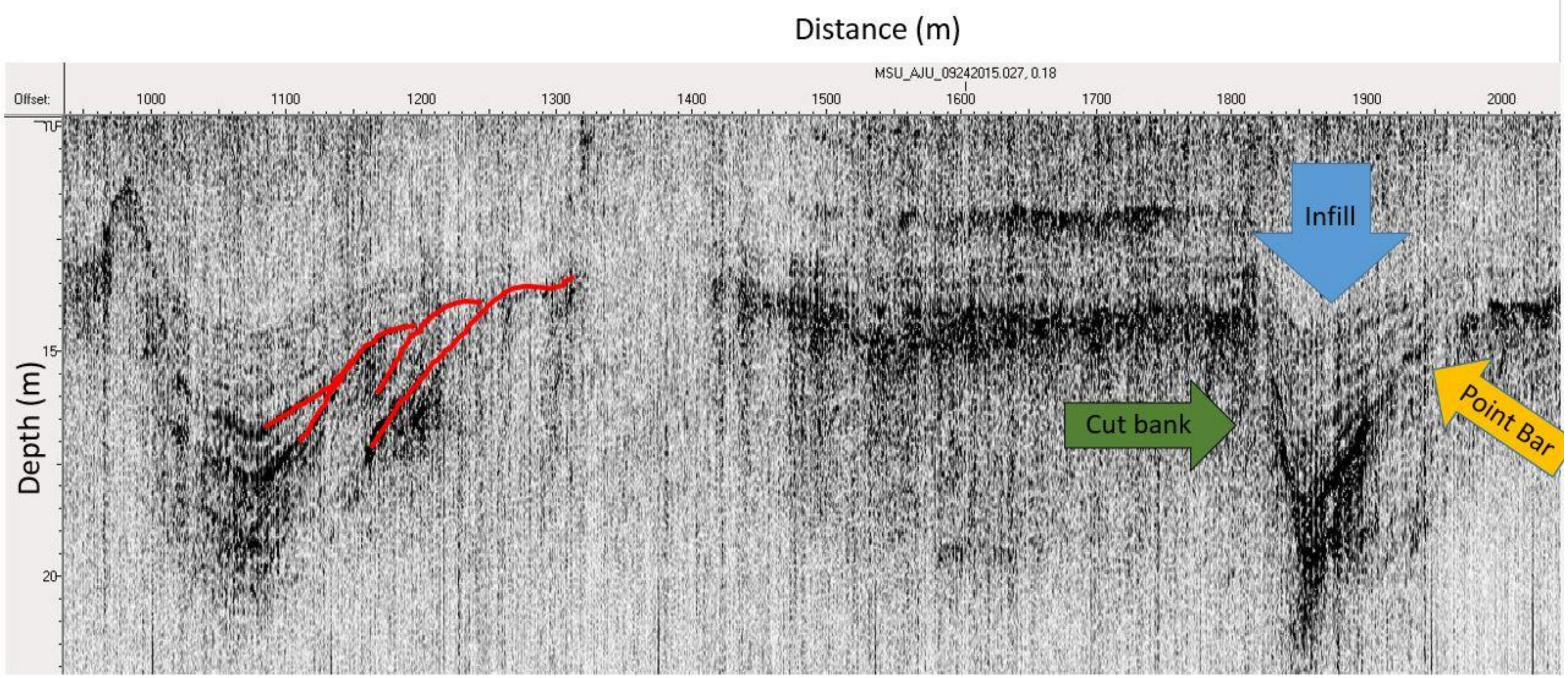


Figure 3.14 Paleochannel deposits type A

Type A paleochannel deposits were assigned a 75-100% confidence level. Structural features such as the point bar, cut bank, and channel fill can be identified with type A channel deposits.

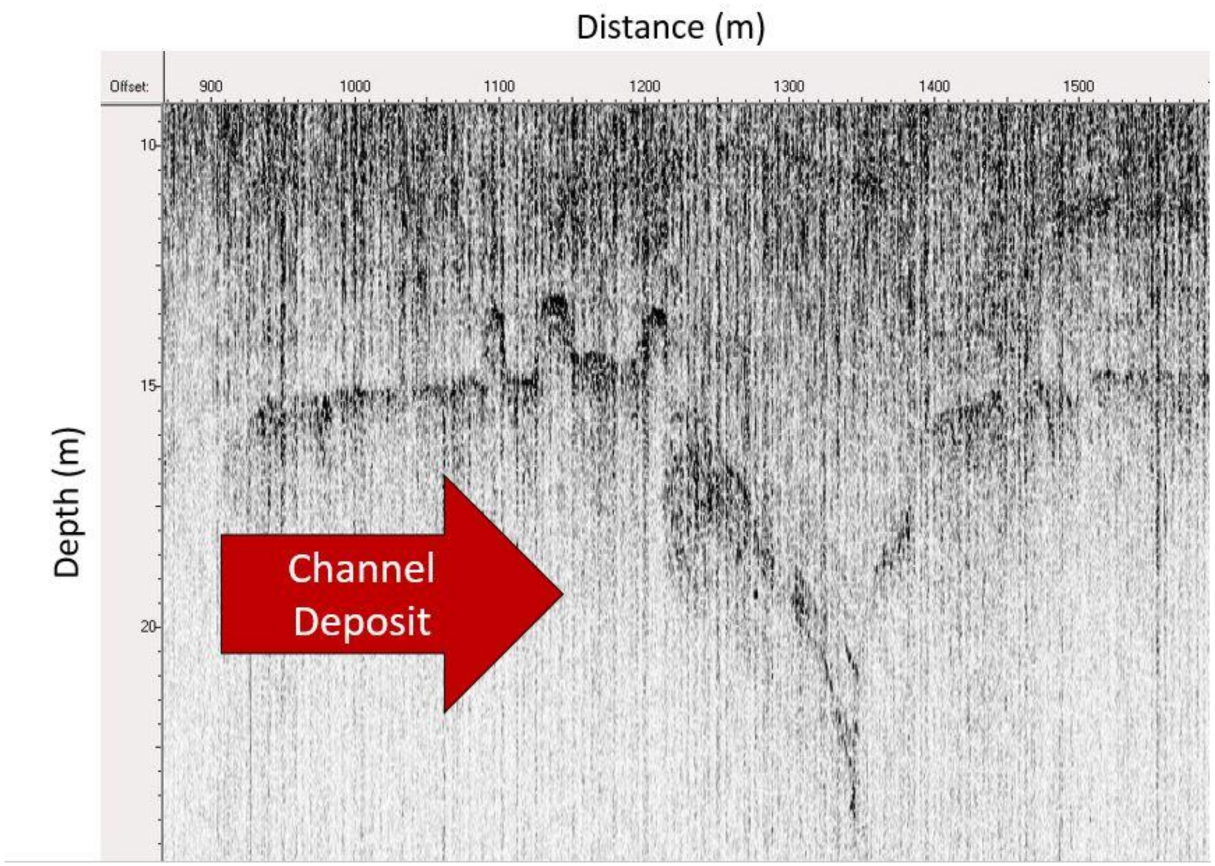


Figure 3.15 Paleochannel deposits B type

Type B paleochannel deposits were assigned a 50-75% confidence level. Structural features such as the point bar and cut bank can often be identified. However, type B deposits are more difficult to distinguish than type A.

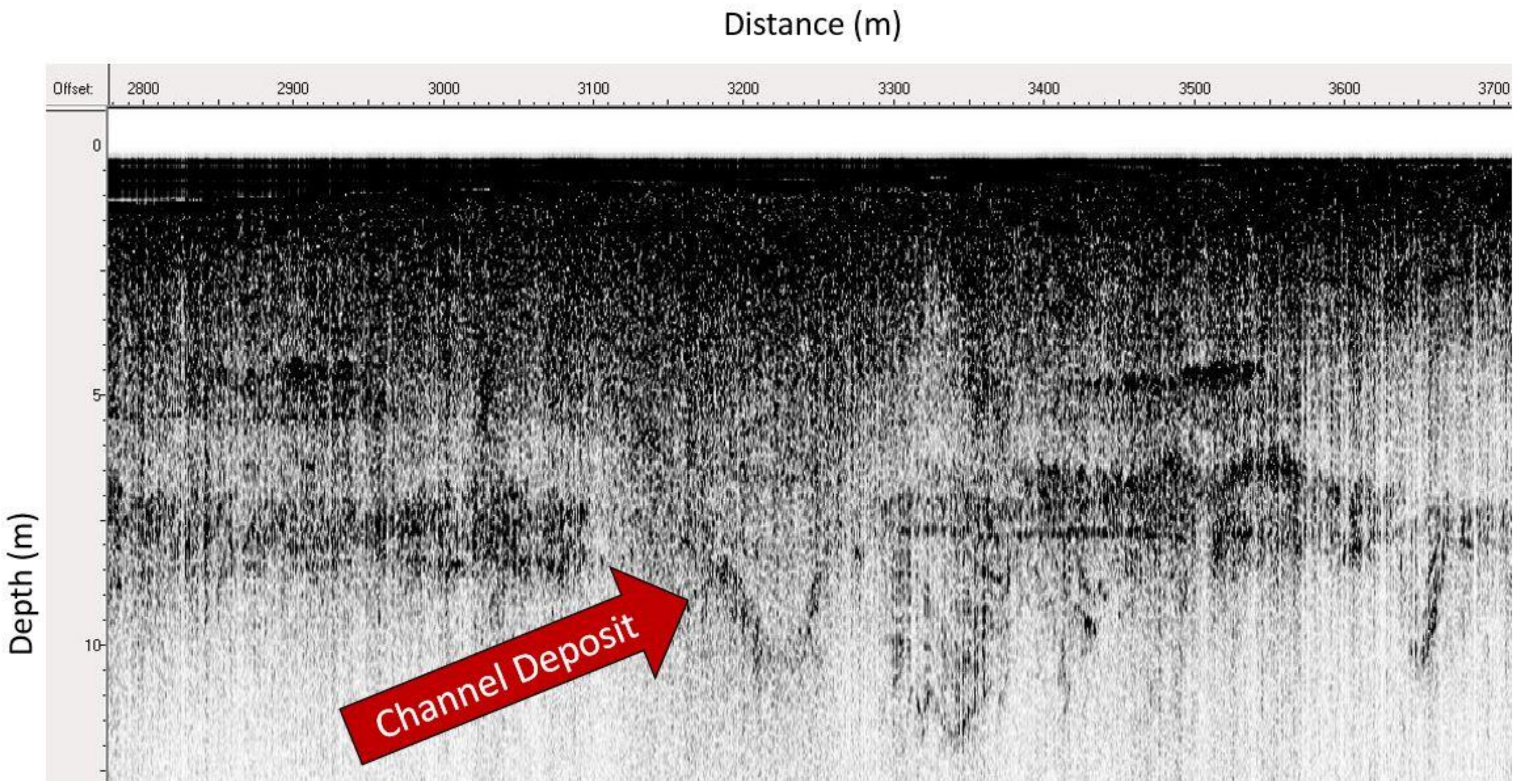


Figure 3.16 Paleochannel deposits C type

Type C paleochannel deposits were assigned a 25-50% confidence level. Structural features such as the point bar and cut bank are often difficult to identify.

Geospatial interpretation

Historical shoreline data was retrieved from Google Earth historical images and the MDEQ. The shoreline for this study was defined as the contact between the waterline and the shore. Grand Bay has a low tidal excursion and limited beachlines so using water level is appropriate. Shorelines collected from Google Earth historical images were built by using the Path tool within Google Earth. Shorelines from Google Satellite images were digitized for the fallowing years: 1992, 2004, 2006, 2010, 2011, 2012, and 2015. The images were taken from different government agencies but have a resolution of approximately 2 m per pixel. Each digitized shoreline was then saved as a .kml file and later converted to an Arc shape file. The MDEQ shorelines were digitized by Louisiana State University from US Coast and geodetic T-sheets. Shoreline data retrieved from MDEQ were already stored as shape files at the MDEQ website; however, the files contained extraneous data from other areas of the Mississippi sound. To remove the unwanted data, located outside the study area, the MDEQ historical shorelines within the study area were traced in ArcMap and saved as a new shape file. MDEQ shorelines were produced from the following years; 1850, 1917, 1950, and 1986. Error associated with shorelines of each age were assigned based from findings from Crowell et.al. (1991). This study assumed worst case error. In regards to shoreline data collected from 1844-1880, Crowell et.al. (1991) advise a worst case error of 8.9 m based on errors due to location of planetable relative to true position, location of plotted rodded points relative to planetable, field interpretation of shoreline, inaccurate location of control points, digitizing error associated with margins of plotted shoreline, digitizer error, and digitizer operator error. A value of error in meters is assigned for each of the above error factors and the factors are summed to determine total error. For dates ranging from 1880 to 1930 a worst-case error of 8.4 m was assigned based on the same factors previously listed. For shorelines derived from aerial photography from 1940 until present were given a worst case error of 6.1 m due to distortion of photo, inaccurate location of control points on vintage T-sheets, delineation of shoreline, digitizing margin of annotated shoreline, digitizer error, and Digitizer-operator error.

Once historical shorelines had been established, digital analysis was performed. Digital shoreline analysis software (DSAS) from (Thieler et. al., 2008) was utilized to calculate rates of coastal change based on all 11 shorelines. To achieve a calculated rate of change for the coastline a baseline had to be established. The baseline is an arbitrary line that is placed landward of furthest inland shoreline. A total of 5 baselines were created for the study area. When placed end to end the 5 baselines covered the total length of shoreline of the study area. After the baselines were established transects had to be created. Transects are lines that run perpendicular out from the baseline, and are used to determine the length from each shoreline to the baseline. Also, transects are evenly spaced apart. For this study transects were spaced at 50 m intervals. Four statistical calculations were generated through the use of the software, including shoreline change envelope, net shore movement, end point rate, and linear regression rate. The first to be calculated was the shoreline change envelope. This calculation only considered shoreline without respect to time. It subtracts the closest shoreline to the baseline from the farthest shoreline to indicate change in distance. The next calculation was net shore movement. This calculation considers time, and subtracts the along transect distance of the oldest shoreline from the youngest shoreline. The end point rate was calculated by dividing the net shoreline movement value by the number of years between the oldest and youngest shoreline. Finally, linear regression rate and R^2 coefficient were found by the following expressions for each of the transect points:

$$y = mx + b$$

y = predicted distance from baseline

m = slope or rate of change in (m/yr)

b = where the line crosses the x axis

The value associated with the LRR or linear regression rate is the slope of the line.

$$R^2 = 1 - \sqrt{(\Sigma(y - y')^2)/(\Sigma(y - \bar{y})} \quad (3.1)$$

Where R^2 = coefficient of determination

y = known distance from baseline for a shoreline data point

y′ = predicted value based on the equation of the best-fit regression line,

$\bar{y}$ = mean of the known shoreline data points.

Linear regression rates are determined by plotting points where the distance from the baseline is on the y axis and time (the dates) is on the x axis for each transect. A best-fit line is then generated between the points and the slope of the line represents the coastline advance or retreat rates in distance/time. The R^2 values are determined by how far the points are from the best-fit line. If the points are near the line that represents a more constant rate of change and the R^2 values will be nearer 1. If the R^2 values are lower and the points are further from the line, then the rate of change is more varied over time.

Gravely deposits from paleochannels have been correlated to areas of rapid accretion and erosion on shorelines (Browder and McNinch, 2006; McNinch, 2004; Miselis and McNinch, 2006; Schupp et al., 2006). Because other investigators have observed correlation between paleochannels and areas of shoreline change, coastal change rates were computed and paleochannel deposits were identified in this research. Kingdom software was used to identify paleochannel deposits that were imaged within the seismic surveys. Once the channel deposits were identified, the latitude, longitude, and depth of each channel was entered into an excel spreadsheet and the channels were grouped by depth and certainty as explained above. The locations of each channel were then imported into Arc GIS with the "add data" function. The location of the paleochannels were then saved as layers. A total of six layers were generated. Each layer was color coded by horizon: Horizon One; blue, Horizon Two; brown, Horizon Three; pink. Each layer was then shaded based on certainty where darker shading represents certainty of 75-100% and lighter represents certainty of less than 50%. The NOAA digital elevation model was placed as a layer under the paleochannel layers so spatial correlations could be drawn from paleochannel location and modern surface topography. Examples are depicted in Figures 3.17-3.19.

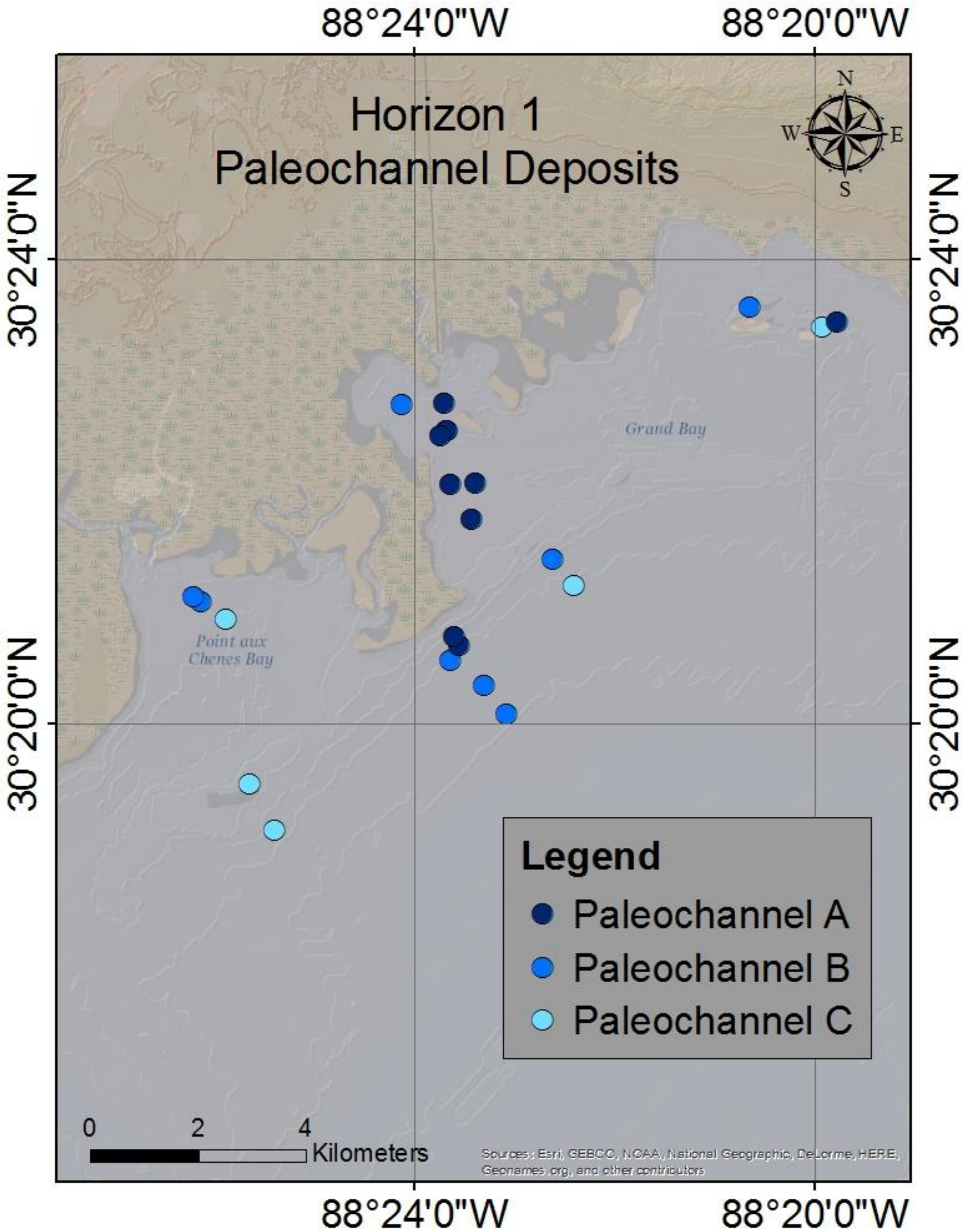


Figure 3.17 Paleochannel deposits associated with Horizon One

Paleochannel deposits were plotted and categorized by horizon (blue) and confidence level where the most confidence is dark and the lest confidence is light.

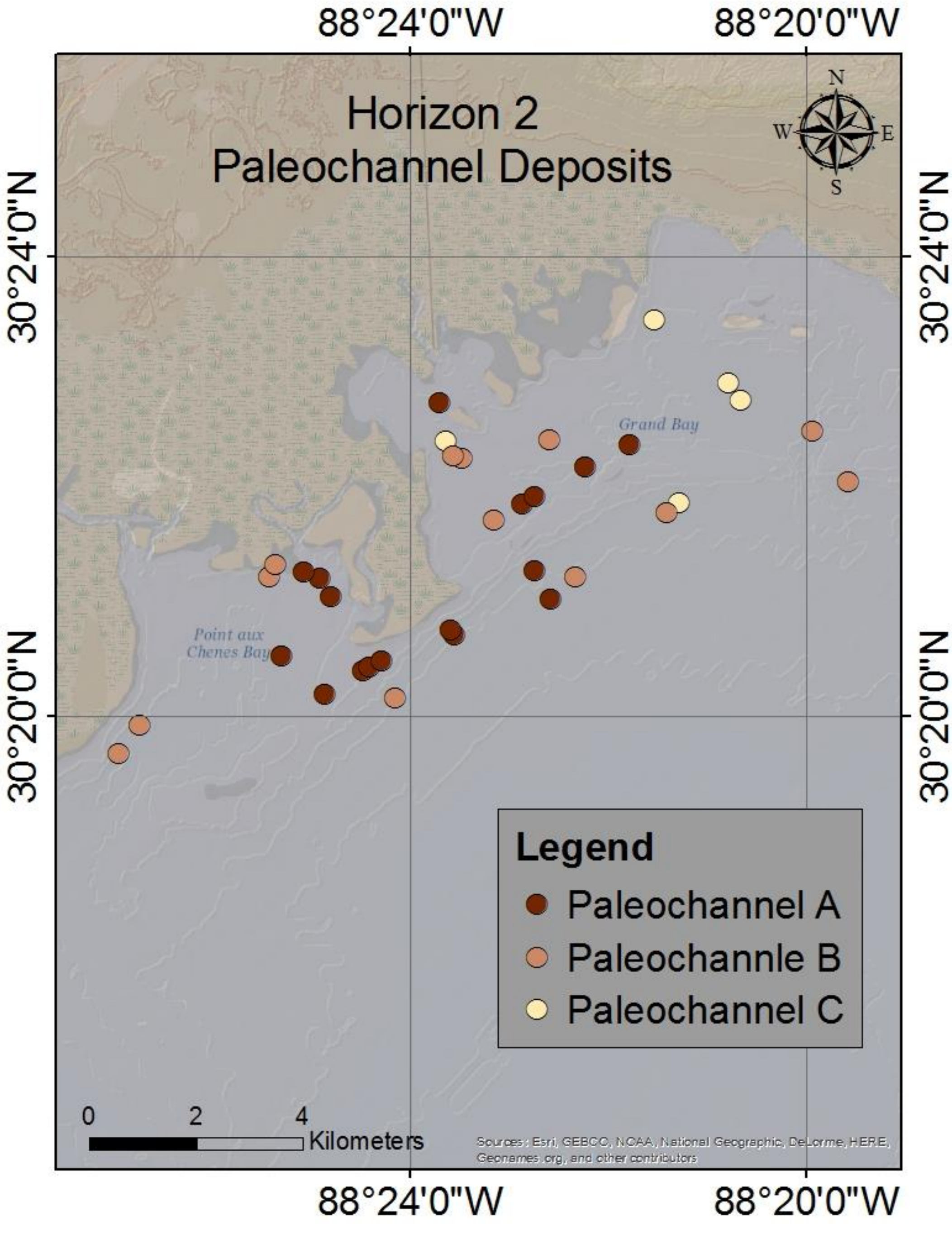


Figure 3.18 Paleochannel deposits associated with Horizon Two

Paleochannel deposits were plotted and categorized by horizon (brown) and confidence level where the most confidence is dark and the lest confidence is light.

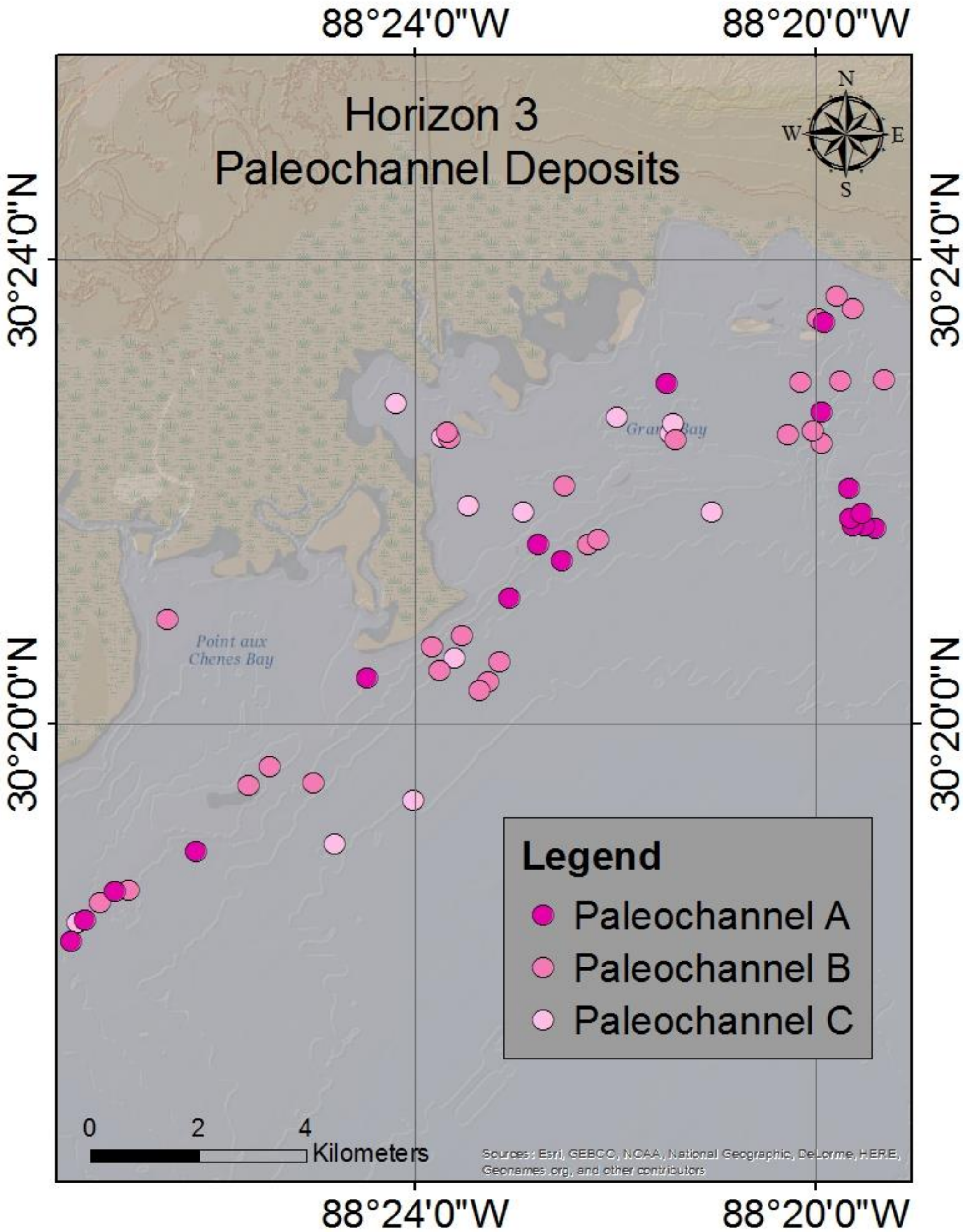


Figure 3.19 Paleochannel deposits associated with Horizon Three

Paleochannel deposits were plotted and categorized by horizon (pink) and confidence level where the most confidence is dark and the lest confidence is light.

CHAPTER IV

RESULTS

Cross-sections/horizons

A total of four parallel-to-shore and six perpendicular-to-shore cross-sections were generated from the seismic data. Figure 4.1 illustrates the location and extent of each cross section. The cross sections perpendicular to shore indicate a deepening seaward trend for the sediments bound by each horizon (Figures 4.2-4.11). Three horizons were chosen from the data. The first horizon chosen was the deepest horizons visible and laterally extensive, Horizon One. Horizon One deepens just seaward of (present day South Rigolets Island), shallows and levels to the west of the relic deltaic headland within Pointe Aux Chenes Bay (Figures 4.2-4.3). Also, a deepening seaward trend of Horizon One can be seen when observing figures 4.6, 4.9-4.11 and comparing figures 4.2-4.4. Horizon Two remains relatively constant in depth along cross sections parallel to shore (Figures 4.2-4.5). However cross sections perpendicular to shore indicate that Horizon Two is deepening seaward (Figures 4.6-4.11). Horizon Three was identified 1m to 3m below the sea surface and has a gentle seaward deepening trend observed in figures 4.6-4.11. Additionally, the seafloor was easily recognized as the shallowest and strongest reflector. The seafloor was digitized with the Kingdom software, and map displaying the depth to seafloor was produced from the digitized seafloor line.

The seafloor is visible in all the surveys and, as would be expected, dips in a seaward direction.

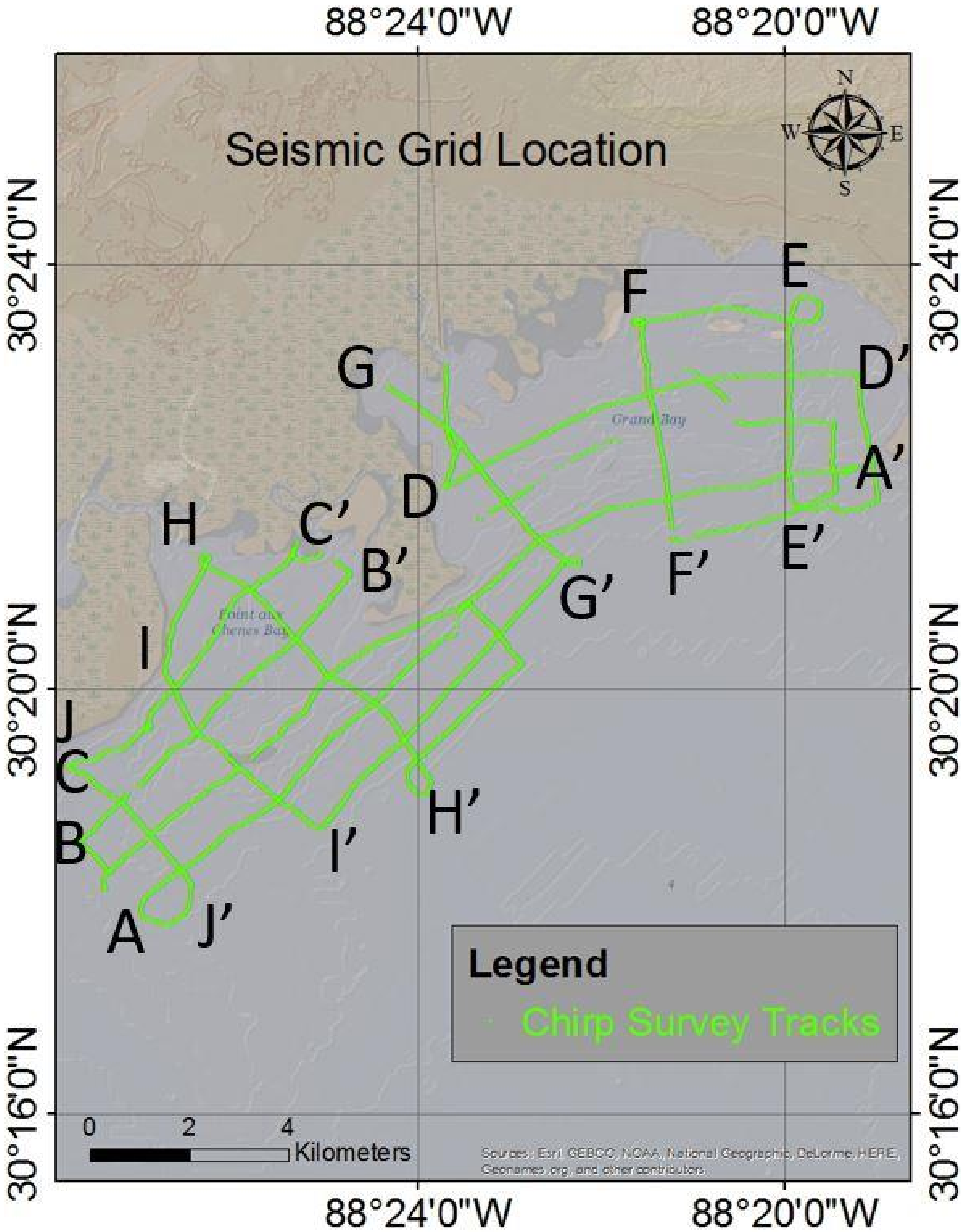


Figure 4.1 Seismic track grid

The image depicts the seismic survey track pattern. The letters indicate ends of the cross sections interpreted from the surveys.

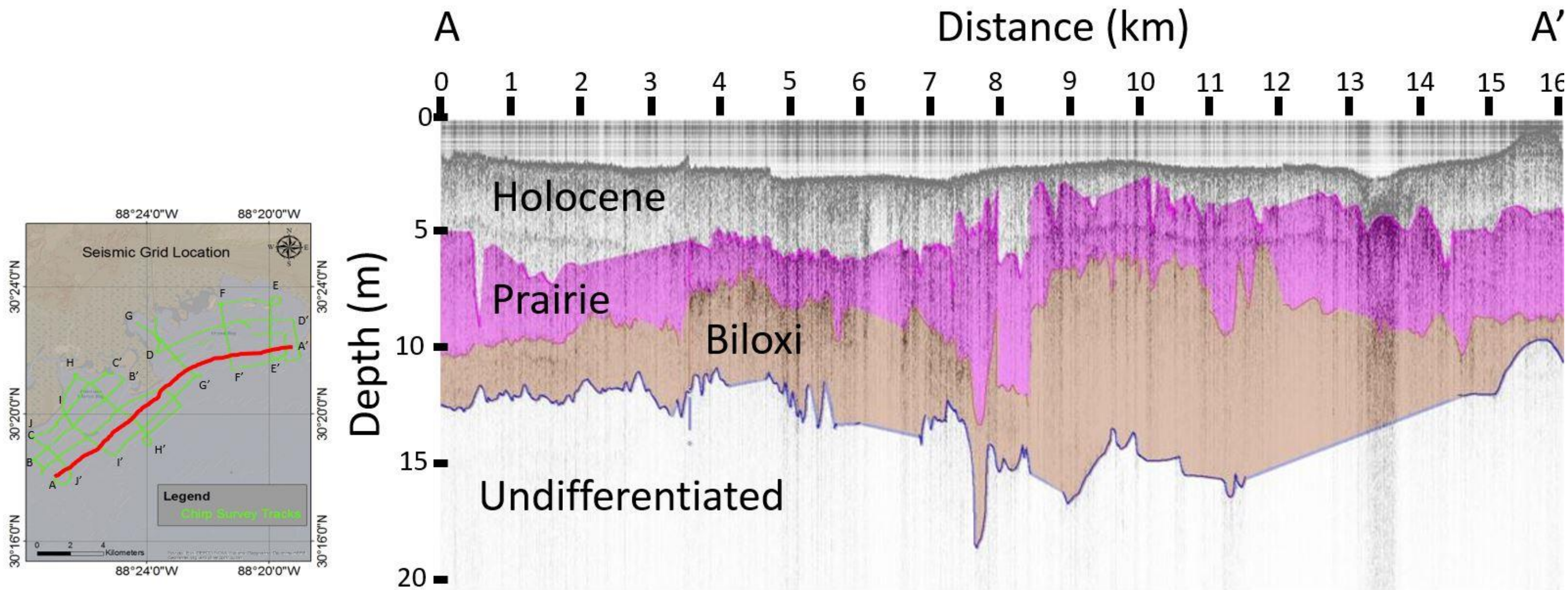


Figure 4.2 Interpreted seismic line A-A'

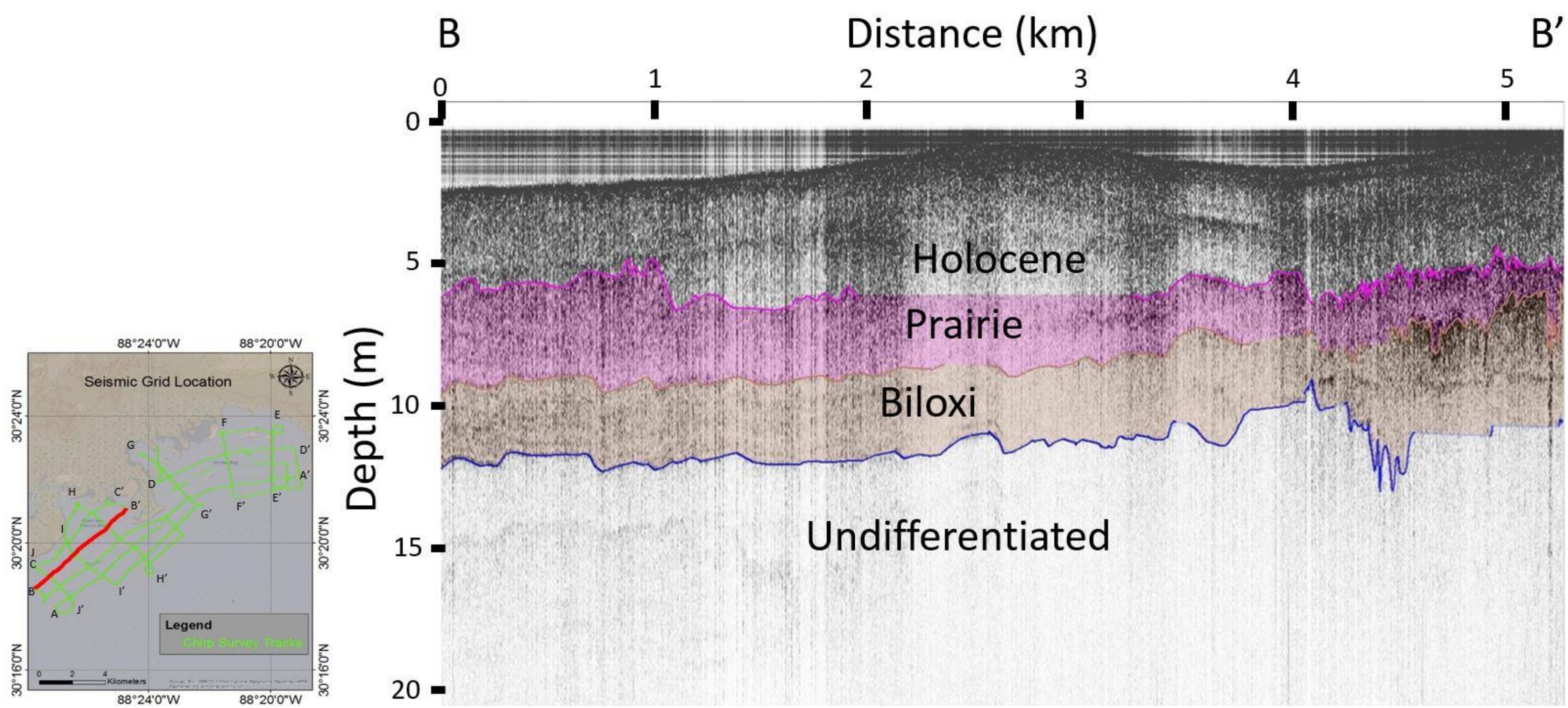


Figure 4.3 Interpreted seismic line B-B’

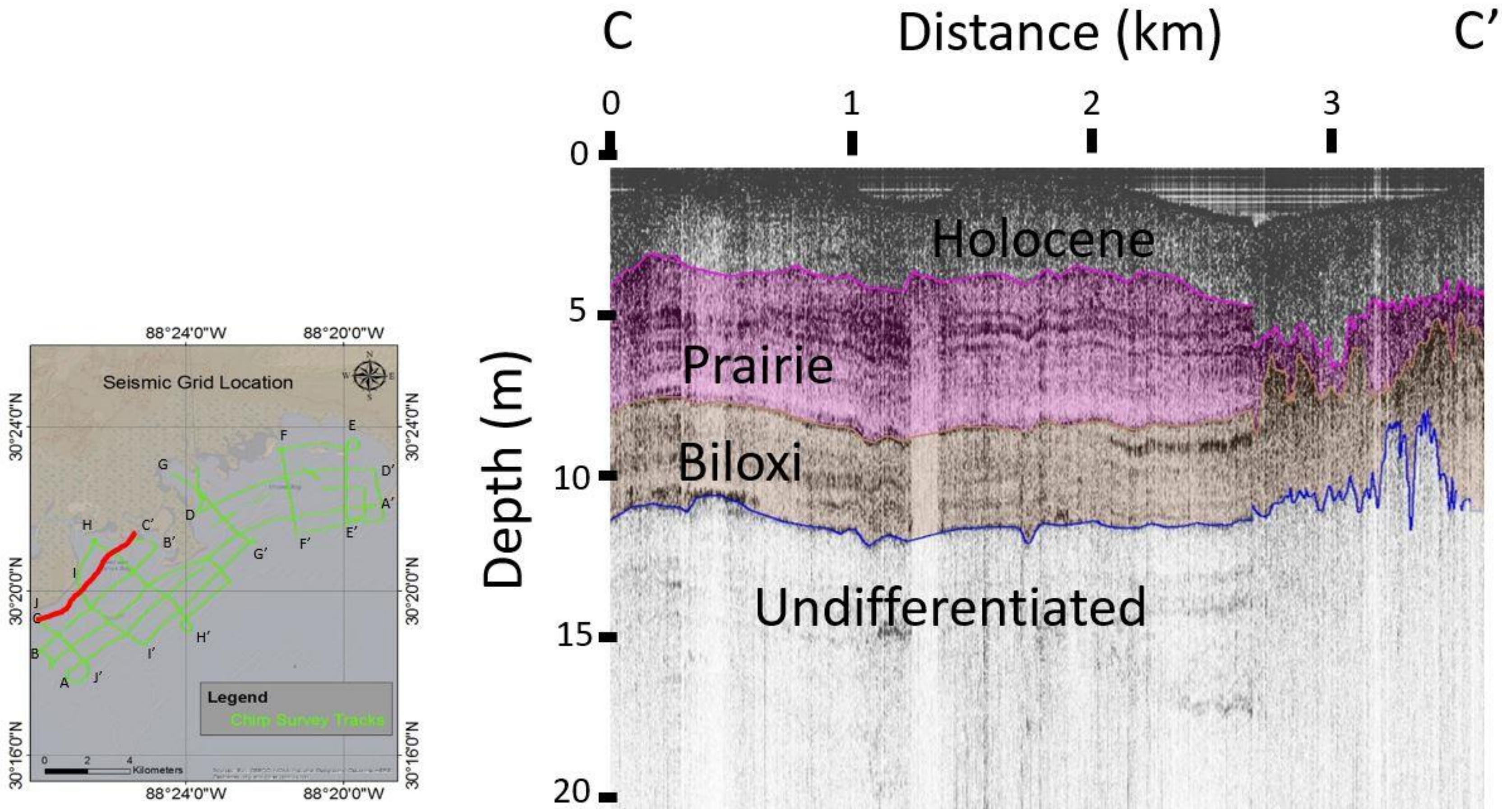


Figure 4.4 Interpreted seismic line C-C'

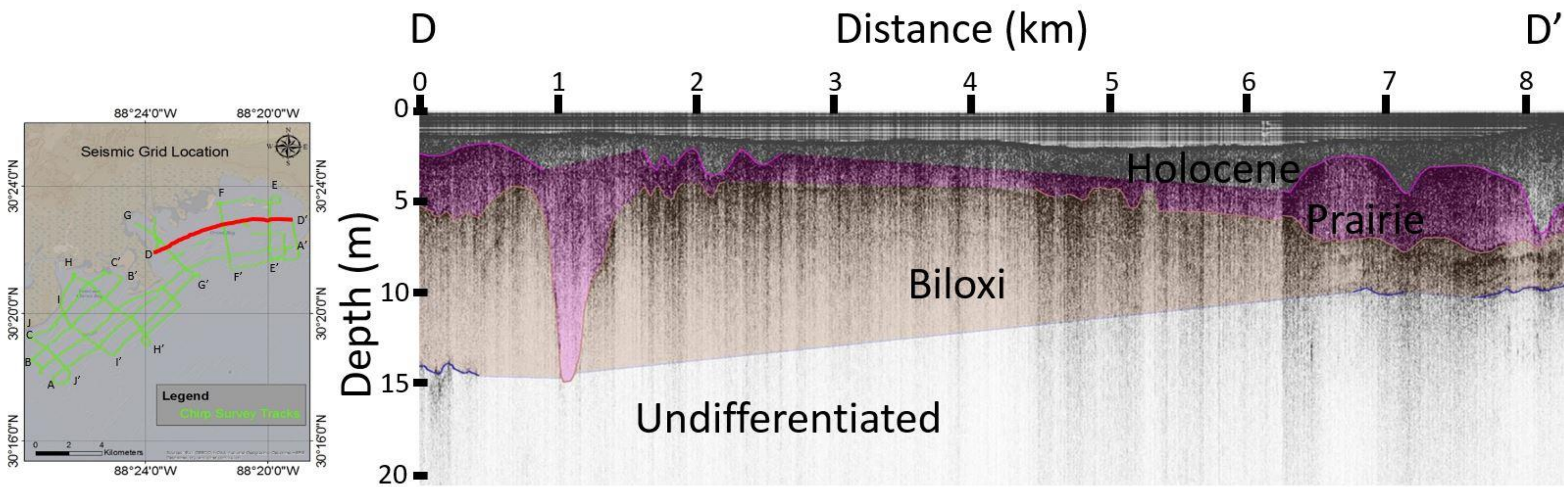


Figure 4.5 Interpreted seismic line D-D’

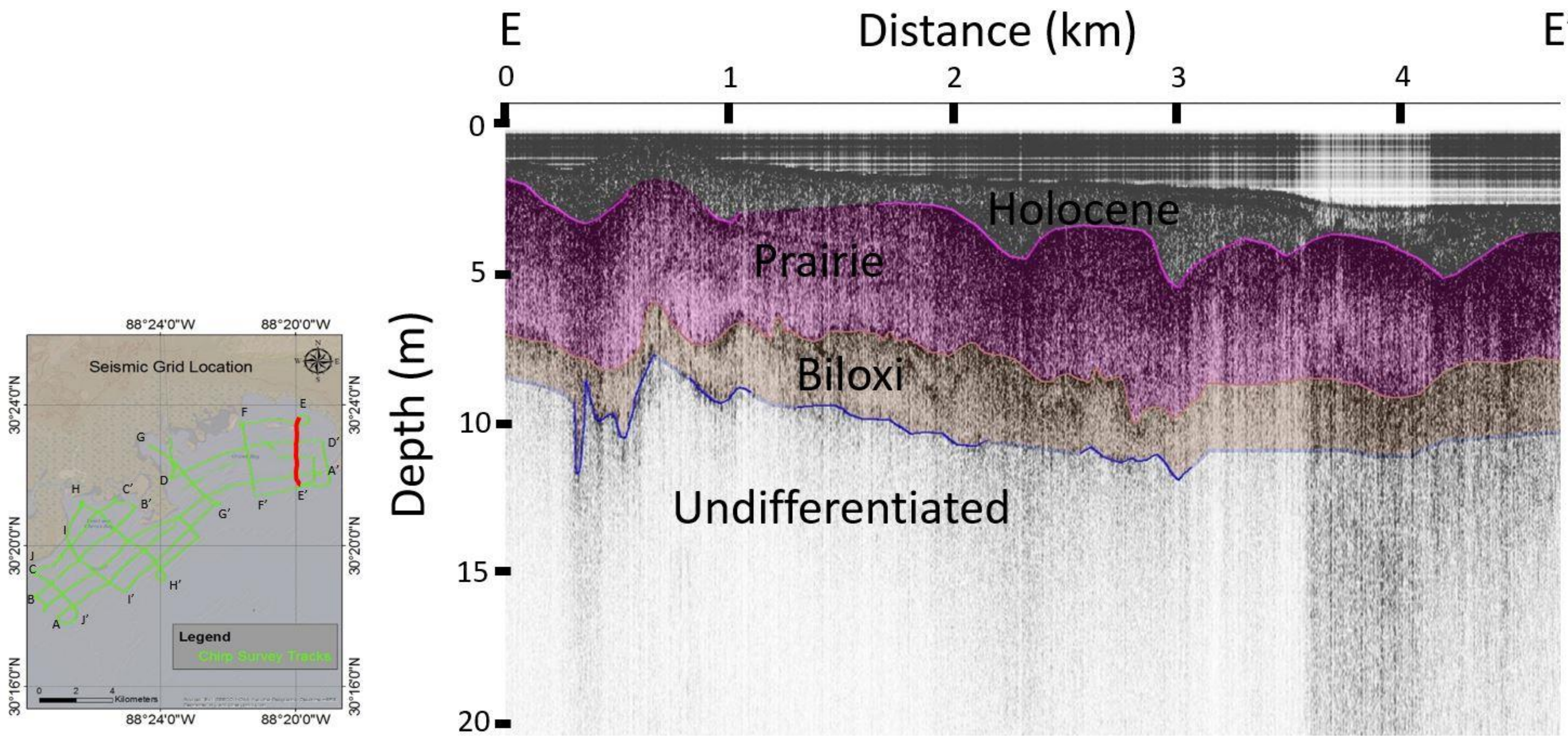
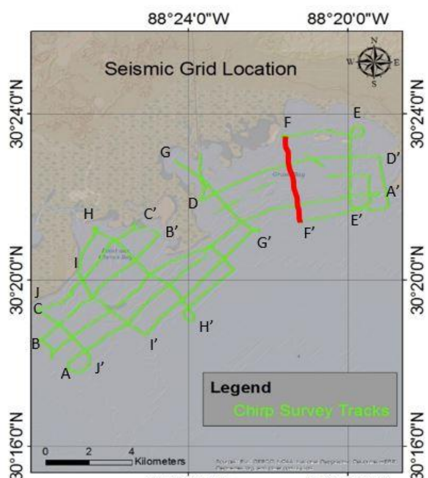


Figure 4.6 Interpreted seismic line E-E'



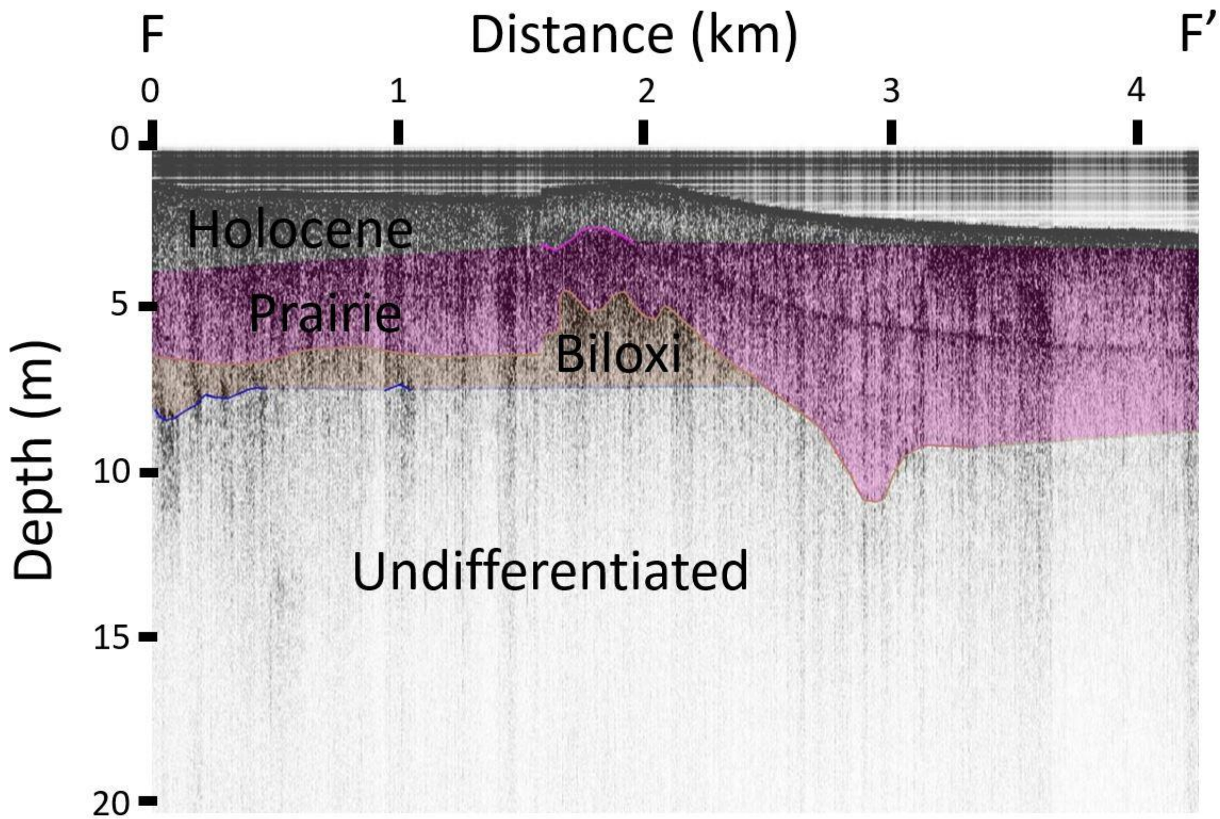
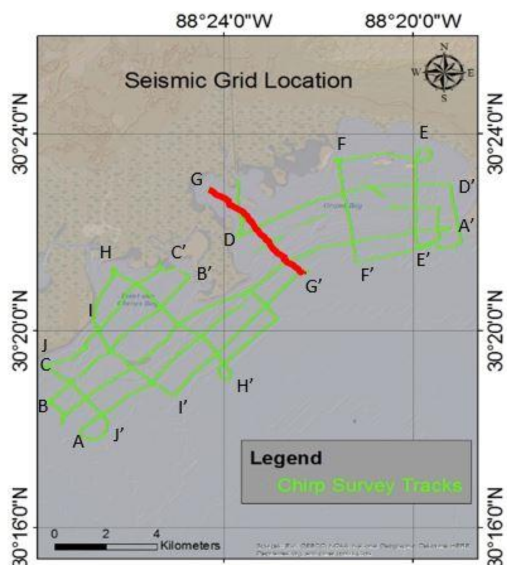
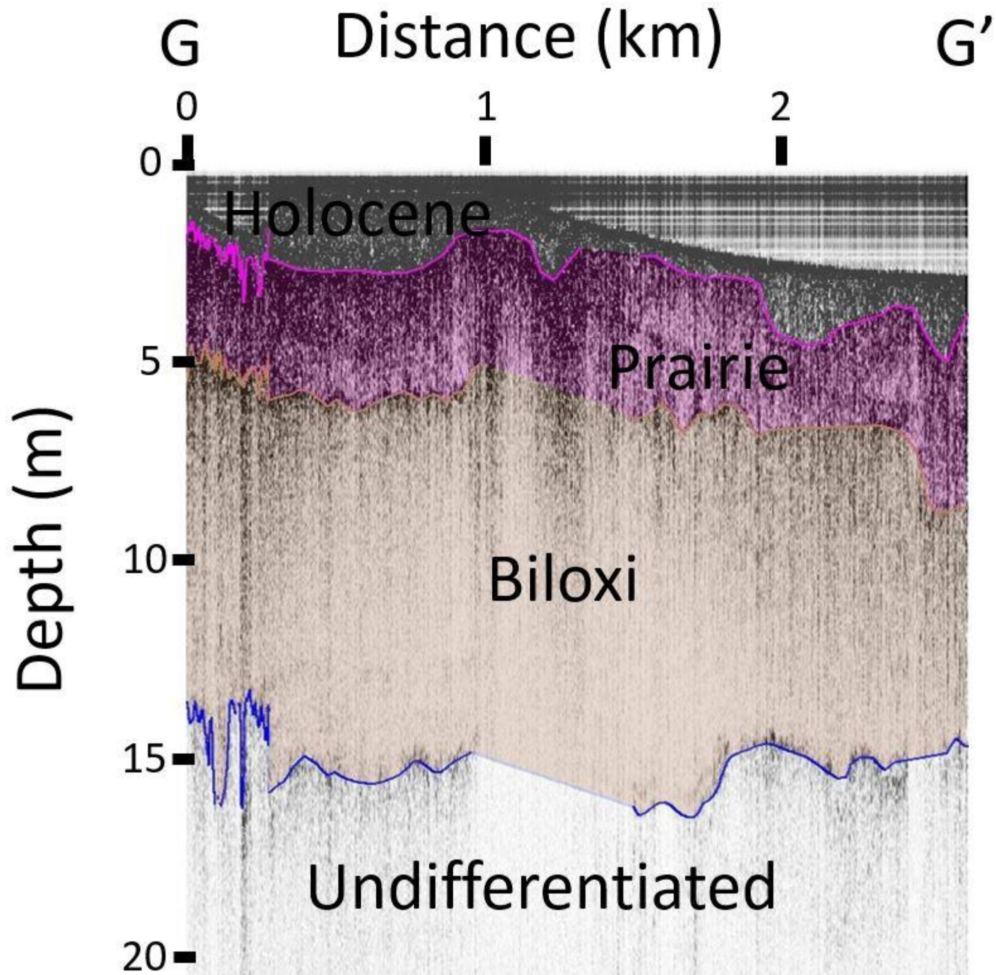


Figure 4.7 Interpreted seismic line F-F'





55

Figure 4.8 Interpreted seismic line G-G'

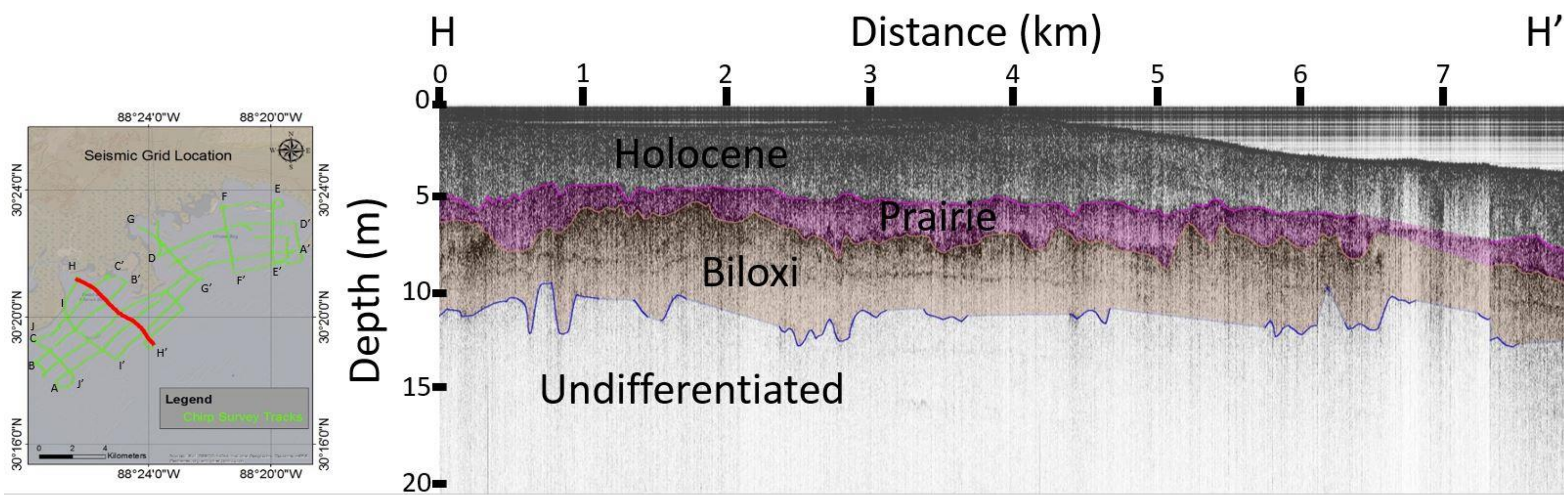


Figure 4.9 Interpreted seismic line H-H'

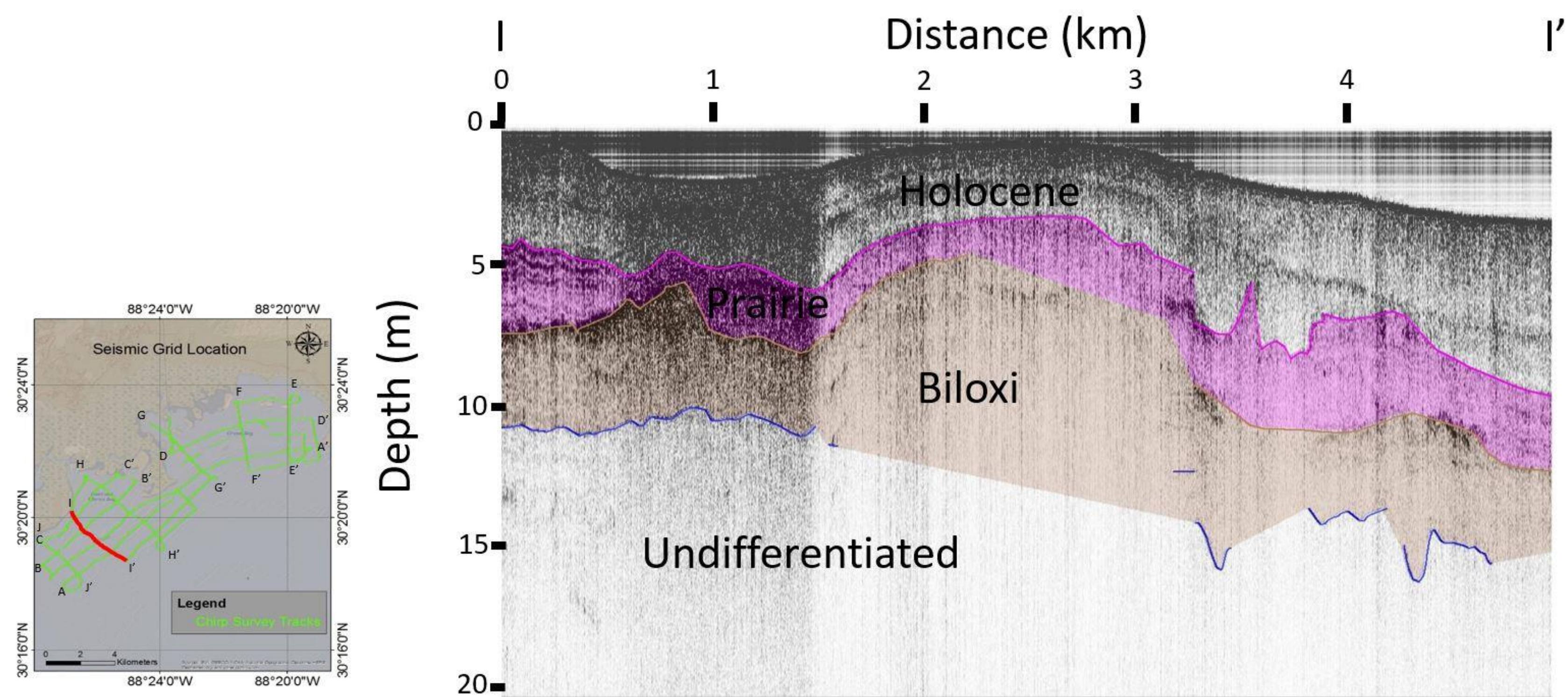


Figure 4.10 Interpreted seismic line I-I’

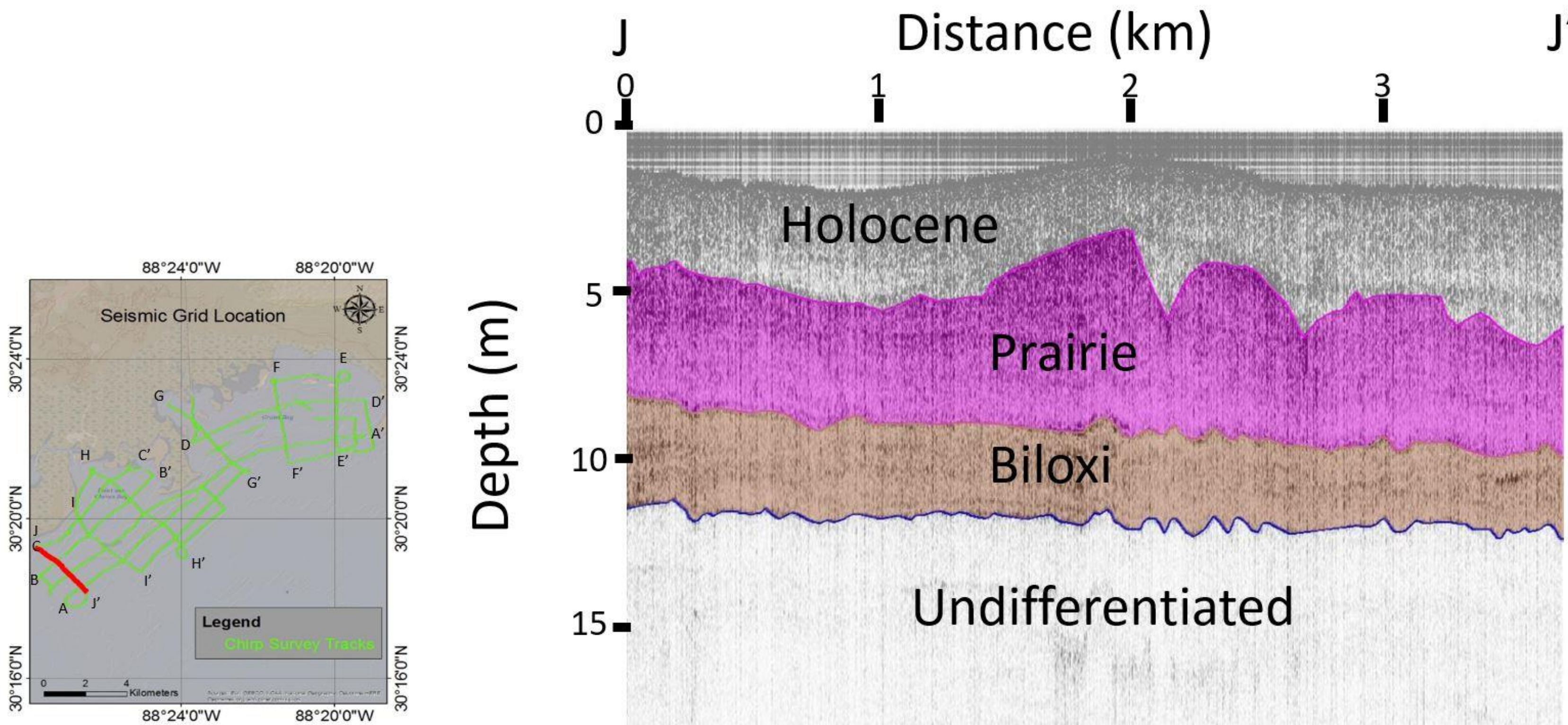


Figure 4.11 Interpreted seismic line J-J'

Depth maps

Four depth maps were generated from the selected horizons. The first "depth map" created was a bathymetry map of the seafloor. This map indicates a general southeastward dipping trend with a strike parallel to shore. The depth to the bottom of the seafloor within the study area of Grand Bay and Pointe Aux Chenes Bay range from approximately 1m near shore to 2.5m seaward beyond the Grande Batture Shoals. (Figure 3.8)

The next map created was a topographic map of Horizon One. Horizon One is the deepest continuous reflective surface recorded within the seismic data. The Horizon One depth map illustrates a deepening of the horizon to depths near 14m due east of the protruding deltaic headland and landward of the eastern Grande Batture Shoals within Grand Bay. Two topographic highs rest within Point Aux Chenes Bay. The first is located landward of the Grande Batture Shoals. The second is positioned beneath coastal marshland located west and landward of the relic deltaic headland. The depth range of Horizon One is 14 m to 10 m. (Figure 3.5)

Horizon Two was the second horizon to be mapped. The Horizon Two depth map indicates that Horizon Two ranges from approximately 5 m to 11 m in depth. Horizon 2 deepens seaward to the southwest and shallows landward to the northeast. There are two locations where the horizon exceeds 10 m in depth. The most notable is located 1km to 1.5km seaward, of the protruding deltaic headland. The other area with depth exceeding 10m is located approximately 1km seaward of the western Grande Batture shoals near the point where cross sections A-A' and I-I' meet. The areas where

Horizon Two is shallowest is located at the eastern most extent of the Horizon Two depth map within Grand Bay. The shallowest area is less than 5 m deep (Figure 3.6).

The final depth map created was a topographic surface of Horizon Three. This map indicates that Horizon Three ranges between 2 m and 6 m. Two areas of notable depth increase exist along Horizon Three. The most notable depression is located approximately 1km seaward of the relic deltaic headland and extends to a depth of 5m. The second deepest area is located 0.5 km to 1km seaward of the western Grande Batture shoals. Interestingly, the deepest areas of Horizon Three overly the deepest areas of Horizon Two. The shallowest area of Horizon Three is 2 m in depth and is located approximately 0.5 m due east of the protruding deltaic headland within Grand Bay. Horizon Three dips to seaward in a southwest direction within the study area. (Figure 3.7)

All horizons, including the seafloor, dip in roughly the same seaward direction. Each horizon shallows into Point Aux Chenes Bay specifically along the western shore of the bay. The horizons are also similar in that each horizon deepens just seaward of the southern Grand Batture shoals. Both Horizons Two and Three deepen in depth significantly just seaward of South Rigolets Island where as Horizon One slopes to the east in the same location. Also, Horizons Two and Three shallow landward in Grand Bay behind the Grande Batture shoals; whereas, Horizon One deepens landward in that area.

Isopach maps

A total of three isopach maps were created to determine sediment thickness between the seafloor and each horizon and between each consecutive horizon. The first isopach map was produced to identify the thickness of sediment between Horizons One and Two. The thickness of sediment between these two horizons ranges from 3 m to 7 m. One area of where sediment thins to 3 m exists beneath the western Grande Batture shoals. The general trend of thickness for the study area is a thickening to the northeast and a thinning to the southwest; however, limited data is available in the eastern extent of Grand Bay. (Figure 3.12)

An isopach map was created for the thickness of sediment between Horizons Two and Three. The thickness of sediment between these two layers ranges from 3 m to 6 m. The area where sediment is thickest, 6 m, is located approximately 1.5 km seaward of the protruding relic deltaic headland. The thinnest area is located along the northern and western shores of the Pointe Aux Chenes Bay. The general trend for this section is a thickening seaward and a thinning in a general landward direction. (Figure 3.13)

The final isopach map created was from Horizon Three to the seafloor. The isopach map is similar to the Horizon Three depth map in that it thins in areas where the map is the most shallow and thickens in areas were the horizon is deepest. The sediments atop of Horizon Three thicken to the southwest. They are particularly thin, less than 2 m thick, and located 1.5 km to 2 km south of the relic deltaic headland. However, the sediment thickness reaches 3.5 m 1 km south east of the relic deltaic headland in the same location as the topographic low seen in the Horizon Three depth map. Another thin area of 1m is found 1 km east of the relic deltaic headland. The thickness for this sediment ranges from 1 m to 5 m within the study area. (Figure 3.9)

Depth below seafloor maps

Three maps illustrating the depth below the seafloor were also created. The first map created was the depth of Horizon One below the seafloor. Horizon One to the sea floor consisted of two areas shallower than 10m beneath the seafloor. The first is located less than 0.5km landward of west Grande Batture shoals in Pointe Aux Chenes Bay. The second is located just within the marsh west and landward the relic deltaic headland. The deepest area below seafloor is located along the eastern Grande Batture shoals. The deepest portion of this horizon is located within Grand Bay and shallows to the northeast and southwest. The maximum depth, below seafloor, found in the study area is 13 m while the shallowest is 8 m. (Figure 3.11)

The next map created included the sediments from the seafloor to Horizon Two. The Horizon Two to seafloor is similar in appearance to the Horizon Two depth map. The sediments deepen below the seafloor in areas where Horizon Two is the deepest and shallow in areas where the horizon is the shallowest. The areas of maximum depth below the seafloor, greater than 8m, are found 1km seaward of western Grande Batture shoals, and 1km to 1.5km seaward of the relic deltaic headland. The areas where the sediments above Horizon Two are the thinnest is located west the protruding relic deltaic headland, within Grand Bay. Overall the sediment overlying Horizon Two thin to the northeast and thicken to the southwest. The maximum depth below the seafloor is 8m while the minimum depth is 4m within the area of study. (Figure 3.10)

The final depth to seafloor map to mention is Horizon Three to seafloor. This map is the same as the Horizon Three isopach map, which is described earlier in this work.

Paleochannels

Paleochannels were identified from seismic surveys produced in Pointe Aux Chenes Bay and Grand Bay, Mississippi. The channels were cataloged in an excel work book based on the horizon they were associated with and the level of confidence that the feature was truly a channel deposit. A total of 115 channels were Identified. Of the 115 channels 23 were associated with Horizon One, 36 were associated with Horizon Two, and 56 were associated with Horizon Three. Horizon One consists of 10 A-type channels, 8 B-type channels, and 5 C-type channels. Horizon Two consists of 18 A-type channels, 13 B-type channels, and 5 C-type channels. Horizon Three consists of 17 A-type channels, 28 B-type channels, and 12 C-type channels. The channel locations were plotted into ArcMap. The maximum spatial density of channel deposits associated with Horizon One are located in Middle Bay and just offshore of the relic deltaic headland. There are also channel deposits located due south of the relic deltaic headland (Figure 3.17). The paleochannels linked to Horizon Two flank the eastern and western shores of the relic deltaic headland (Figure 3.18). Finally, paleochannels linked to Horizon Three greatest frequency occur between Marsh Isle and Sandy Bay (Figure 3.19). The paleochannels in all horizons paleochannels cut through East/West seismic surveys more frequently than north/south trending seismic surveys.

Historical shorelines

A total of 3 ArcGIS coastline change maps were created using the DSAS tool. Additionally, 17 coastline change plots were created in excel. The ArcGIS maps included End Point Rate Maps (EPR) (Figure 4.12), Linear Regression Rate (LRR) (Figure 4.13), and R^2 Coefficient (LR2) maps (Figure 4.14). Results from analyzing the ArcGIS shoreline maps indicate in both Figure 4.12 and 4.13 an average retreat rate of 2 m/yr to 0 m/yr. The greatest degree of retreat along Grand Bay shoreline is the western portion of South Rigolets Island which experienced EPR of more than 8 m/yr of shoreline loss and LRR of greater than 6 m/yr of shoreline loss. Other areas of higher shoreline retreat rates are in Jose Bay and in the far western extent of the study area just west of Pointe Aux Chenes Bay. The shoreline change rates vs. transect distance plots were created plotting R^2, LRR, and EPR against transect distance for each established baseline. These images help to offer another visual aid to show the same results from the ArcGIS shoreline maps.

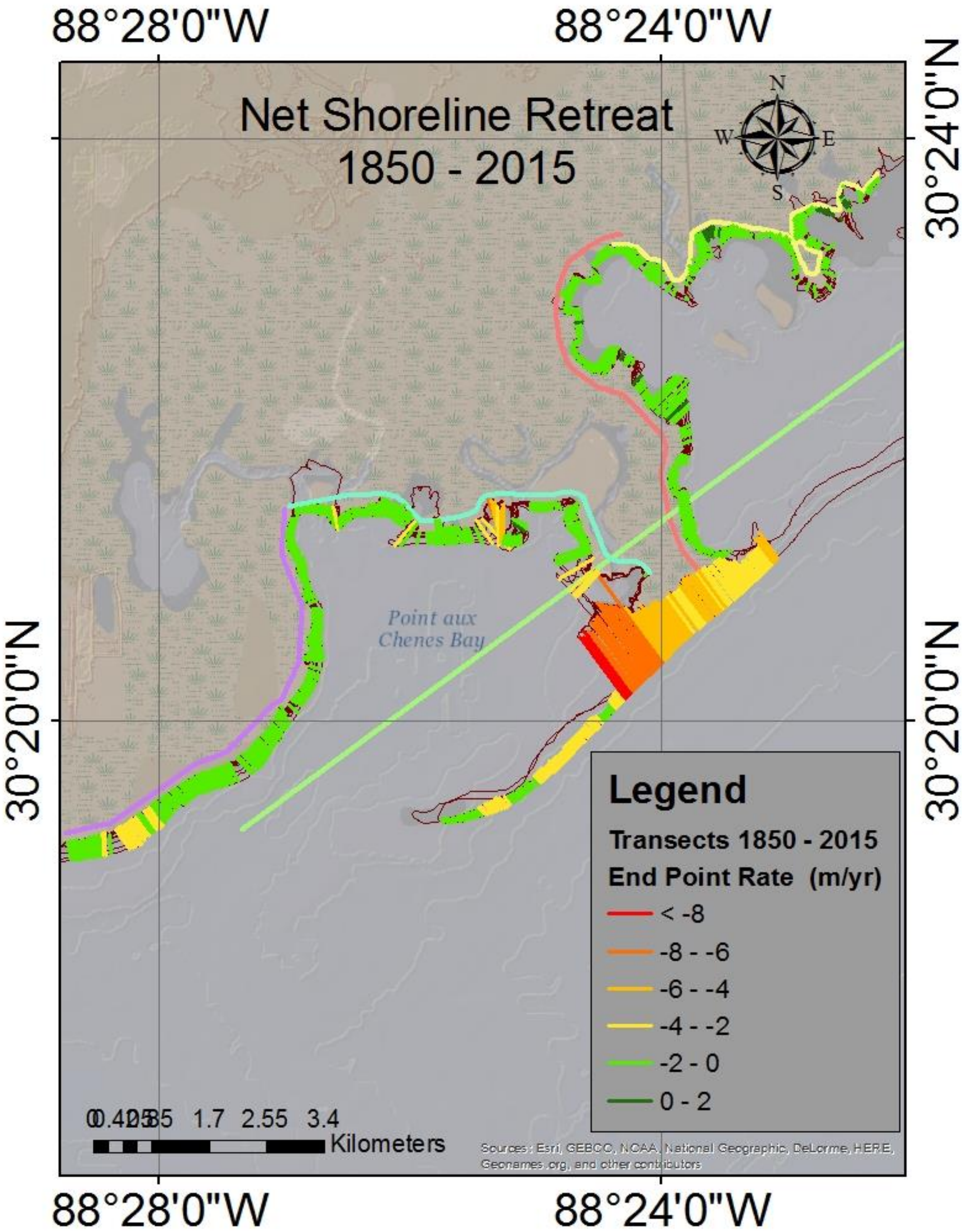


Figure 4.12 End point rate of net shoreline retreat

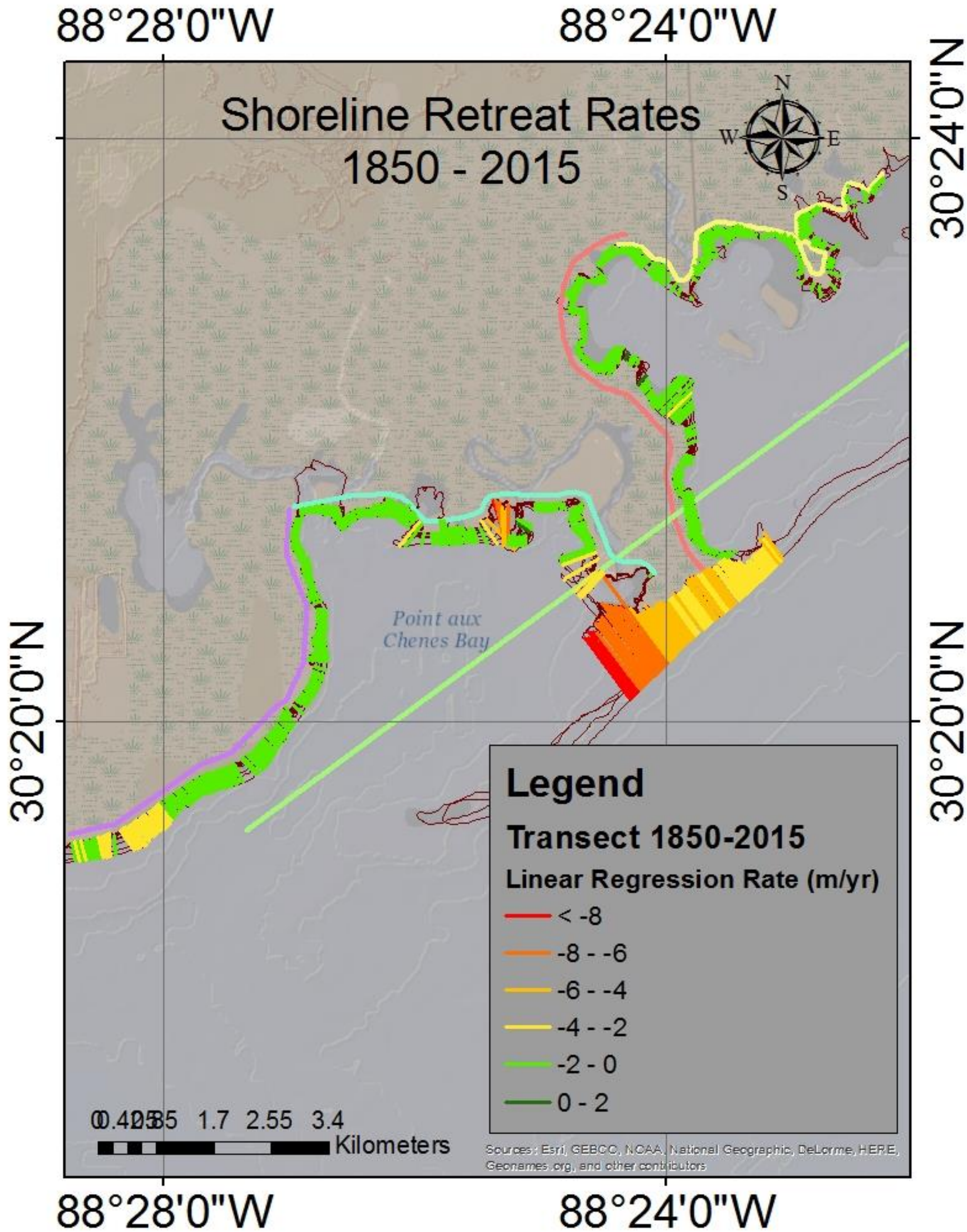


Figure 4.13 Rate of retreat determined by linear regression

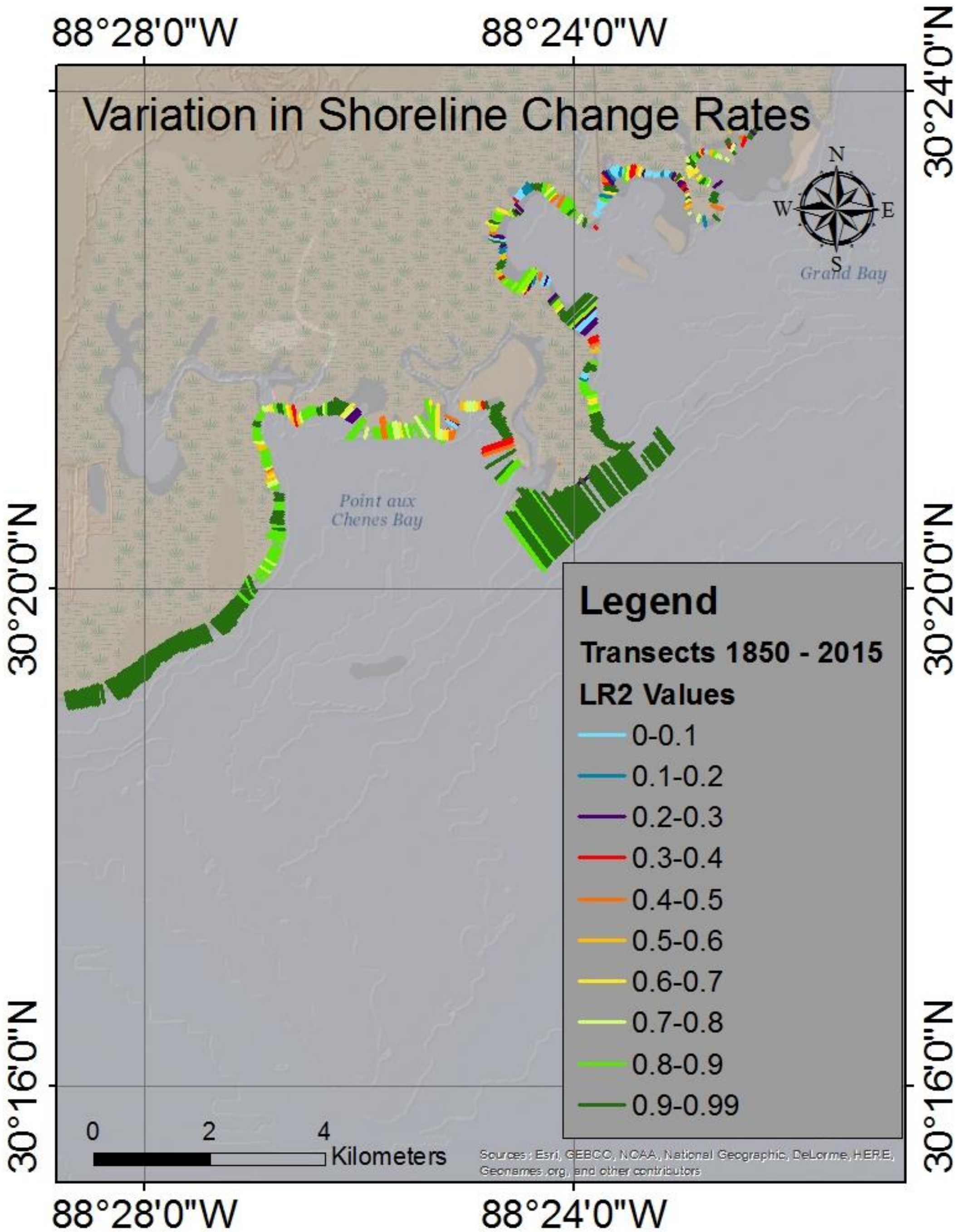


Figure 4.14 Variation of shoreline change

Paleochannels vs. shoreline change rates

Six maps were created which plotted both shoreline change and location of paleochannel deposits (Figures 4.15-4.20). Specifically, LRR and LR2 maps were plotted with paleochannel location. Paleochannels associated with Horizon One plotted near a point of the relic deltaic headland that experiences LRR of 2-6 m/y of shoreline retreat and R^2 values of 0.9-1.0. In the northwest corner of Grand Bay where the paleochannels extend under the shoreline we find no significant difference in the rate of change from the rest of the area (Figures 4.15 and 4.18). Paleochannels associated with Horizon 2 plotted at points along South Rigolets Island and Jose Bay experiencing LRR of greater than 4 m/y of retreat. Additionally, the same locations had lesser R^2 values of 0.70 to 0.90 (Figure 4.16 and 4.19). Horizon Three channels could be correlated with areas of South Rigolets experiencing LRR of > 4 m/y retreat. Additionally, it could be argued that an area experiencing > 4 m/y of shoreline retreat along western Pointe Aux Chenes Bay is associated with Horizon Three paleochannel deposits located farther off shore because the paleochannel lie directly perpendicular to the shoreline that is experiencing the higher rates of retreat (Figure 4.17-4.20). The most frequently experienced coastal retreat rates within the study area were from 0 to 2 m/y; however areas associated with paleochannel deposits tended to have higher coastal retreat rates of > 4 m/y.

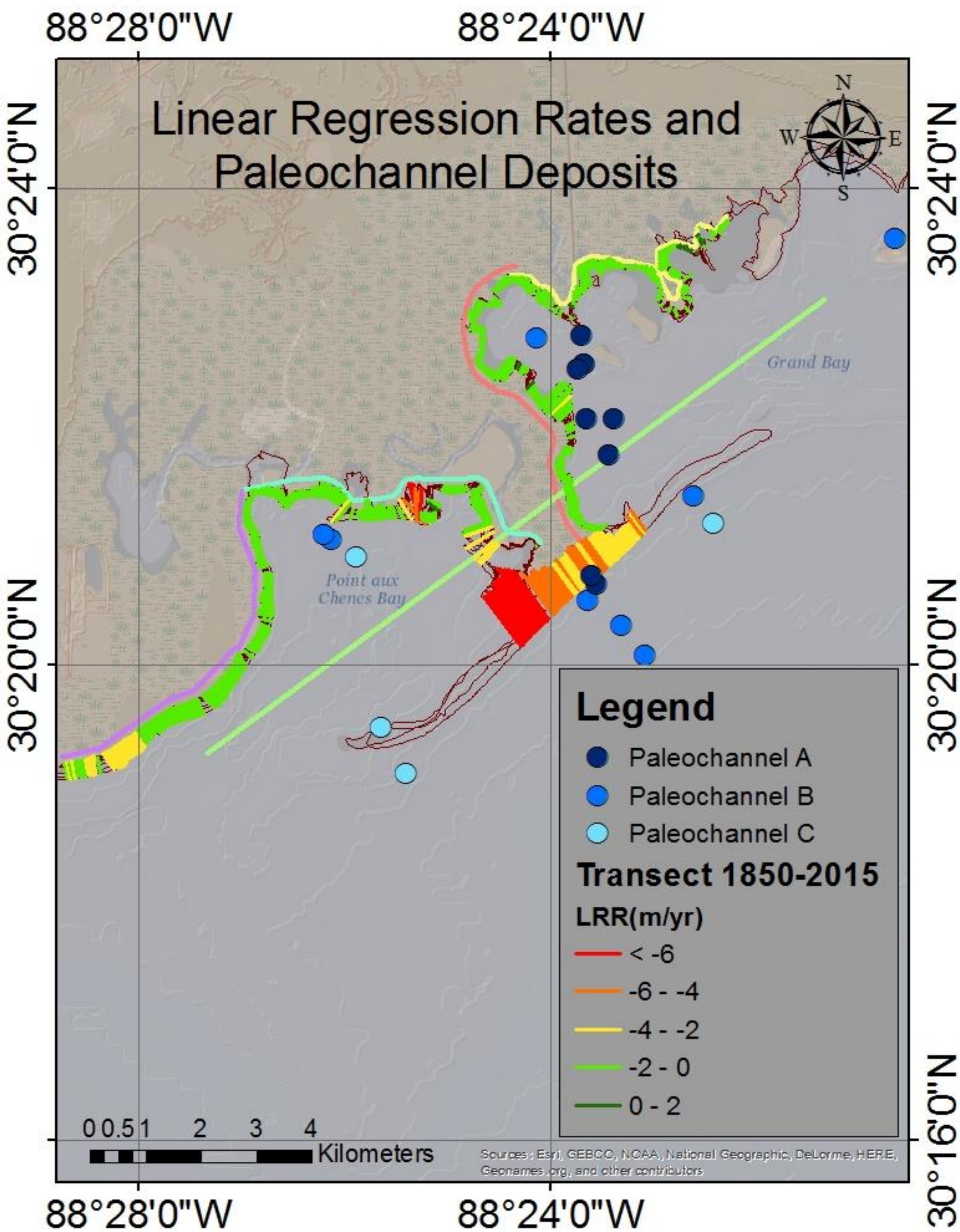


Figure 4.15 Horizon One paleochannel deposits and shoreline retreat

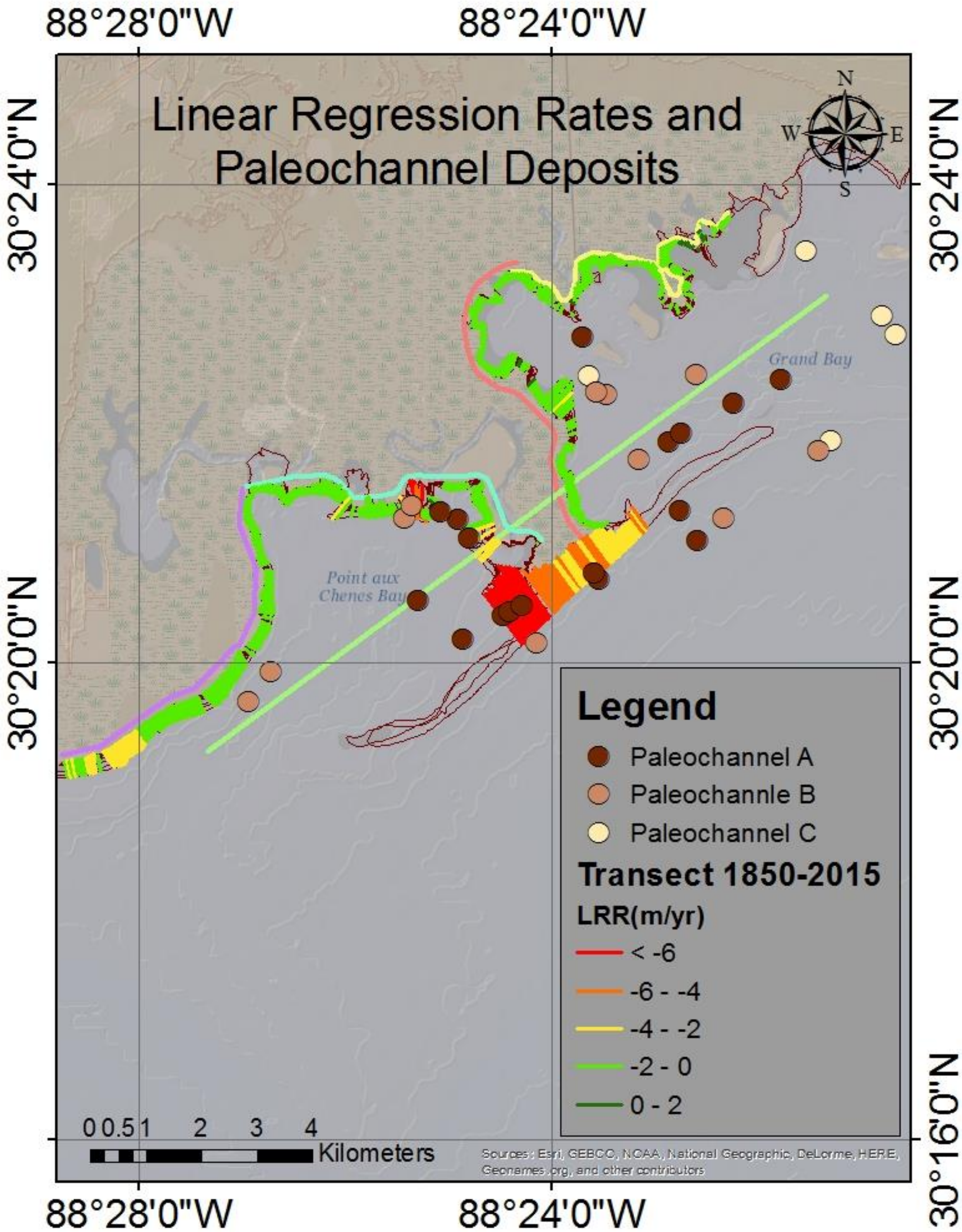


Figure 4.16 Horizon Two paleochannel deposits and shoreline retreat

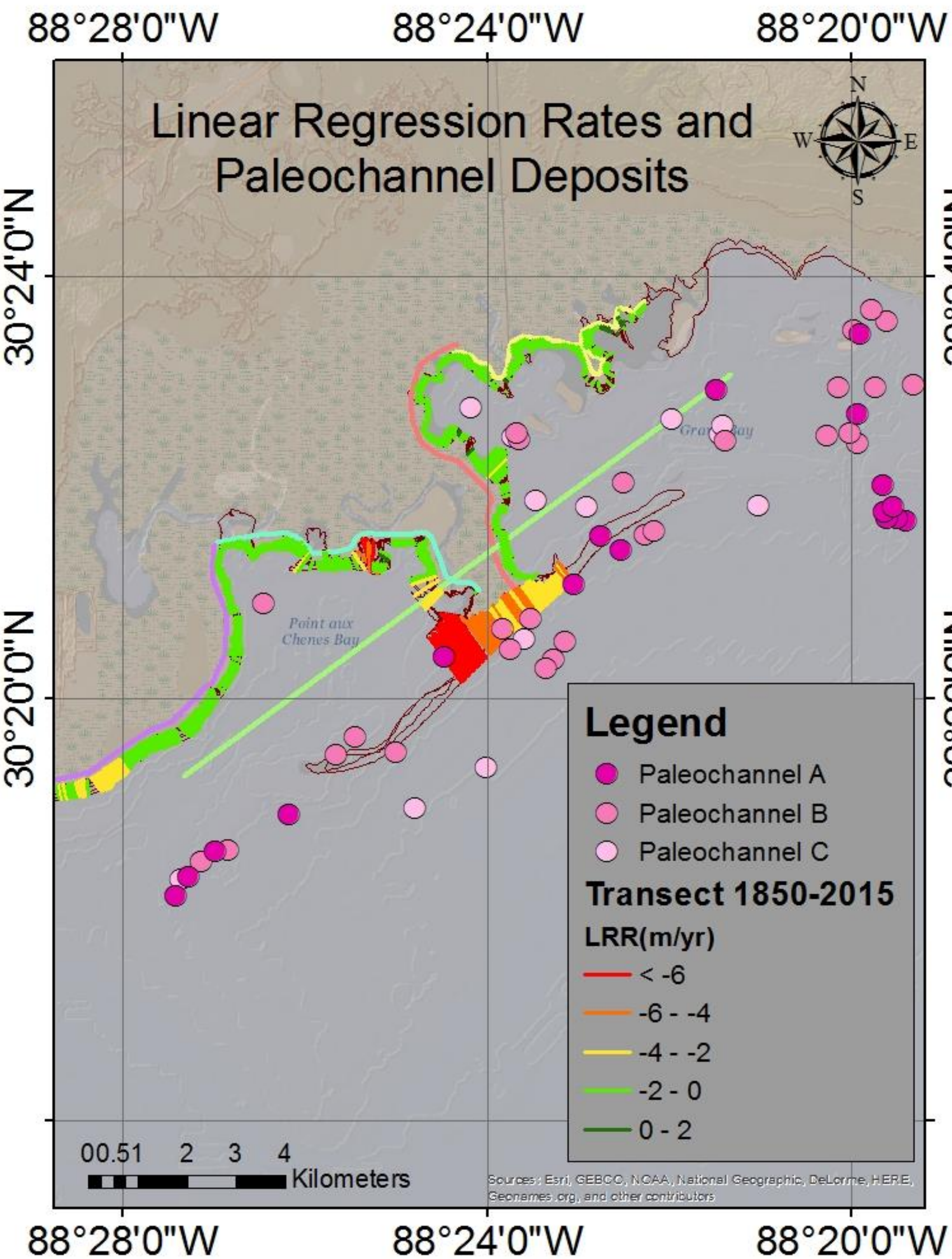


Figure 4.17 Horizon Three paleochannel deposits and shoreline change

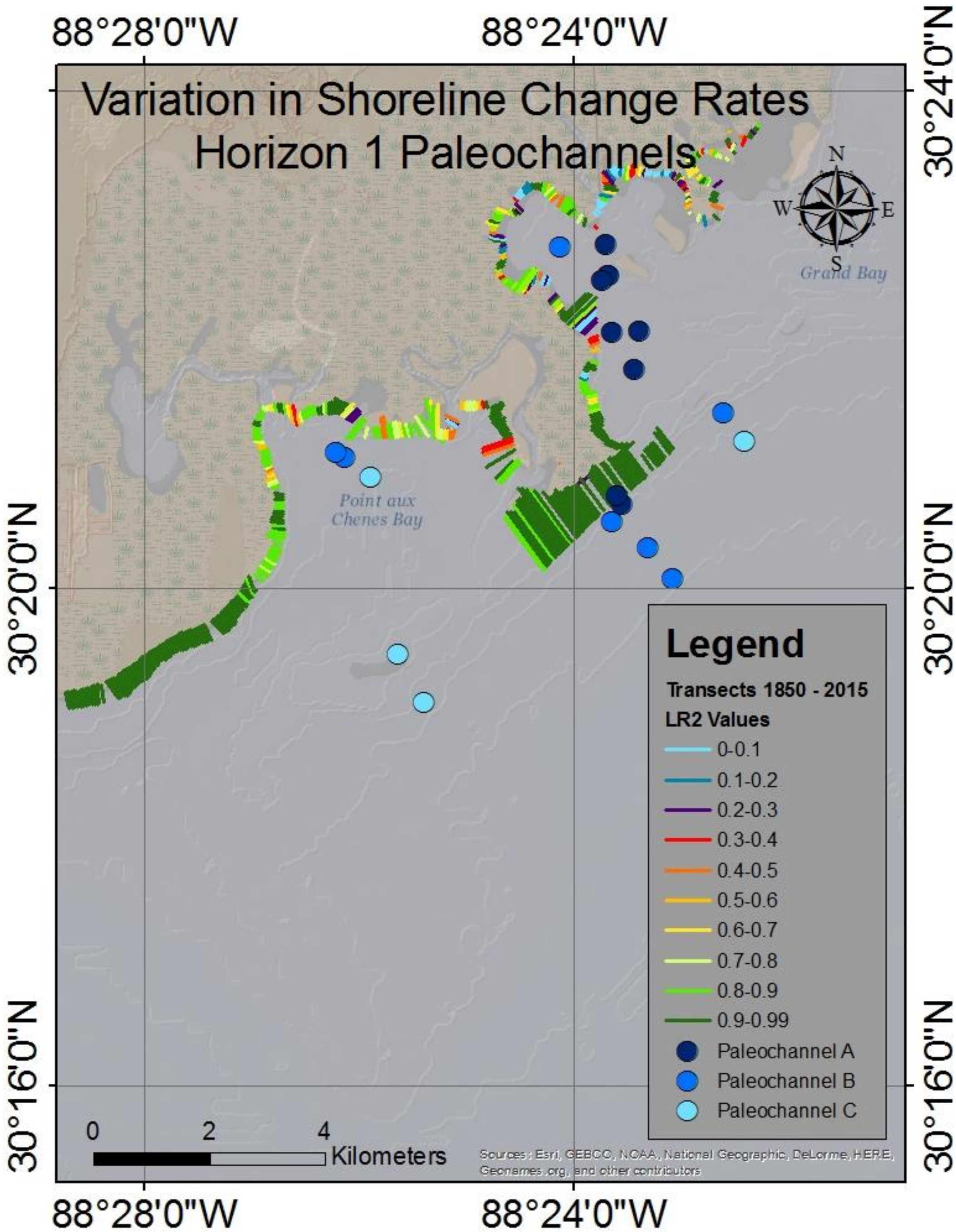


Figure 4.18 Horizon One paleochannels and shoreline variation

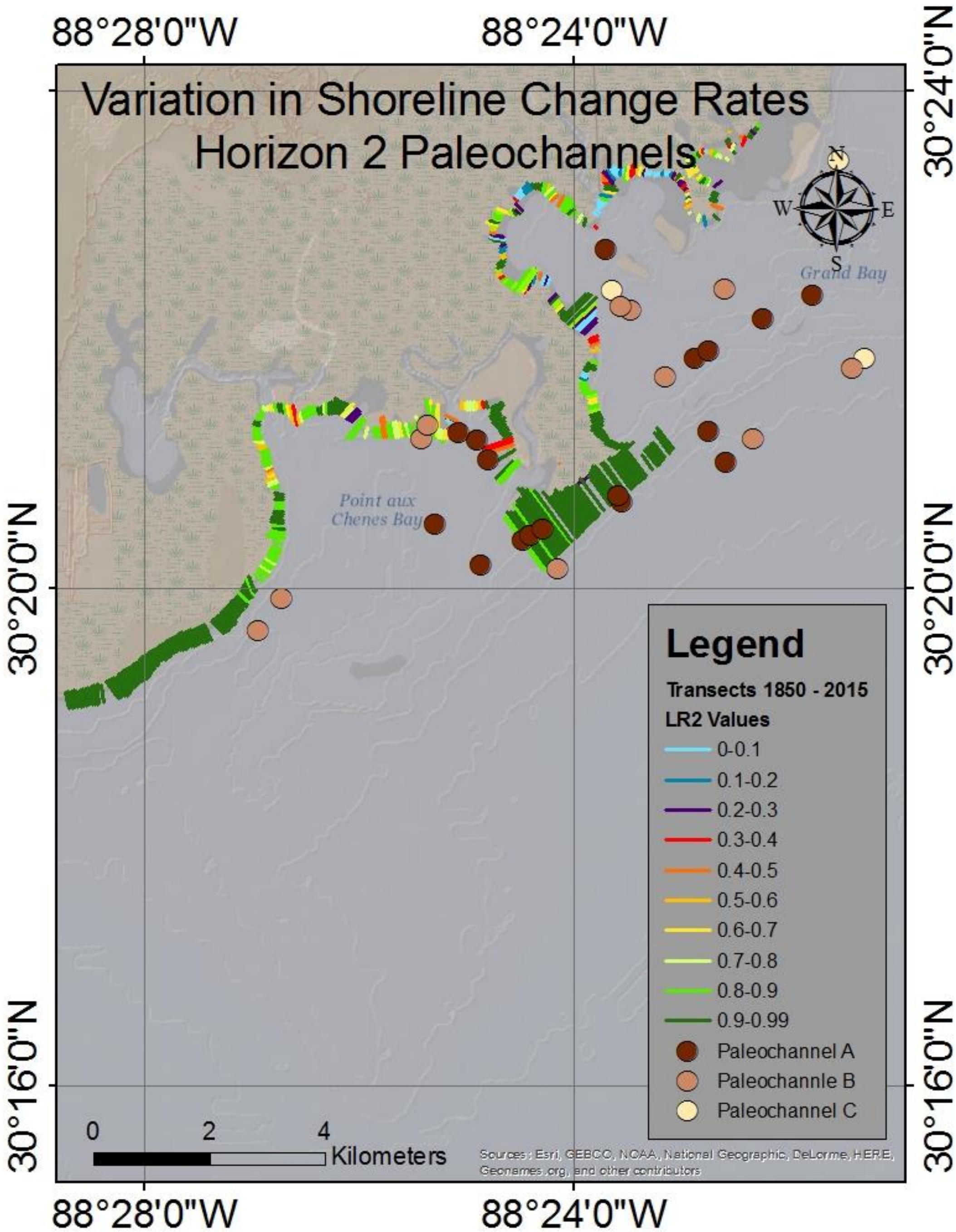


Figure 4.19   Horizon Two paleochannels and shoreline variation

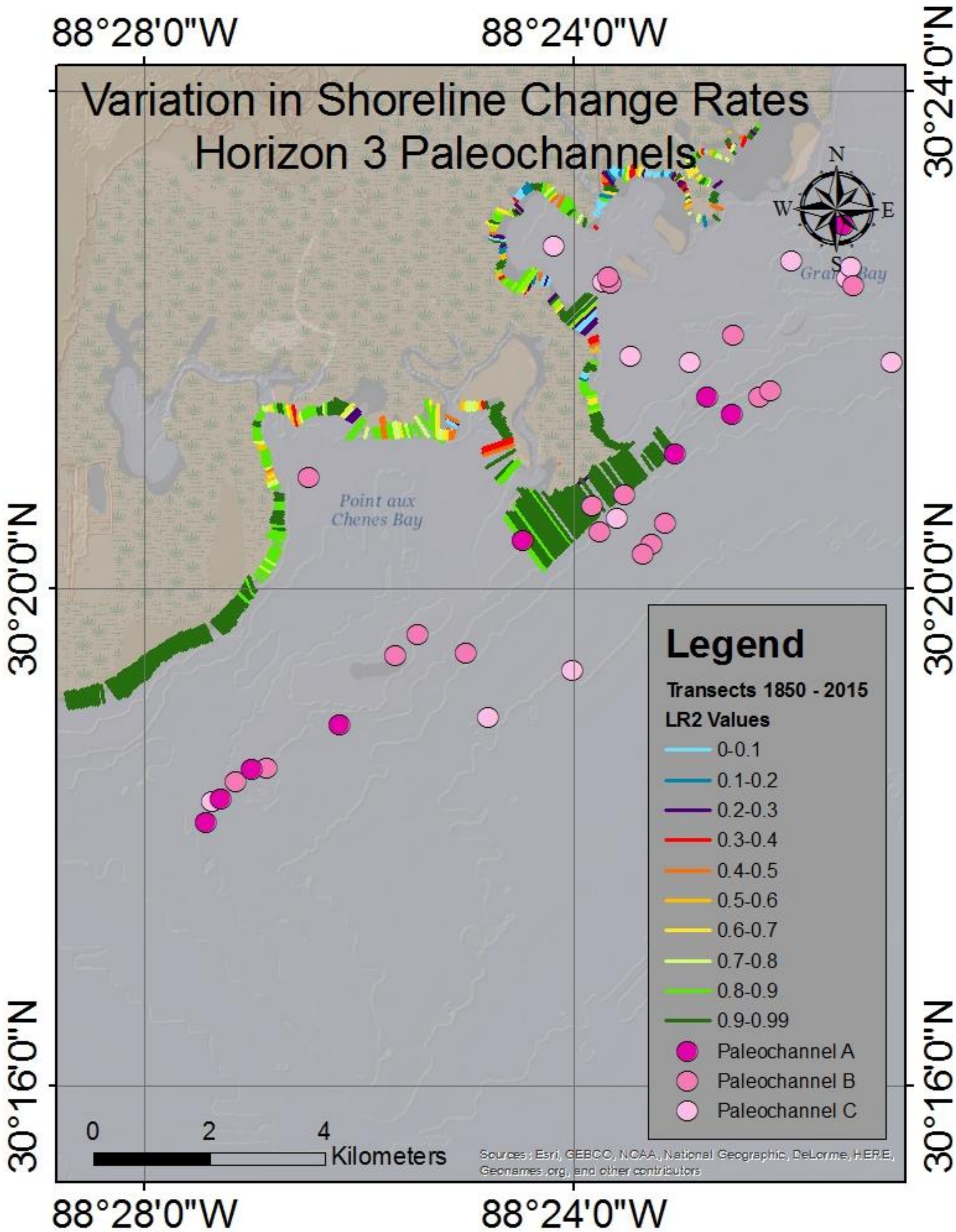


Figure 4.20 Horizon Three paleochannels and shoreline variation

CHAPTER V

DISCUSSION

Geologic interpretation of Grand Bay

Transgression/regression

This study sought to understand how the shallow subsurface stratigraphy of the study area has contributed to variations in modern coastal morphology and shoreline retreat rates. Therefore, an understanding of sea level transgression and regression cycles is pertinent to this study. Because the oldest geologic formation outcropping near the study area is of Late Pliocene age an understanding of regional sea level from Early Pleistocene to Holocene was conducted through literature search. It is known that the Pleistocene experienced numerous sea level highstands and lowstands caused by glaciation (Donoghue, 2011; Hearty et al., 2007; Lambeck and Chappell, 2001; Peterson et al., 2007). Sometime before the last interglacial period marked a period of sea level fall that left an erosional unconformity on the underlying sediments described as undifferentiated Early Pleistocene to Late Pliocene (Donoghue, 2011; Lambeck and Chappell, 2001; Mississippi Department of Envronmental Quality, 1994; Otvos, 1985). During the Last Interglacial, 130-118 ka, the Gulf coast experienced rapid transgression, with a sea level slightly higher than that of today (Donoghue, 2011; Hearty et al., 2007; Lambeck and Chappell, 2001). This period marked the deposition of the clay rich Biloxi Formation. During the end of the L sea levels once again began to regress, depositing the

Prairie Formation, with the onset of the last glacial maximum (Kramer, 1990; Mississippi Department of Envronmental Quality, 1994; Otvos, 1985; Peterson et al., 2007). Finally, with the end of the LGM sea level began to rise until it reached its present level approximately 7 ka (Törnqvist et al., 2004). (Figure 5.1)

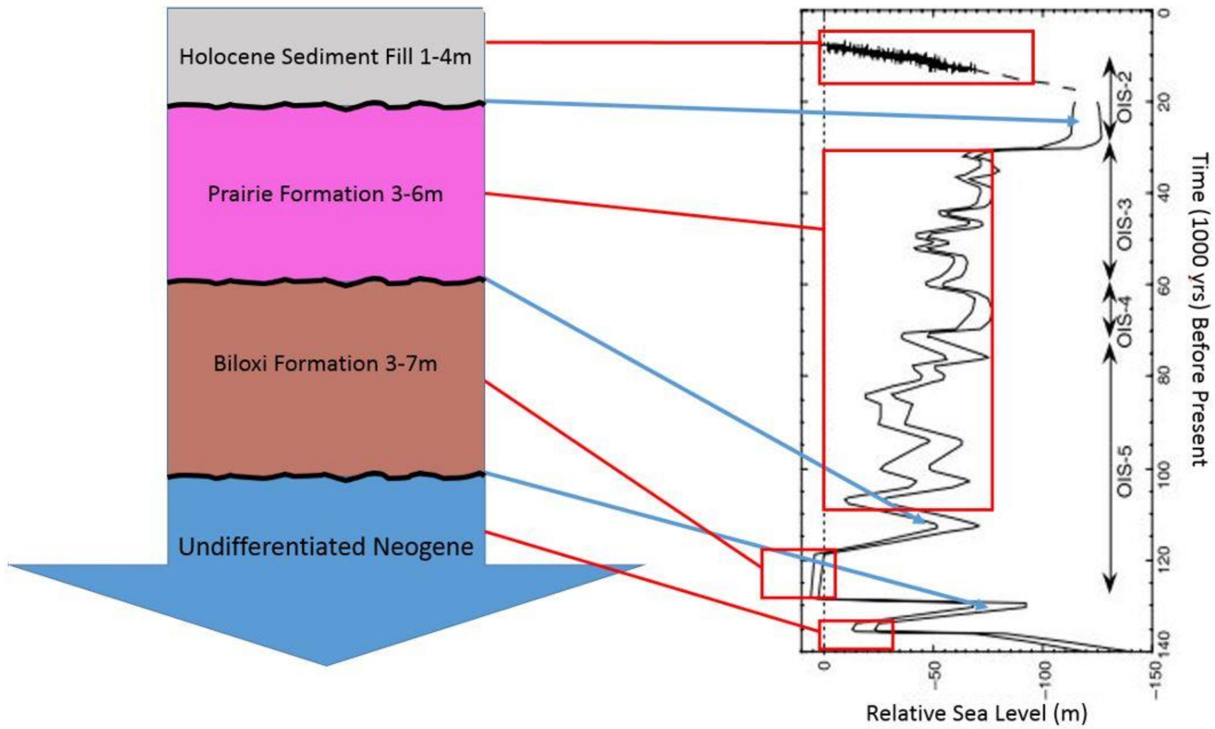


Figure 5.1 Depositional History

Modified from (Lambeck and Chappell, 2001). Image depicts approximate times of deposition for each of the formations within the study area.

The afore-mentioned regressive and transgressive cycles can be used to explain unconformities found within the subsurface of the study area. Within the study area there is evidence of three unconformities. The most recent unconformity, located 1 m to 4 m below the surface has been labeled Horizon Three. Horizon Three is interpreted as the Pleistocene/Holocene boundary. The erosional unconformity indicates subaerial exposure, possibly caused by regression during the last glacial maximum. Sediment core collected on marshland in the southwest corner of the Grand Bay National Estuarine Research Reserve was logged and interpreted by the MDEQ. The interpretation of 2 of the 5 cores taken indicate a contact between the Holocene and the Pleistocene to be between 1.5 m and 5 m the remaining 3 sediment core interpretations indicate that the Pleistocene units outcrop on the land surface (Figure 3.3). Additional core data from MDEQ extracted in the Mississippi Sound south of Grand Bay indicates a depth to the Pleistocene surface at approximately 4m below the surface of the seafloor (Figure 3.3). Finally, a southward trending cross section from Pointe Aux Chenes Bay to Petit Boise Island produced by (Otvos, 1985) indicates a shallowing of the Pleistocene-Holocene contact landward. The MDEQ core coupled with Otvos' cross section, in conjunction with the location of Horizon Three, which can be traced between 1 m and 4 m below the seafloor, suggest that Horizon Three is the Holocene/Pleistocene boundary in this area.

Horizon Two is located between 4 m and 8 m meters below the seafloor. This unconformity most likely occurred before the deposition of the Prairie Formation post the Last Interglacial (LIG) high stand. MDEQ collected in the marsh east of Pointe Aux Chenes Bay indicate a sharp contact between 3 m and 5 m. The shallowing landward of the contact was anticipated and illustrates a sigmoidal architecture expected as sediments thicken seaward. This contact was interpreted as the contact between the Prairie-Biloxi formations. Seismic data collected indicates the contacted between the two formations is erosional. Thus, the contact marks the late LIG highstand during a time of regional regression.

Seismic data indicates a final unconformity, Horizon One, located 8 m to 12 m beneath the seafloor. Core from Chevron RC project show a depth to the undifferentiated Neogene sediments to be approximately 16 m to 18 m in depth from the ground surface. The Mississippi Sound core collected by MDEQ displays the contact between 12 m and 19 m below seafloor. The horizon has been interpreted as the boundary between the Biloxi and Undifferentiated Early Pleistocene/Late Pliocene sediments. The contact represents erosion that occurred prior to the onset of the LIG highstand (Figure 5.1).

Depositional environments

The deepest deposits studied in the area have been interpreted to be late Pliocene to early Pleistocene in age. The late Pliocene, early Pleistocene sediments are nearshore to alluvial deposits indicative of a deltaic setting. They can be differentiated from younger sediment by compaction sometimes referred to as “firm” or “stiff” both by Otvos, (1985) and interpreters of the MDEQ sediment core. The younger, LIG aged, Biloxi Formation was deposited during a marine highstand during the last interglacial time. Shallow marine deposits of the Biloxi Formation underlie brackish lagoonal to estuarine deposits of the same formation. The Prairie Formation, of late LIG to early Wisconsinan age, consists of alluvial to fluvial deposits. The Prairie Formation is indicative of floodplain deposits with meandering streams cutting through out. Finally, the Holocene in the area are indicative of deltaic, fluvial, estuarine, bay, and bayou deposits of the last 11 ka. Interestingly, from the early to mid-Holocene the Escatawpa River drained into the Grand Bay and emptied near present day South Rigolets Island. The Escatawpa built a delta in Grand Bay that, through archeological evidence, has been interpreted to have been in existence prior 2000 years ago. During the last 1000 to 5000 years the Escatawpa was captured by a small tributary of the Pascagoula and began draining east. Lack of sediment supply, a rising sea, and regional subsidence has contributed to the drowning of the delta and the Grande Batture Islands. (Schmid and Otvos, n.d., Otvos, 1985; Kramer, 1990; Meyer-arendt et al., 1991; Envronmental Quality, 1994; Lambeck and Chappell, 2001; Lambeck et al., 2002; Hearty et al., 2007; Mississippi Department of Peterson et al., 2007; Donoghue, 2011)

Unit depth

The uppermost unit found within the study area has been interpreted as deltaic and estuarine deposits of the Holocene. The seafloor marks the upper extent of the Holocene units within the study site. Horizon Three marks an erosional unconformity that marks the Holocene/Pliestocene boundary. The bathymetry of Grand Bay and Pointe Aux Chenes Bay is relatively uniform deepening in a seaward direction toward the Mississippi Sound from 1.25 m to 2.25 m.

The next unit encountered in the study area is marked by the erosional unconformity labeled Horizon Three. This horizon is interpreted as the Pleistocene/Holocene boundary and indicates the top of the Prairie Formation. Depth to the top of the Prairie Formation ranges from 2 m to 6 m. The general trend of Horizon Three is a deepening seaward in a southwest direction, which is to be expected, because sediment tends to deepen and thicken seaward of shore. The deepest locations are found seaward of Pointe Aux Chenes Bay underlying and seaward of the Grande Batture shoals and southeast of the protruding deltaic headland. Both the low area located south of the protruding deltaic headland and Southern Grande Batture shoals. The low area seaward of the protruding deltaic headland appears to be in spatially correlated to paleochannels cross cutting Horizon Three. This observation is what would be expected; distributaries of the now relic delta would have fallowed areas of lower relief as they flowed to sea. It is therefore not surprising that an area of lower relief is associated with channel deposits overlying it. (Figures 3.7 and 3.19)

Horizon Two was the next unconformity to be recognized, and signifies the contact between the top of the Biloxi Formation and the base of the Prairie Formation. Horizon Two ranges from depths of 5 m to 10 m, and, similarly to Horizon Three, deepens overall in a southwesterly direction. Horizon Two is also deepest southeast of South Rigolets and South Grand Batture shoals. Comparable to Horizon Three, Horizon Two also has paleochannels underling the area southeast of the deltaic headland; however, unlike Horizon Three the deepening south of Southern Grande Batture shoals is not in conjunction with paleochannels. (Figures 3.6 and 3.18)

Horizon One was the final unconformity identified within the study area. This unconformity has been interpreted as the base of the Biloxi Formation and the top of undifferentiated early Pleistocene late Pliocene sediment. The depth rages from 7 m to 14 m. Horizon One deepens in a southwesterly direction. The deepest area (14 m) however, is located beneath Grand Bay and is not associated with paleochannel influence. Each Horizon One through Three are all generally dipping to the southwest. However, the seafloor is dipping in a southeast direction. (Figures 3.5 and 3.17)

Unit thickness as it changes horizontally

Holocene sediments bound by the seafloor and Horizon Three range from 1 m to 4 m thickness. The thickest and thinnest areas are located coincident to the deepest and shallowest depths of Horizon Three respectively. Generally the thinnest units are located landward whereas the thickest units are located seaward. The Prairie Formation, bound by Horizon Three and Horizon Two, ranges from 3m to 6m thick (Figure 3.13). It thins landward, particularly near modern river channels. The Prairie Formation thickens in areas just seaward of Southern Grande Batture shoals and South Rigolets Island. The deepening of the Prairie Formation could be indicative of a similar coastline during the late Pleistocene as present day where sediment built up and out where presently the relic delta headland is located. The Biloxi Formation is bound by Horizon Two and Horizon One (Figure 3.12). The Biloxi Formation ranges from 3 m to 7 m thick in the study area and thins in a southwestwardly direction. The thickest area of the Biloxi Formation underlies South Rigolets Isaland.

Links between underlying geology and surface morphology

Paleochannels

Paleochannel deposits that incise Horizon One are interpreted as pre LIG in age. These channel deposits underlie marine and estuarine deposits of the Biloxi Formation. There are 10 very well defined channel deposit that incise Horizon One. Nearly all the well-defined channel deposits can be interpreted as an area where a main paleochannel flowed in a south (seaward) direction along the eastern shore of the protruding deltaic headland. (Figure 3.17)

Paleochannels cutting through Horizon Two are interpreted as regressive deposits following the last interglacial maximum. These paleochannel are associated with the Prairie Formation. Within the study area 18 very well defined paleochannel deposits have been identified. Of the 18 very well defined deposits, 5 have been interpreted as a paleochannel flowing north to south along the eastern shore of North and South Rigolets Islands near the same channel identified in the pre LIG deposits. Another paleochannel identified by 8 channel deposits is located south of Crooked Bayou along the western shore of North and South Rigolets. The additional 5 well defined channel deposits could be relic tributaries or distributaries of the 2 main paleochannels found within this boundary. (Figure 3.18)

The paleochannels that cut through the Prairie Formation are of Holocene age. There are 17 very well defined paleochannel deposits associated with Holocene age sediment. These channel deposits are associated with relic distributaries during the time that the delta was building out in the current Grand Bay area. Interestingly the most recent, Holocene, paleochannels do not spatially correlate to areas along the Grand Bay coast prone to erosion or deposition. However, the older deposits of the Prairie and Early LIG age are spatially correlated to the area of landward of the South Rigolets coast. In fact South Rigolets and the land behind the island are located between paleochannels of Pleistocene age. Where other studies have found paleochannel and antecedent geology spatially correlated to areas of rapid erosion or accretion, this study has found that paleochannels within the Grand Bay area correlate to more permanent geomorphic features. (Figure 3.19)

Four depth maps and five isopach maps were created to better analyze the stratigraphy of the study site, and to correlate the stratigraphy with land surface morphology. The isopach maps and the depth maps produced from horizons 2, 3, and the seafloor all indicate an area of greater depth located seaward of South Rigolets Island this could be caused by Holocene paleochannels fallowing Pleistocene topographic lows and other older channel pathways. Another area of greater depth associated with all maps was an area just seaward of the Southern Grande Batture shoals. This area did not appear to be directly correlated with paleochannels but rather from bed morphology and dip angle. Interestingly historical maps and current maps indicate that areas with topographic lows are located seaward of areas along the shoreline that were the last to experience drowning eg., South Rigolets Island and the western most extent of the former Grande Batture Isands. As stated previously, Holocene aged paleochannel deposits correlate with the areas of greater depth along the Holocene/Pleistocene boundary. The sediment supplied by the relic Holocene channels could have attributed to those areas being the last to drown because there was more sediment to submerge.

Historical maps

Numerous historical maps were utilized to better understand changes in the modern coastal geomorphology. Historic maps taken from Google Earth and MDEQ. The shorelines were digitized from 1850 until present as previously described in Chapter Two. Analysis was conducted for eleven shorelines from 1850 to 2015. The completed shoreline change maps were then projected along with paleochannel locations and Kingdom generated isopach maps. There is significant correlation between areas of high coastal retreat overlying paleochannel deposits particularly in respect to middle to late Pleistocene alluvial deposits.

Inconsistencies with Kramer/Otvos's interpretations

Kramer (1990), collected 38 sediment core samples ranging in depth from 0.5m to 3m throughout the Grand Bay area. She was able to identify eight distinct facies including fine-grained sand, sand and shell, organic sandy silt, bedded sand and silt, bioturbated sandy clayey silt, oxidized clayey silt facies, light olive gray silty sand, and clean laminated sand. Kramer correlated the facies from well to well and produced eight cross sections for her study area. She interpreted each unit according to depositional environment. Specifically, she interpreted the oxidized clayey silt facies as the Pleistocene/Holocene boundary that was located 0.5m to 2.0m below the sea surface. Kramer correctly noted that this unit was subaerially exposed in the past before being recovered by the upper layers of sediment. However, high stands during Holocene time are not unprecedented e.g. (Blum and Carter, 2002; Morton et al., 2000). Also changes in sea level rates or sedimentological conditions could also cause periods of erosion and oxidation of sediment (Rodriguez, 2006; Törnqvist et al., 2004). Current research has utilized seismic data, which has offered greater penetration than that of Kramer's sediment core samples. Additionally, the seismic data has offered a more detailed image laterally than core analysis alone can provide. The current seismic data used in conjunction with previous MDEQ data indicates a Pleistocene/Holocene contact between 1m and 4m depth. Kramer was not incorrect in interpreting the oxidized layer as subaerially exposed however may have incorrectly chosen that facies as the Pleistocene/Holocene contact because she never penetrated the actual contact.

Software aiding interpretation

Use of technology and software that had not been previously utilized for this study site has greatly aided the current research. Chirp seismic data analyzed by Kingdom software (designed for the petroleum industry) has allowed researchers to identify and map sedimentary structures that may have gone unnoticed if sediment coring had been used alone. Seismic data was collected in the field and integrated into Kingdom software and used to produce 2D seismic profiles of the study site. The profiles allowed researchers to access a greater penetration in the subsurface than sediment coring tools could easily access. The profiles also filled in gaps that would otherwise be impossible to access with coring alone. A greater degree of spatial control has given researchers the ability to analyze changes in the subsurface with greater detail than previous research. The higher detail has allowed researchers to produce subsurface maps that illustrate in greater detail changes in bed thickness and topography. The enhancement in detail has allowed researchers to draw correlations between surficial morphology and antecedent geology that had previously been over looked. The greater penetration of seismic data has also offered clearer insight into locating regional formations at depth with a higher degree of confidence than previous investigations.

Human influence and restoration proposals

A number of geo-political campaigns have proposed to restore the Grande Batture Islands to their previous subaerial elevation. Three main ideas have been introduced to help restore the former islands. The first restoration plan is to reopen a spill-way from the Escatawpa River, north of Highway 90, to the waterway that empties into Crooked Bayou. Though this would supply additional sediment into the Grand Bay marsh during times of flooding. The overall sediment input would not be enough to significantly slow shoreline erosion and marsh loss. Pascagoula Bay is not building a delta outward, it has sediment emptying into it from both the Pascagoula River and the Escatawpa River. Therefore, it is highly unlikely that the sediment from overflow of the Escatawpa alone would have any significant effect on marsh stability in Grand Bay.

The second proposed method involves directly rebuilding the Grande Batture Islands through the use of dredged material. Adding dredged material to rebuild the Grande Batture Islands would temporarily stifle coastal retreat of the Grande Batture and Rigolets headland. However, as the rebuilt island transgressed landward with sea level rise they will migrate over lagoonal or estuarine clays and could become subject to subsidence. Additionally, without an incoming source of sediment the islands will lack nourishment just as the previous Grande Batture Island and will most likely repeat the process of submergence. This may be halted if an adequate volume of dredged sediment was supplied continually to the Grande Batture Islands to counter act the processes of modern sea level rise and regional subsidence. Another factor that would certainly contribute to the volume and frequency for rebuilding the islands is tropical storms and cyclones. Though small and frequent storms can aid in island rollover keeping pace with sea level rise, storms of greater magnitude can cause sediment to be lost from the system and can cut through islands creating erosive tidal channels, leaving the islands vulnerable to erosion and drowning.

The final proposal was similar to the second except, it was proposed that a temporary wall be built to hold the sediment in place until vegetation could be established on the island. Both vegetation and the wall would aid in keeping sediment in place during storm events. However, semi-permanent structures may cause increased erosion elsewhere in the marsh. Additionally, this proposal faces the same problem of lack of sediment input into the system so nourishment projects would have to be continually undertaken. This study considers the above scenarios the pros and cons of the geo-political proposals. No calculations for volume or rate of nourishment were made or considered because that is out of the scope and not the purpose of this project. Nor does this project favor or oppose any measures to rebuild the Grand Batture Islands.

CHAPTER VI

CONCLUSTION

Summary of findings

Results from seismic readings in conjunction with sediment core provided insight into regional stratigraphy. Additionally, seismic data cross-correlated with regional shoreline maps indicate a connection between long-term shoreline change and paleochannel deposits. The fallowing discussion illustrates the products of this research and suggestions for future investigations.

Stratigraphy

The top of the Undifferentiated Neogene sediments lie unconformable under the Biloxi Formation at depth ranging from 8-12 m below the seafloor and reach their maximum depth in southwestern Grand Bay. Core analysis collected by MDEQ interprets undifferentiated Neogene sediments to be 12-24 m in depth, which is consistent with the interpreted seismic horizon. The core also indicates that the undifferentiated sediment underlying the Grand Bay area are comprised of muds, clays, and fine grained sands. The interpretation of the core suggests open marine to estuarine environment.

The top the Biloxi Formation has been interpreted to be between the depths of 4 and 8 m below the seafloor, with its maximum depth seaward of the Grand Batture shoal and South Rigolets Island. Additionally, the Biloxi Formation ranges 5-3 m in thickness under Pointe Aux Chenes Bay. MDEQ core records supports this interpretation by defining the Biloxi 2-8m below the subsurface. The Biloxi Formation is comprised of brackish clay deposits and is interpreted as lagoonal to estuarine in origin.

The Prairie Formation top marks the Holocene/Pleistocene boundary and is located at 1m to 4m below the seafloor in Grand Bay and Pointe Aux Chenes Bay; nevertheless, the formation outcrops landward within the marsh. The Prairie Formation ranges in thickness from 3 m to 5 m. MDEQ core analysis supports the depth range of the Prairie Formation by determining depth to be from 0m to 3 m inland and 4 m off shore. The Prairie Formation is predominately comprised of fine sands and muds, and is interpreted as alluvial deposits.

The Holocene deposits are comprised of surficial deposits. The sediments include unconsolidated organics, fluidized mud, clays, silts, and sands. The Holocene sediment is interpreted as estuarine, bay, bayou, beach, and deltaic deposits of the last 11.5 thousand years

Local sea level fluctuation

Three unconformities have been identified through the use of seismic data in the Grand Bay study area. The oldest unconformity is associated with the contact between the Biloxi Formation and Undifferentiated Neogene sediments. This unconformity has been interpreted as pre-LIG in age and is congruent with regression before the last interglacial highstand. The Biloxi Formation, deposited atop the unconformity, has been interpreted as been deposited at a time of transgression during the last interglacial highstand.

The second oldest unconformity lies between 4m and 8m below the sea surface in the study area. It has been interpreted as occurring during regression after the last interglacial highstand. The Prairie Formation overlies the unconformity. The Prairie Formation has been interpreted as being deposited, after the last interglacial and before the Wisconsinan LGM, at periods of higher sea levels during a time of overall regression.

The final unconformity identified through analysis of seismic data has been interpreted as the Holocene/Pleistocene contact. It occurred during regional regression at the LGM approximately 81-11ka. The sediments above the unconformity are Holocene in age and occurred during overall transgression.

Paleochannel deposits

One Paleochannel associated with Horizon 1 has been identified. This paleochannel cuts through the Undifferentiated Neogene sediments and underlies the Biloxi Formation. This Paleochannel runs in a North to South direction along the current eastern shore of North Rigolets and extends seaward of South Rigolets Island.

Two Paleochannels associated with Horizon 2 incise the Biloxi Formation and underlie the Prairie Formation. The eastern channel fallows a similar north to southward course as the underlying paleochannel associated with Horizon 1. The western channel flows in a north to south direction along the current western shore of L'isle Chaude and seaward of South Rigolets.

McNinch (2004) and Schupp et al. (2006) found that outcropping paleochannel gravel deposits were spatially correlated with sand bar deposits, short term coastline accretion/deposition rates, and high long-term coastline change rates. The current research however, has found little correlation between short term coastline change and paleochannels. Nevertheless, this research has discovered that there is correlation between buried paleochannels and long-term coastal morphology. Specifically, the protruding coastal marshlands of L'Isle, North Rigolets, and South Rigolets rest between Pleistocene aged paleochannel deposits. This suggest that paleochannels may have aided in sustaining this area of Grand Bay coast; however, further research would need to be conducted to test that claim. Additionally, through use of historical maps there does seem to be correlation between barrier island detachments in areas overlying the paleochannels. Barrier island erosion in areas overlying paleochannels is more in agreement with McNinch's research.

Hypothesis supported

In light of recent research, e.g. (Belknap and Kraft, 1985; Browder and McNinch, 2006; McNinch, 2004; Rosati and Stone, 2009; Rosati et al., 2010; Schupp et al., 2006; Twichell et al., 2013) I proposed that spatial correlation could be identified between paleochannel deposits and shoreline erosion. Through the analysis of seismic data cross-correlated with historical maps, the current research illustrates correlation between paleochannels underlying areas of long-term erosion. Unexpectedly however, observations also seem to strongly suggest lands parallel to paleochannel deposits experience lesser long-term erosion effects.

Wider implication

The goal of this study was not to merely test a hypothesis for the sake of science alone. Researchers hope the information gathered from this study is both beneficial at regional levels and is applicable in a wider context. Regionally, this research has identified and interpreted regional formations and features in greater detail than previous investigations. Additionally, transgressive and regressive events have been identified and correlated to regional formations and unconformities to present the geologic history of Grand Bay. The correlation between paleochannels and current coastal morphology identified by this research brings attention to the need to incorporate antecedent geology into shoreline change models for more accurate results. If managers want to better understand long-term morphologic change to the Grand Bay area they should consider how the underlying geology can be used to predict areas prone or less susceptible inundation.

At a wider level this research can be used produce conceptual models that illustrate shore change in areas with similar environments. The research provides insight into how to better manage coastline in deltaic, low energy environments.

Future work and summary

Given more time and funding for this research there are a number of additional data that could be collected to help bolster the current understanding of the area. The first suggestion for future research is to collect deep sediment core along the seismic survey path. Collection of core should be implemented to better ground truth the seismic surveys. Also, analysis of previously gathered surficial sediment samples and additional bottom sediment should be collected and analyzed to identify lateral changes in lithology of the nearshore bottom sediment.

Additionally, paleochannel data could be analyzed in greater detail. Height and width data could be collected for each paleochannel deposit associated with a certain depth. This could help scientist understand environmental conditions and paleo-stream flow. Furthermore, stream width and height may have significance in controlling current shoreline morphology.

Finally, other studies similar to the current study should be implemented elsewhere in the northern Gulf of Mexico. Other studies will shed light on whether the conclusions of this study indeed have broader implications. Specifically, Louisianan islands of deltaic origin may be the optimum study site to confirm the findings of this research.

The Grand Bay is important in that it is a protected estuarine and salt marsh environment. Salt marshes provide habitat for a variety of waterfowl, commercially and recreationally fished organisms, and threaten species. Also, coastal marshes also act as a filter for contaminates before they are expelled into the sea. Finally, coastal marshes lessen storm surge and inundation during tropical cyclones. Therefore, protecting the marsh through proper management is important for coastal communities. Understanding how the coastal marsh has evolved over time can help scientist understand how it will develop in the future. The current research has shown how the Grand Bay coast has changed over time and has correlated sub-surficial features to modern morphology. The goal of this research was to better understand how both sedimentary structures, such as paleochannels, and framework geology are correlated to modern geomorphic changes along the shoreline, so that managers can better predict future changes in the marsh and implement appropriate action to insure the health of Grand Bay lands.

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APPENDIX A

SEDIMENT CORE AND SHORELINE CHANGE GRAPHS

Core

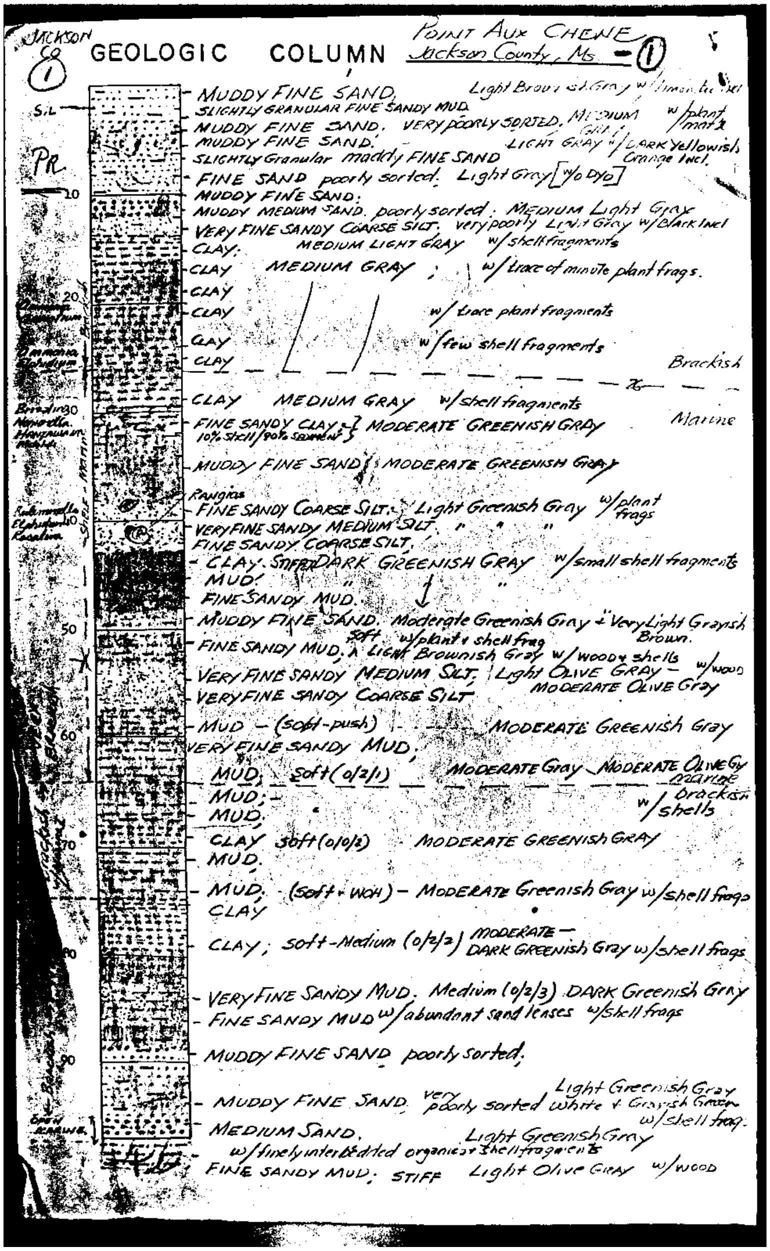
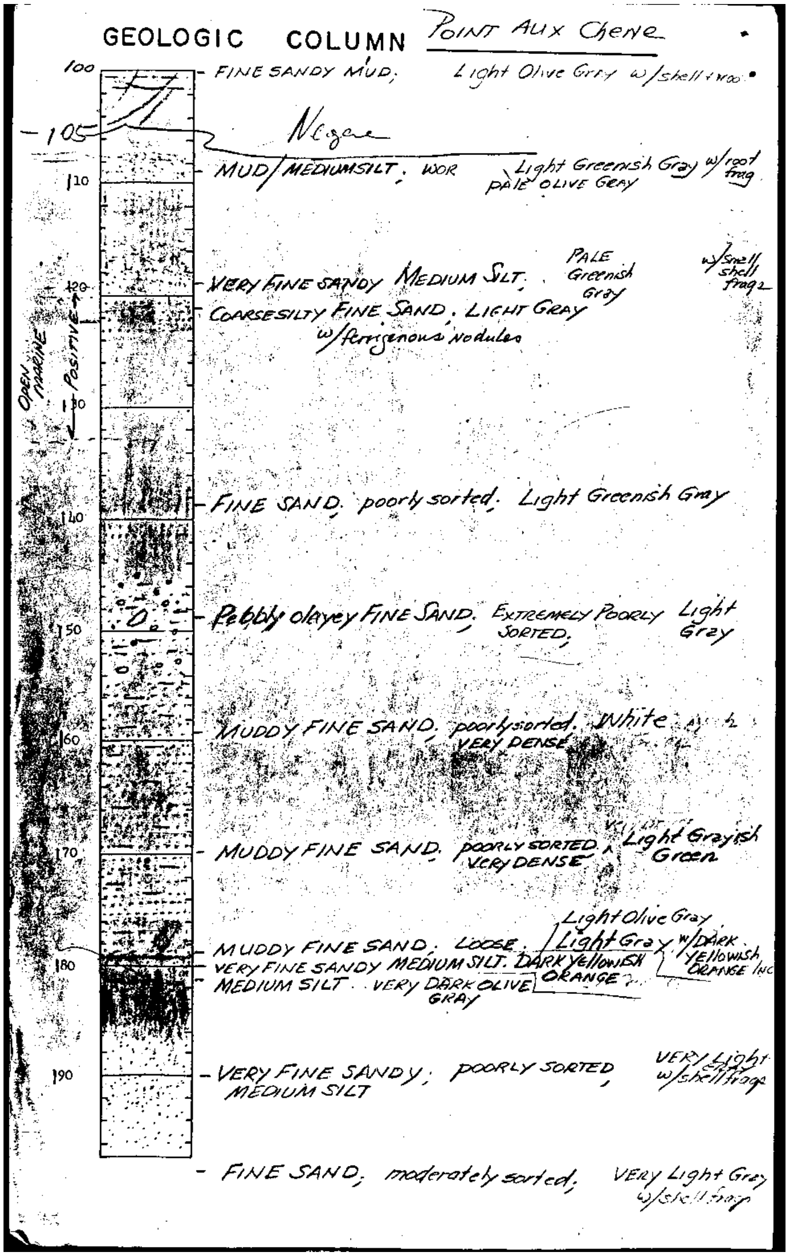


Figure A.1 MDEQ sediment core number 1

Lithology and notes were used for geologic formation.



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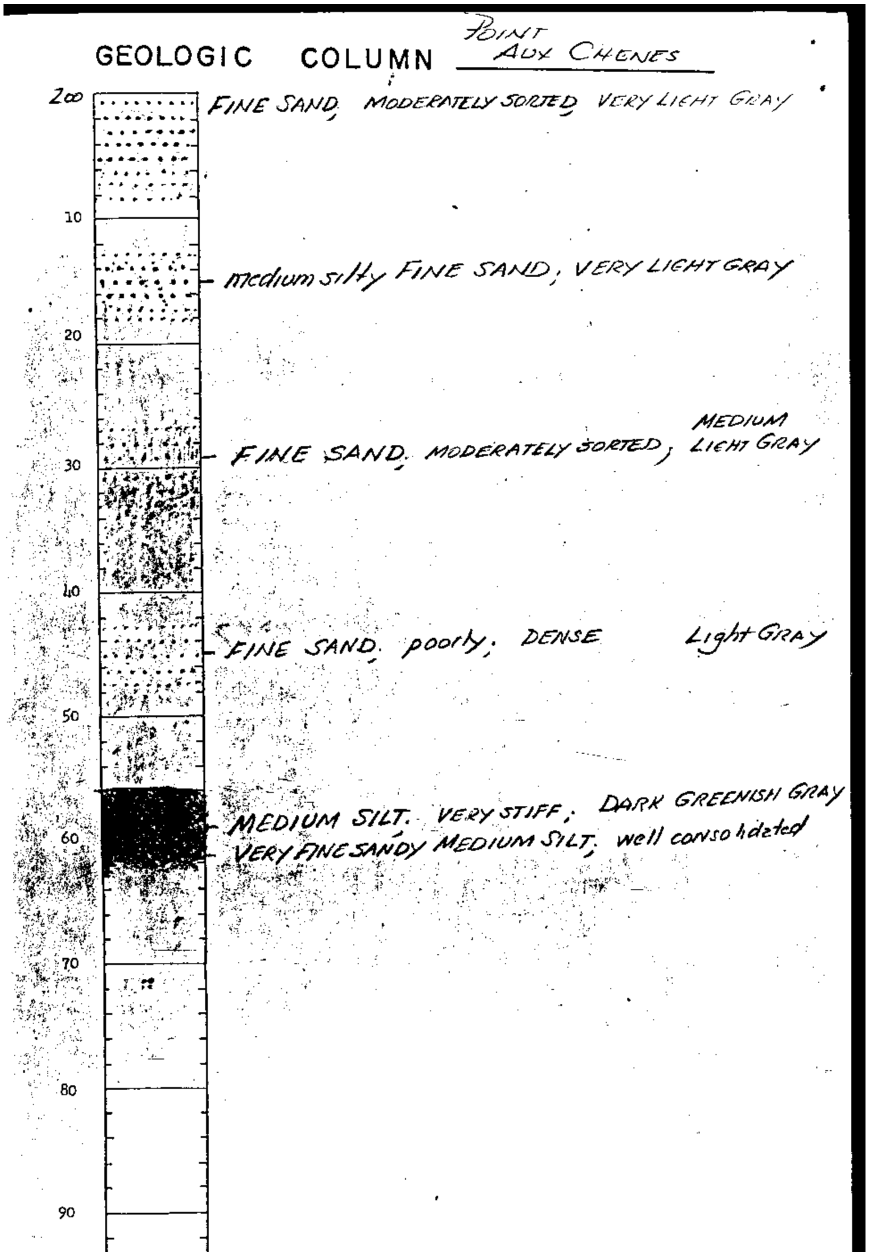

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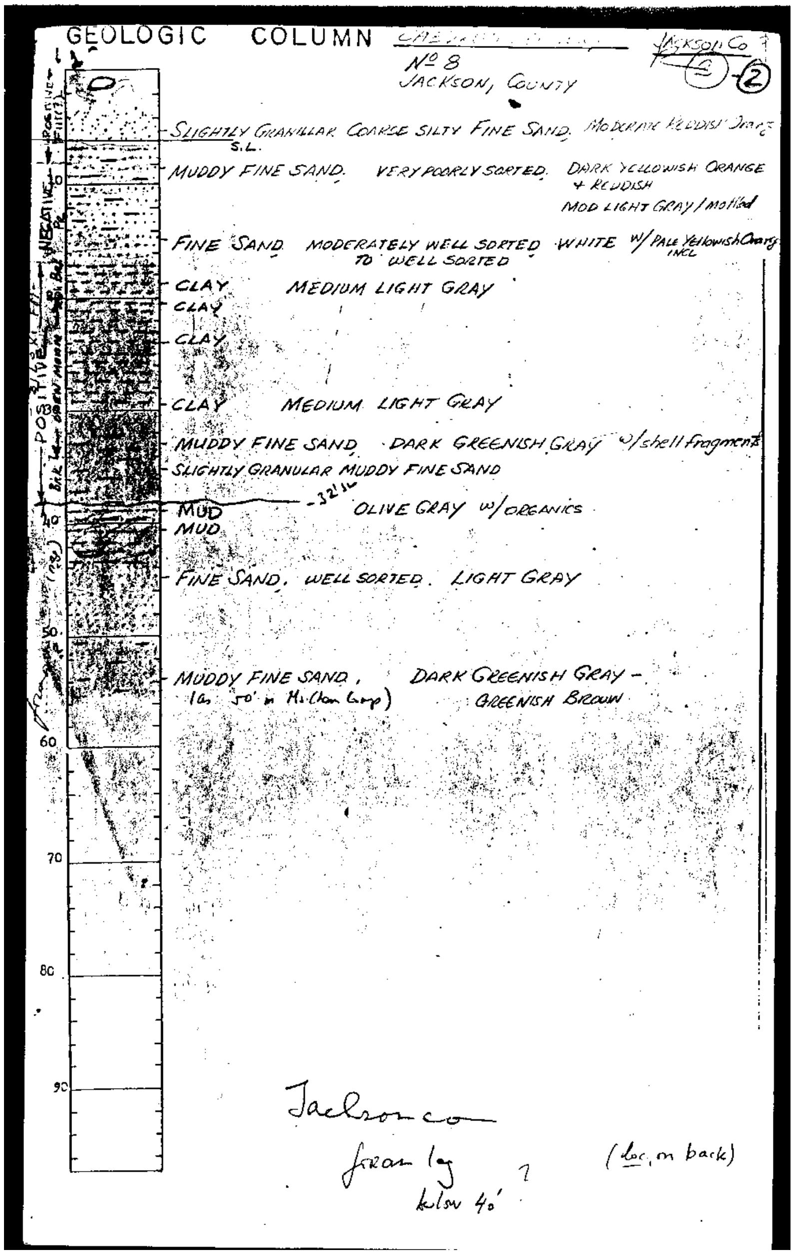


Figure A.2 MDEQ sediment core number 2

Lithology and notes were used for geologic formation.

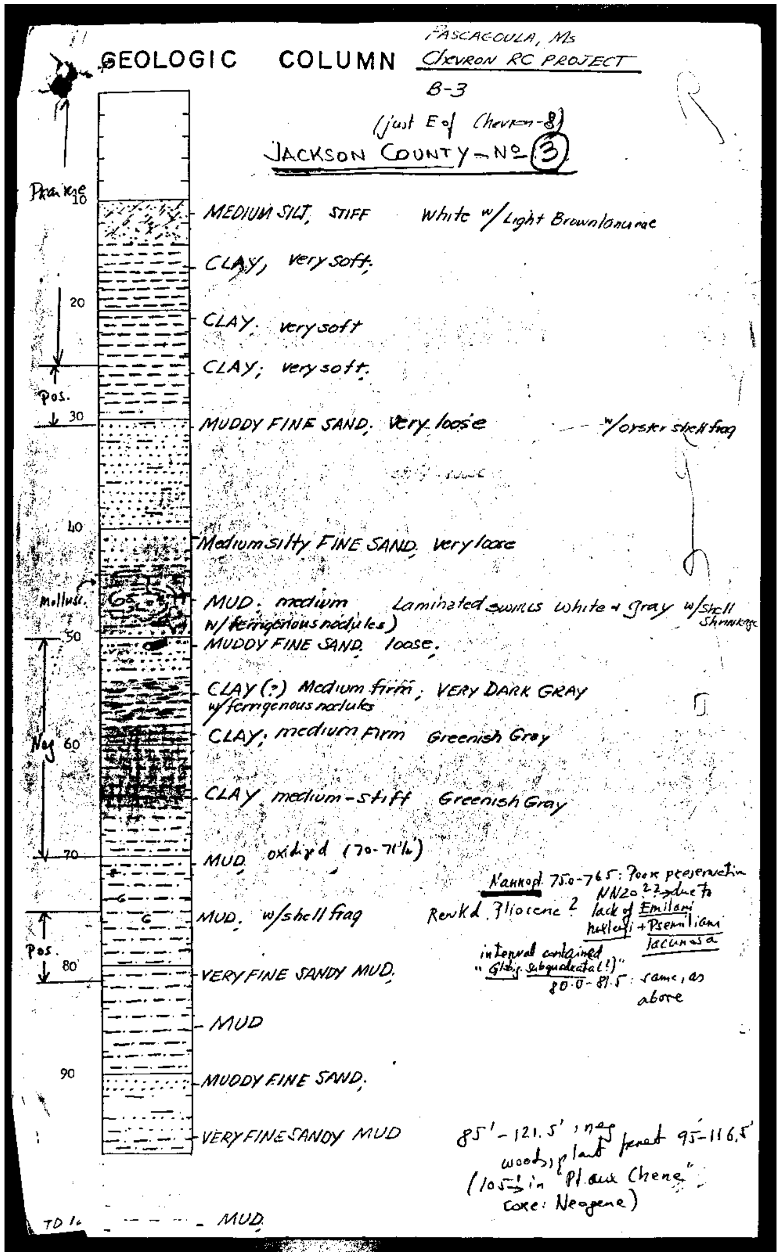
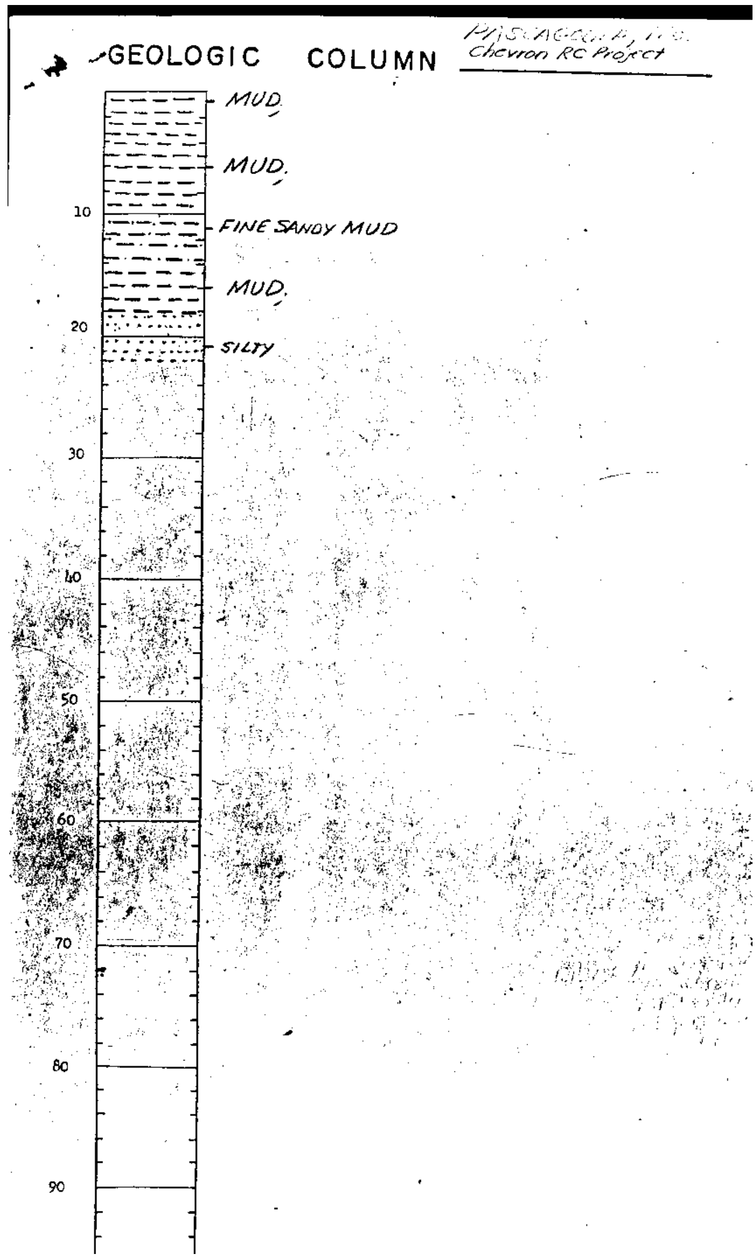


Figure A.3 MDEQ sediment core number 3

Lithology and notes were used for geologic formation.



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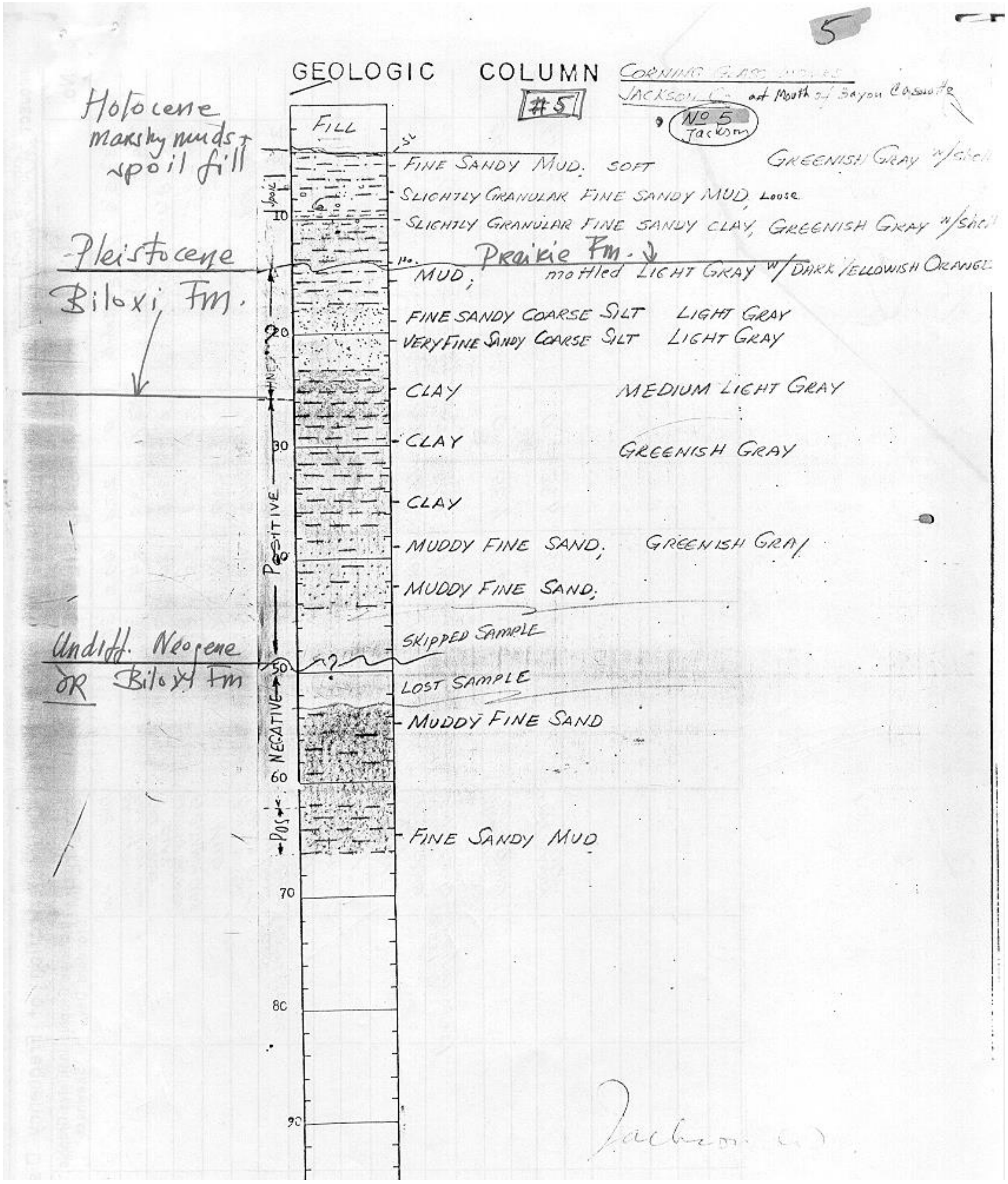


Figure A.4 MDEQ sediment core number 5

Lithology and notes were used for geologic formation.

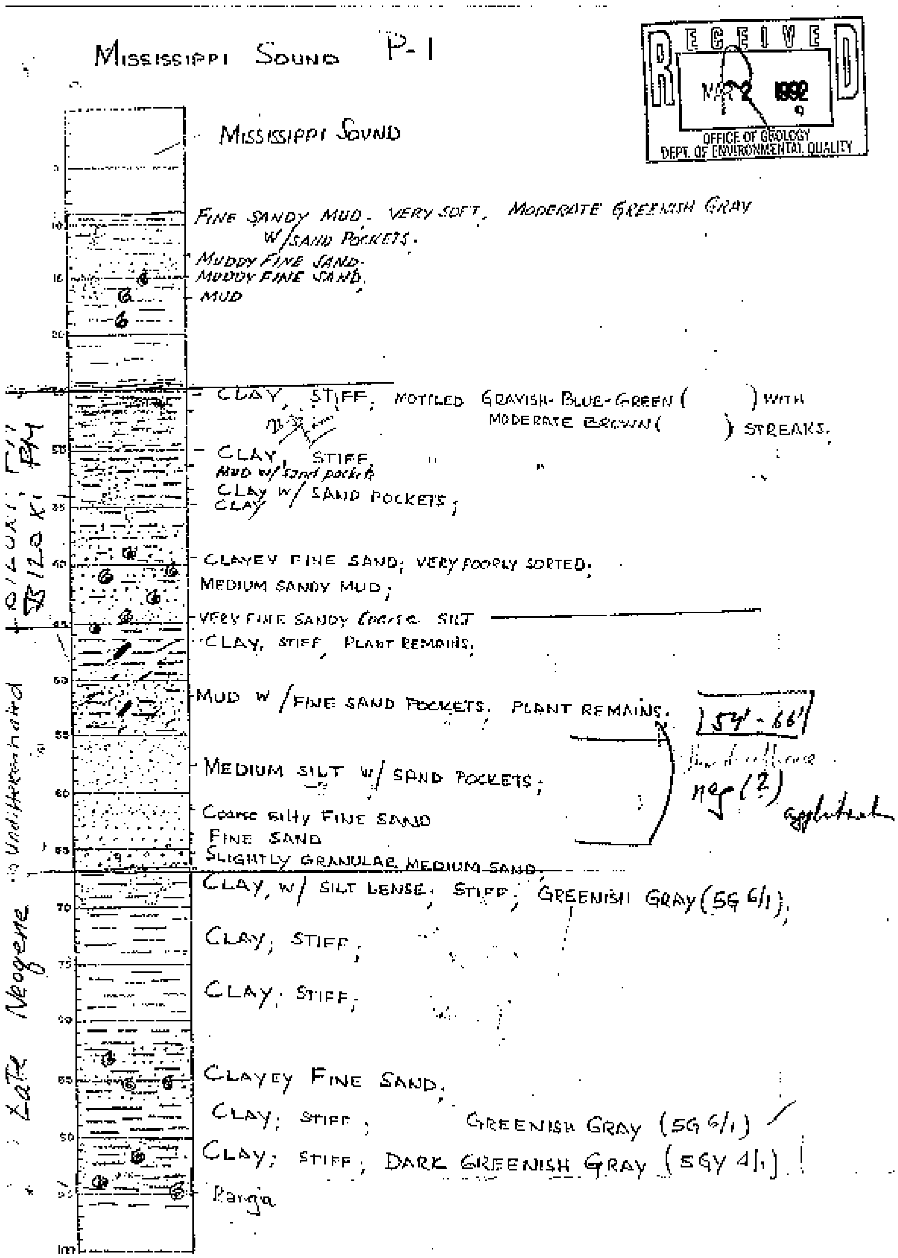


Figure A.5 MDEQ sediment core number MS1

Lithology and notes were used for geologic formation.

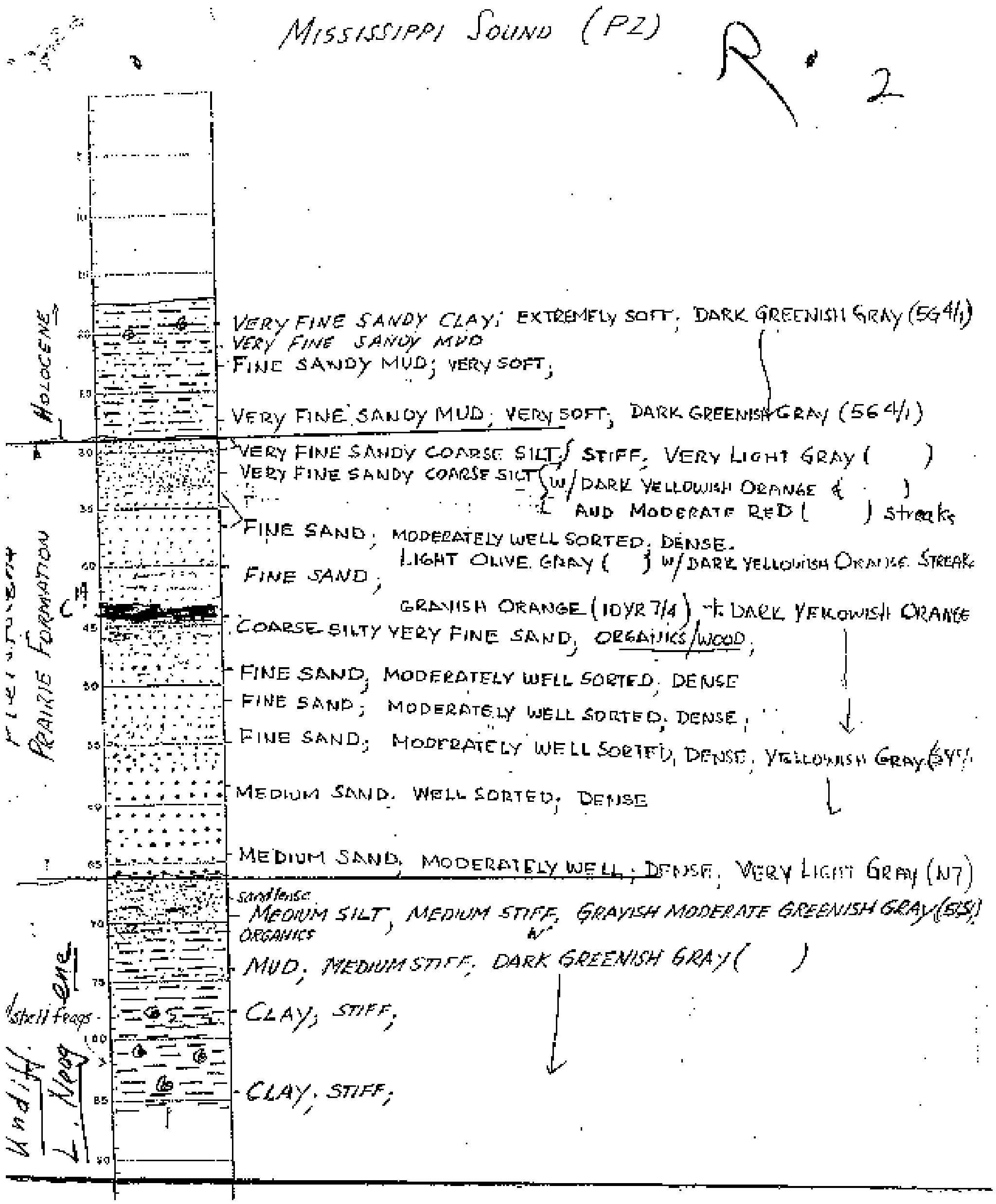


Figure A.6 MDEQ sediment core number MS2

Lithology and notes were used for geologic formation.

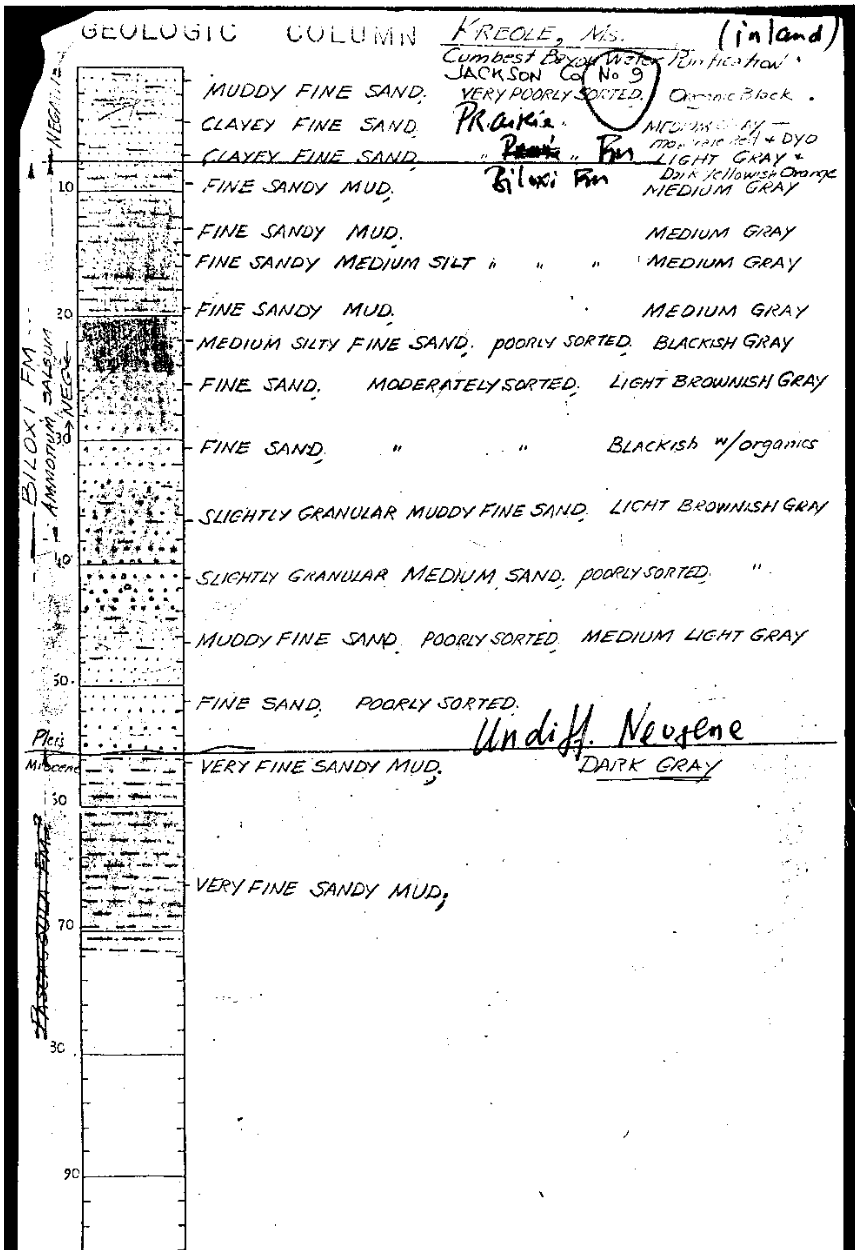


Figure A.7 MDEQ sediment core number 9

Lithology and notes were used for geologic formation.

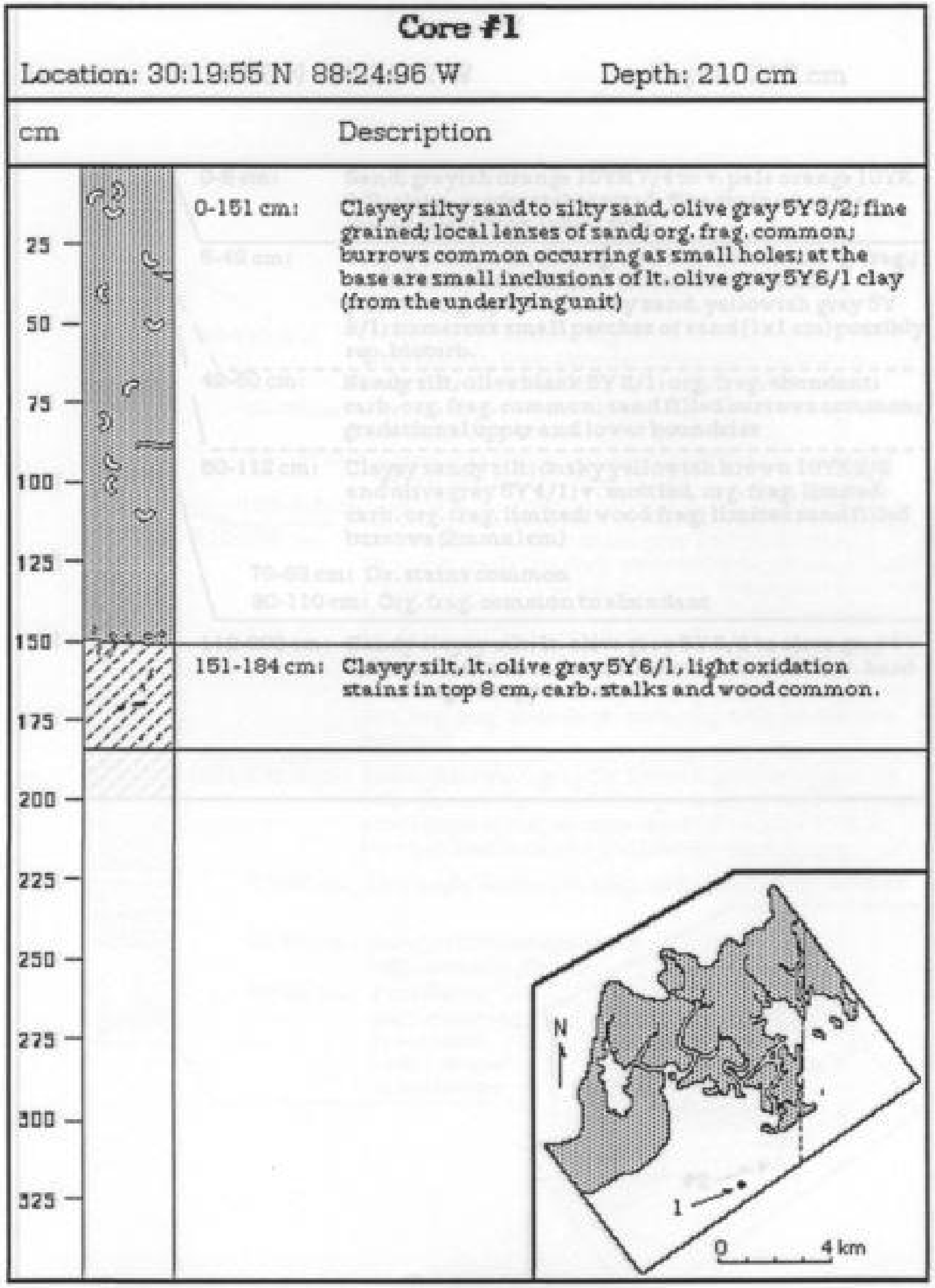


Figure A.8 Kramer sediment core 1

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations.

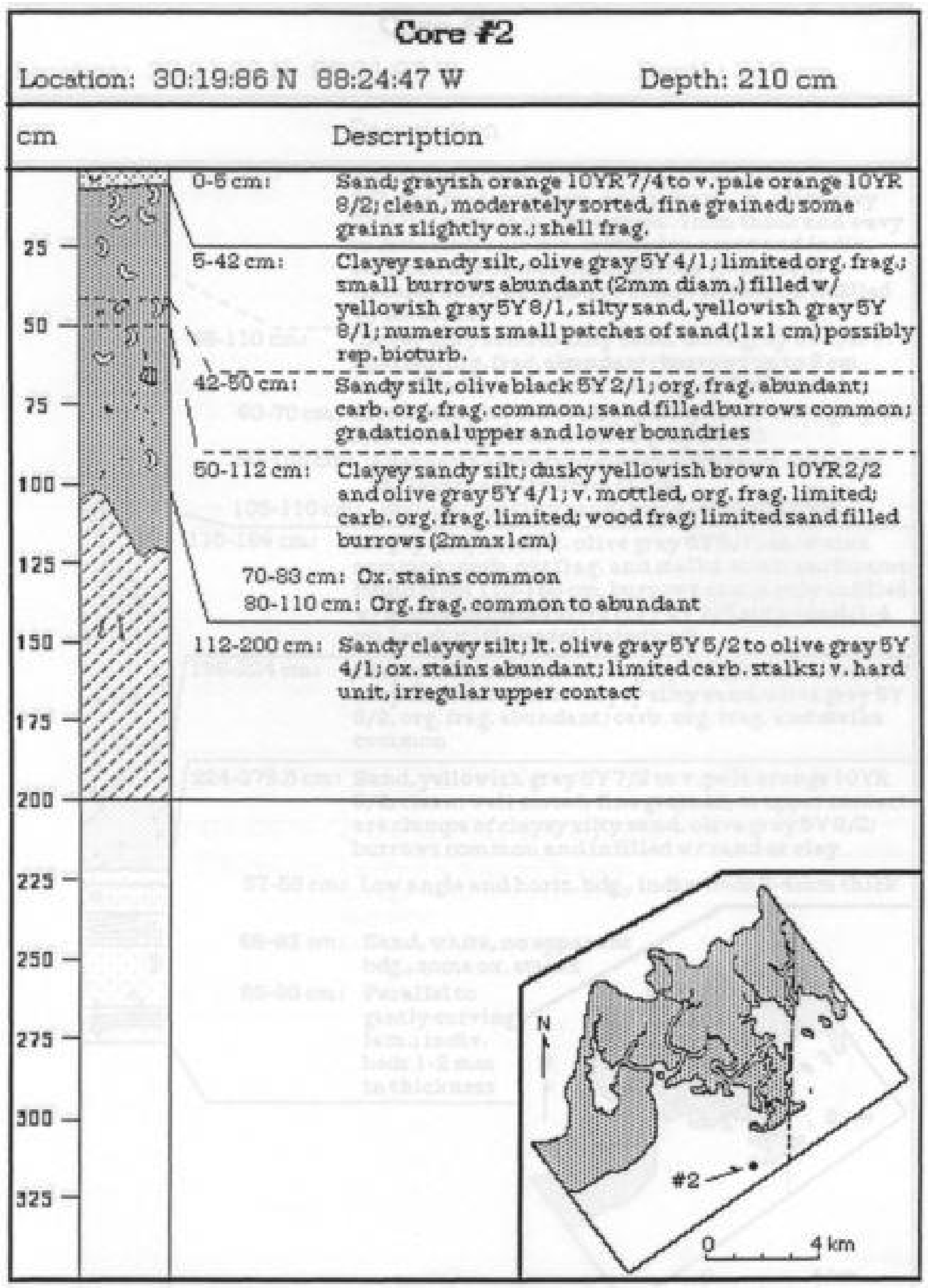


Figure A.9 Kramer sediment core 2

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

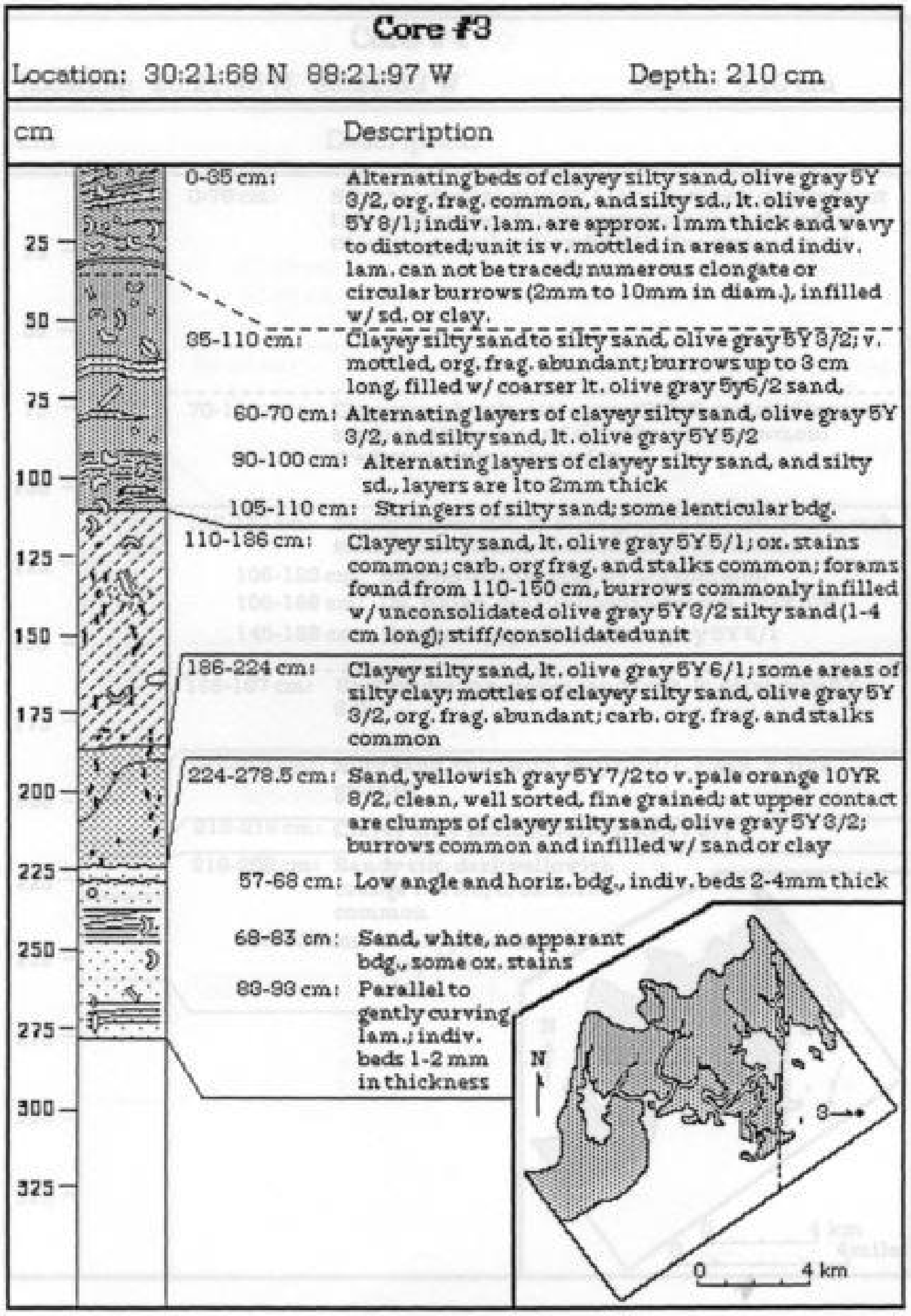


Figure A.10 Kramer sediment core 3

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

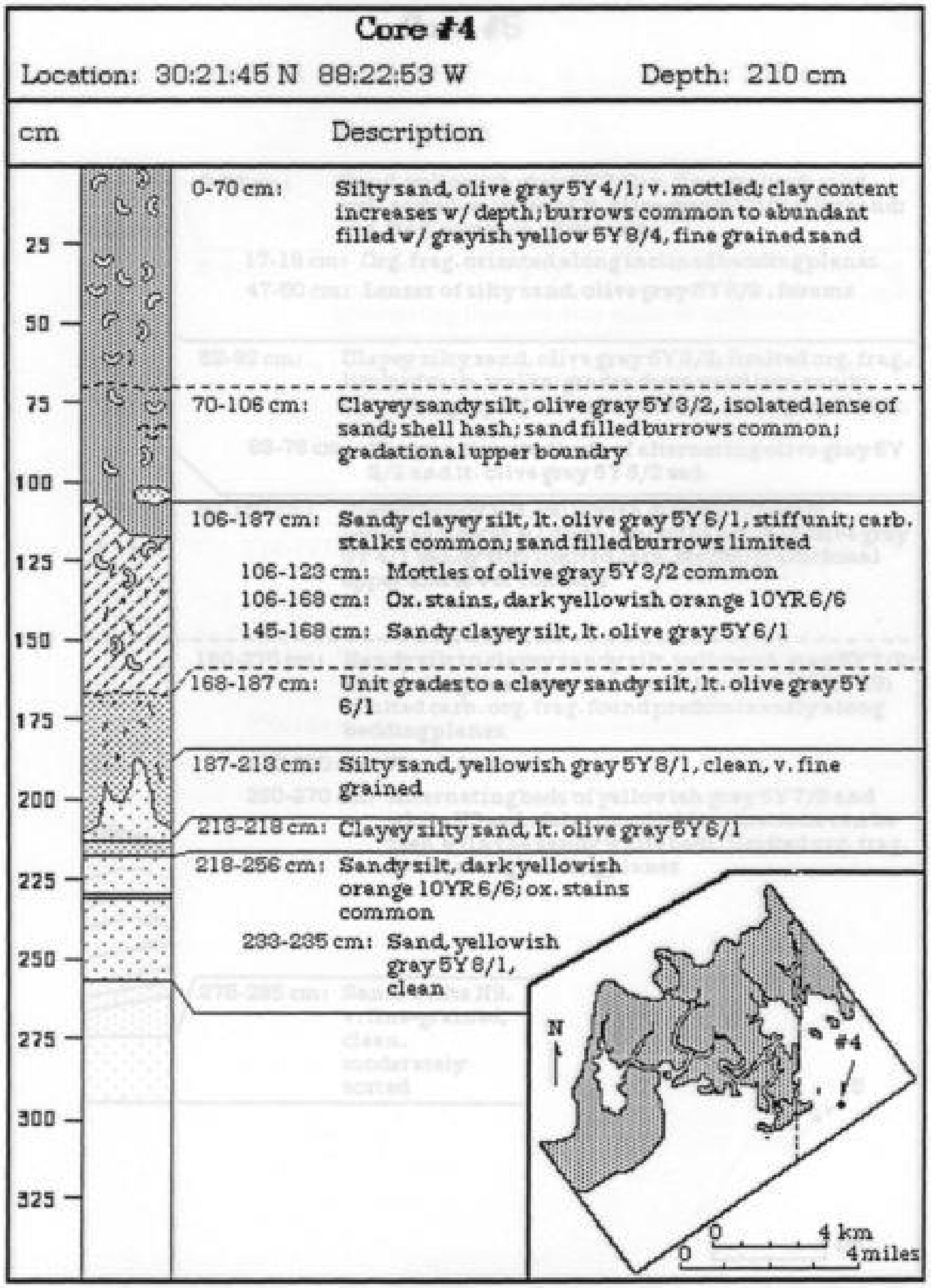


Figure A.11 Kramer sediment core 4

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

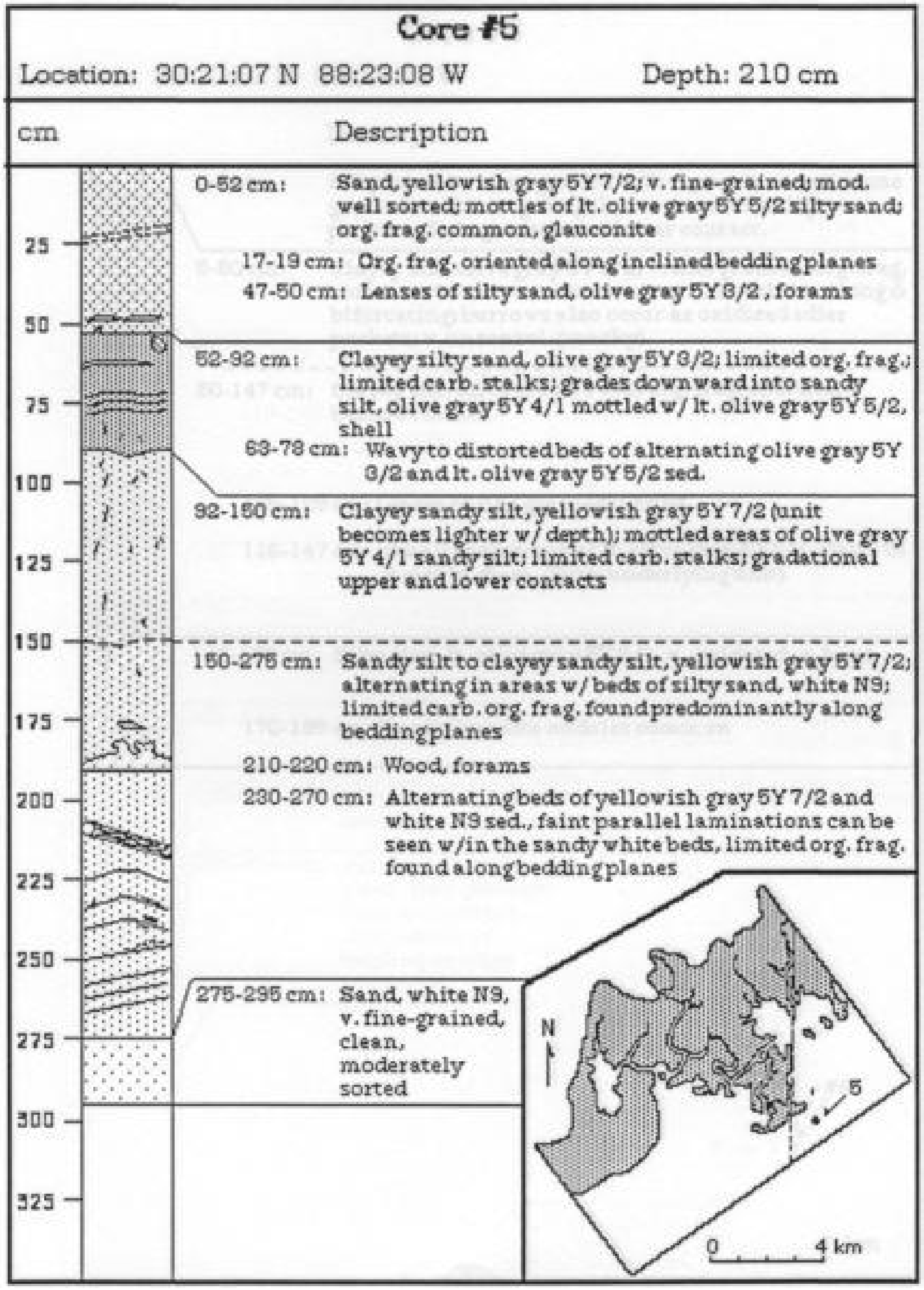


Figure A.12 Kramer sediment core 5

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

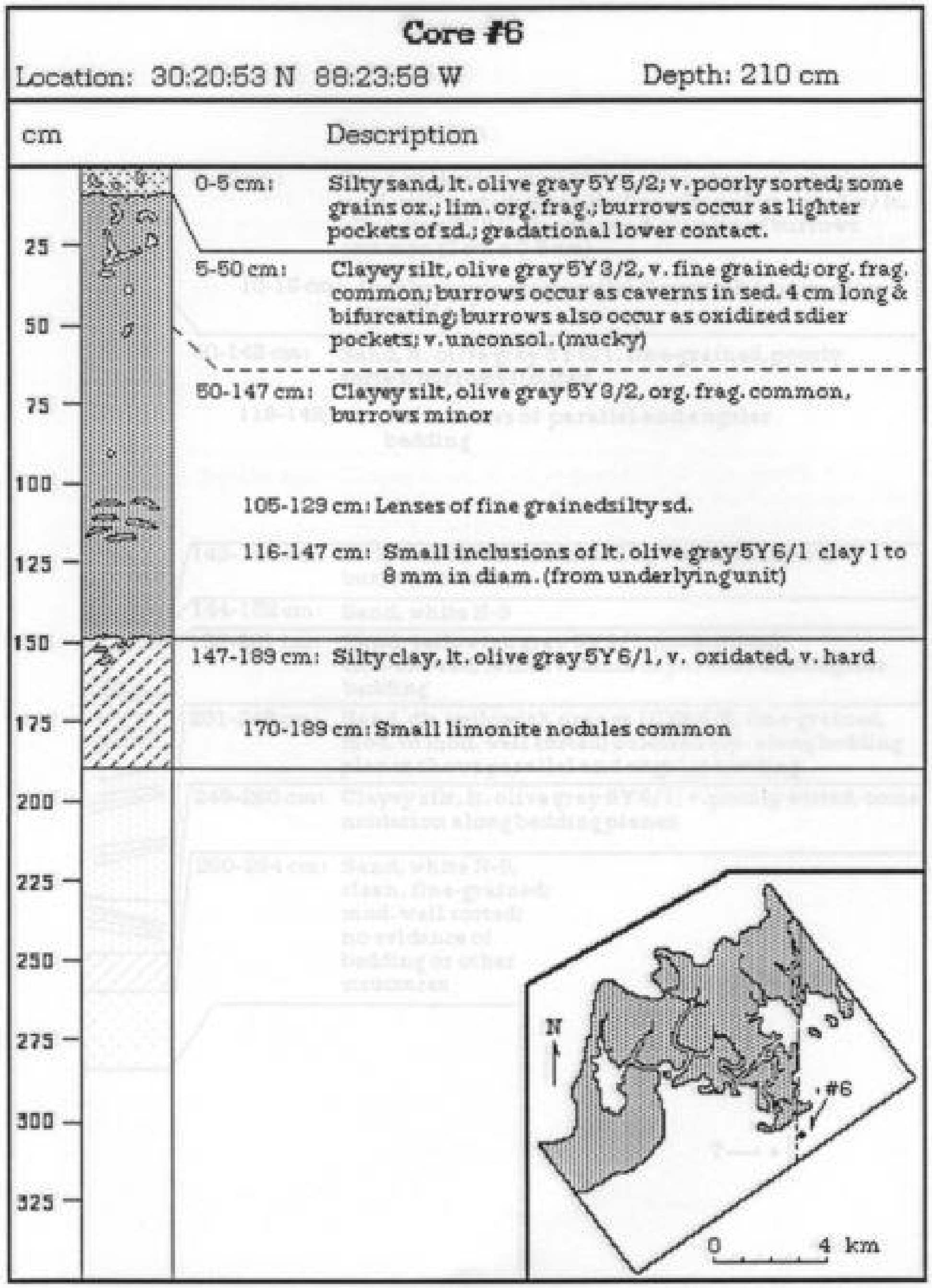


Figure A.13 Kramer sediment core 6

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

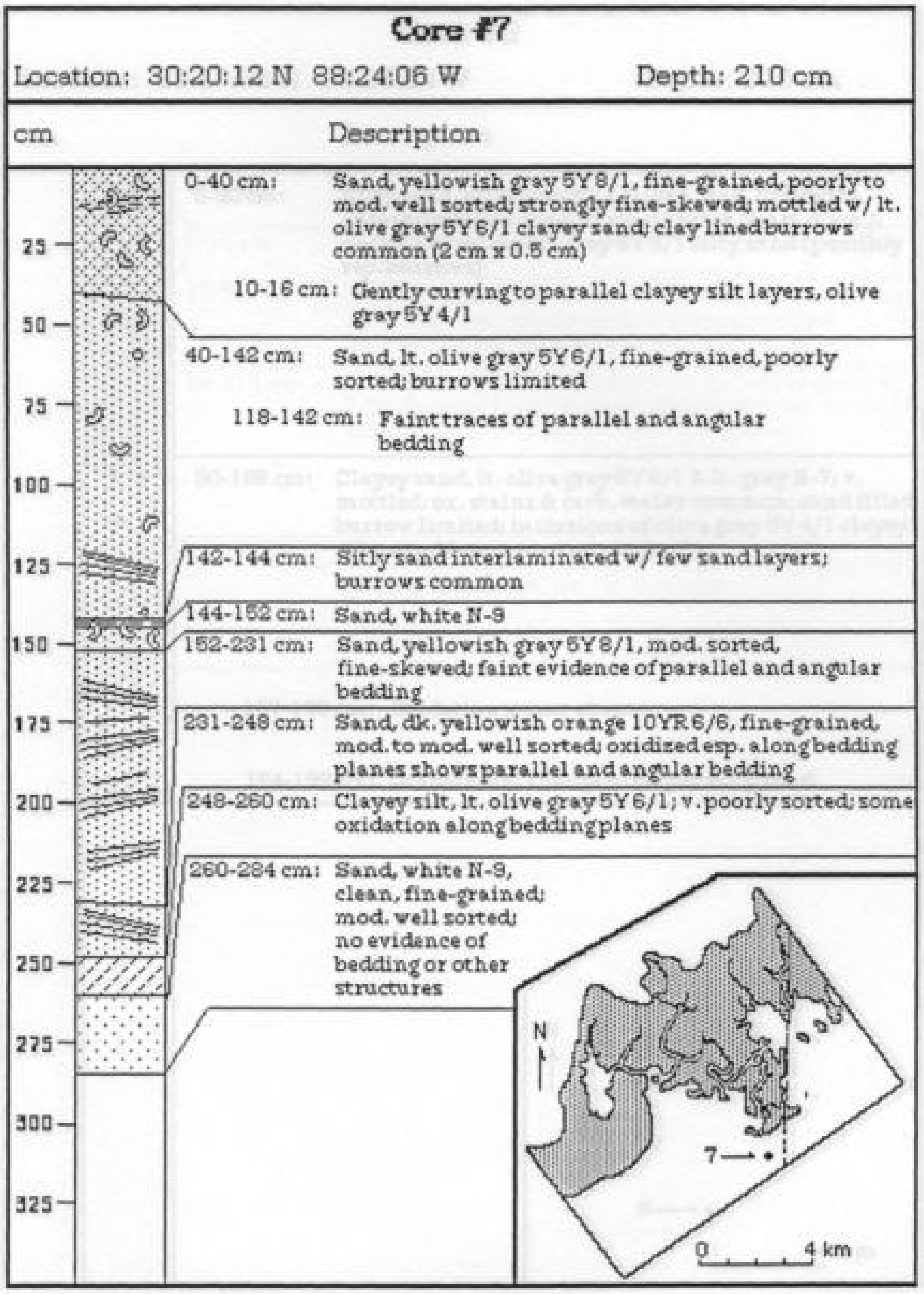


Figure A.14 Kramer sediment core 7

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

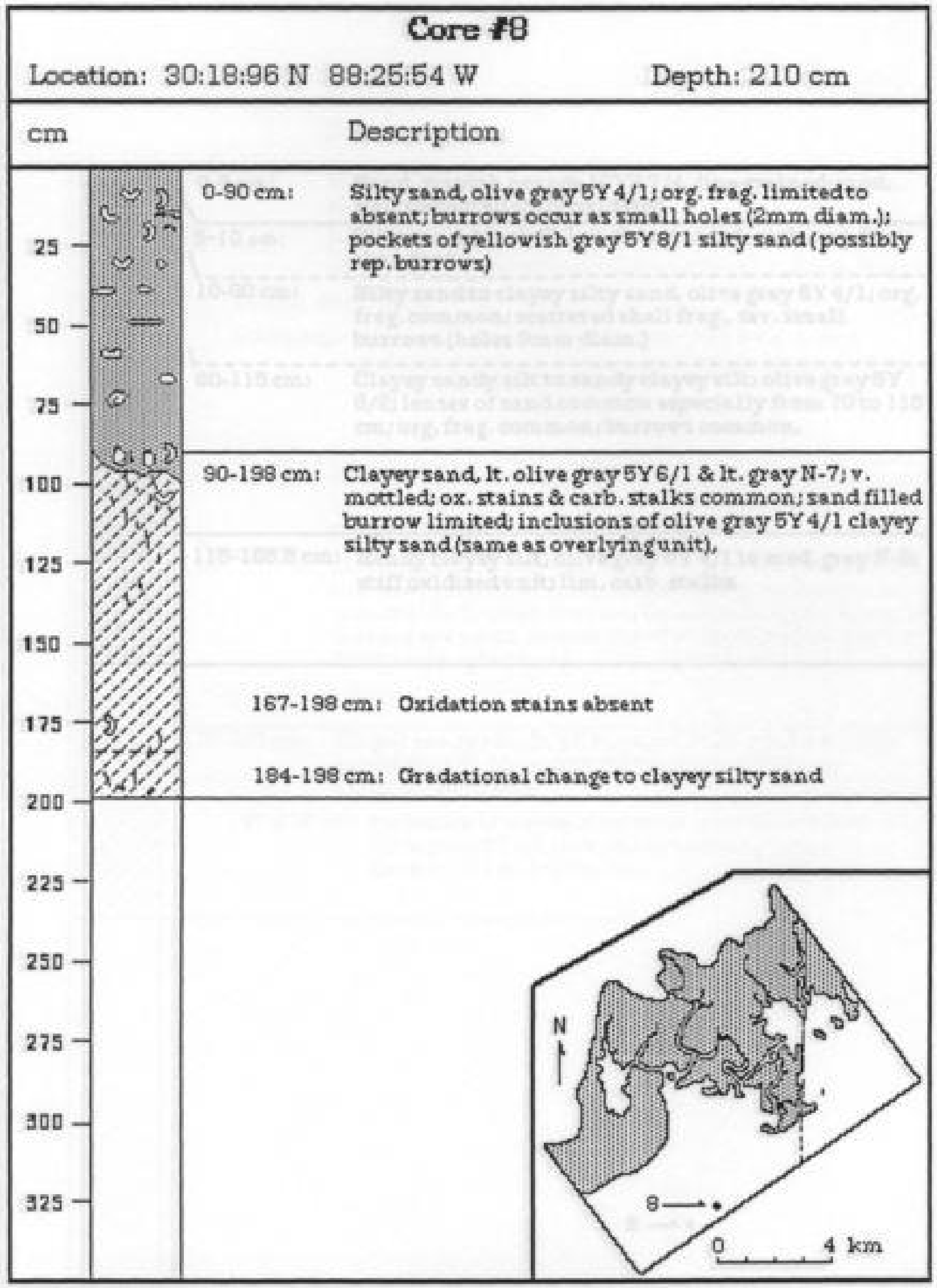
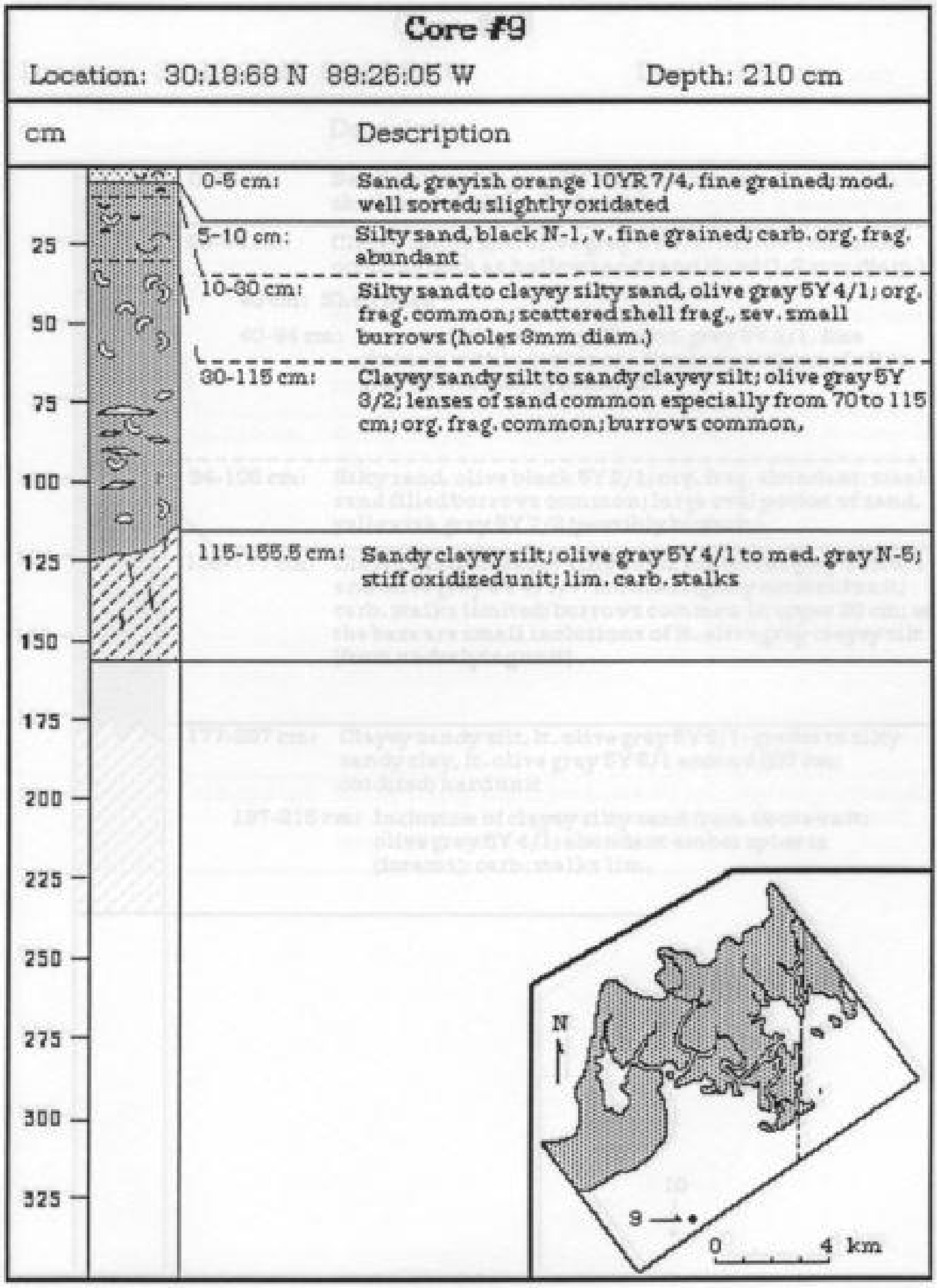


Figure A.15 Kramer sediment core 8

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations



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Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

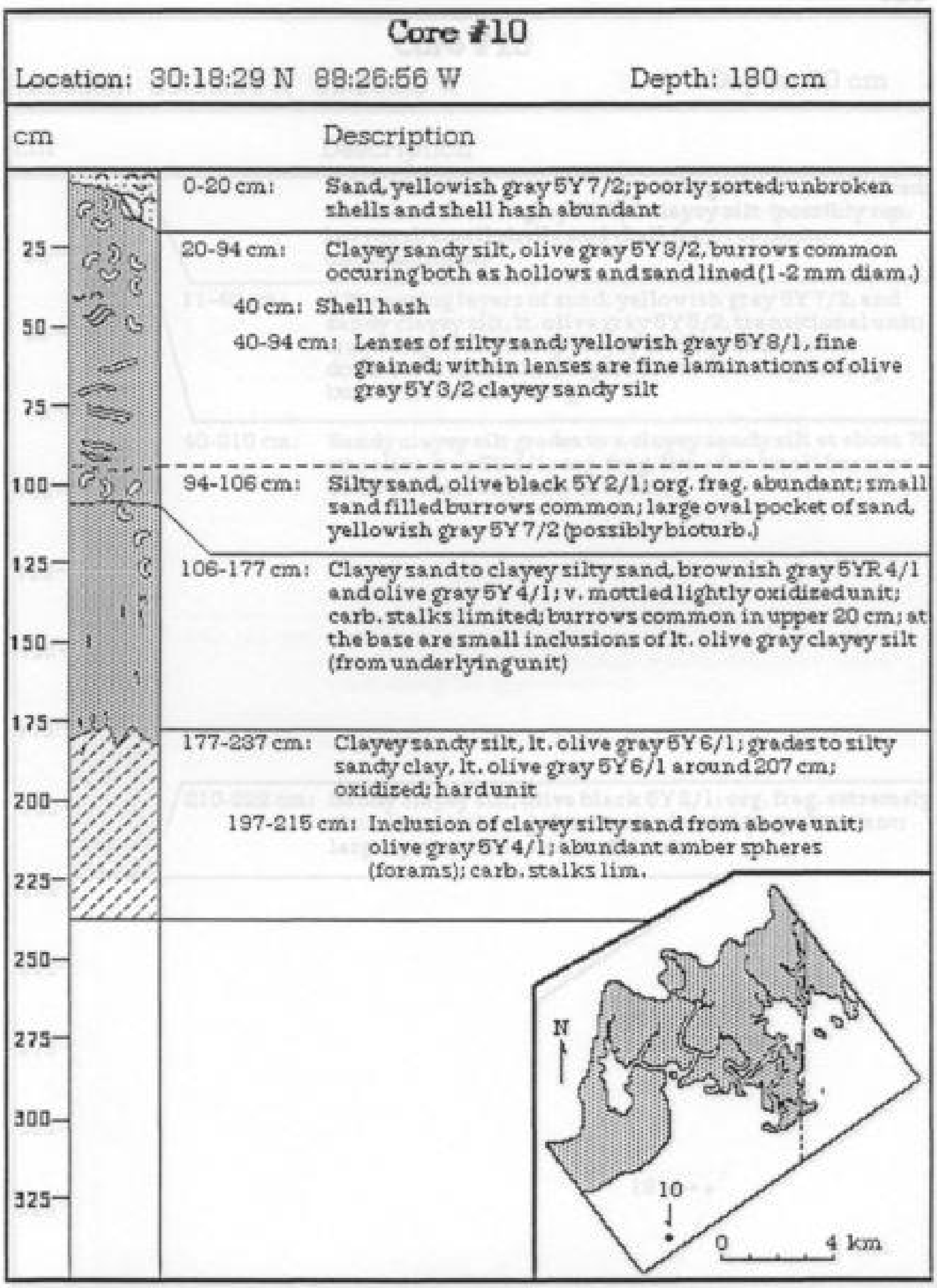
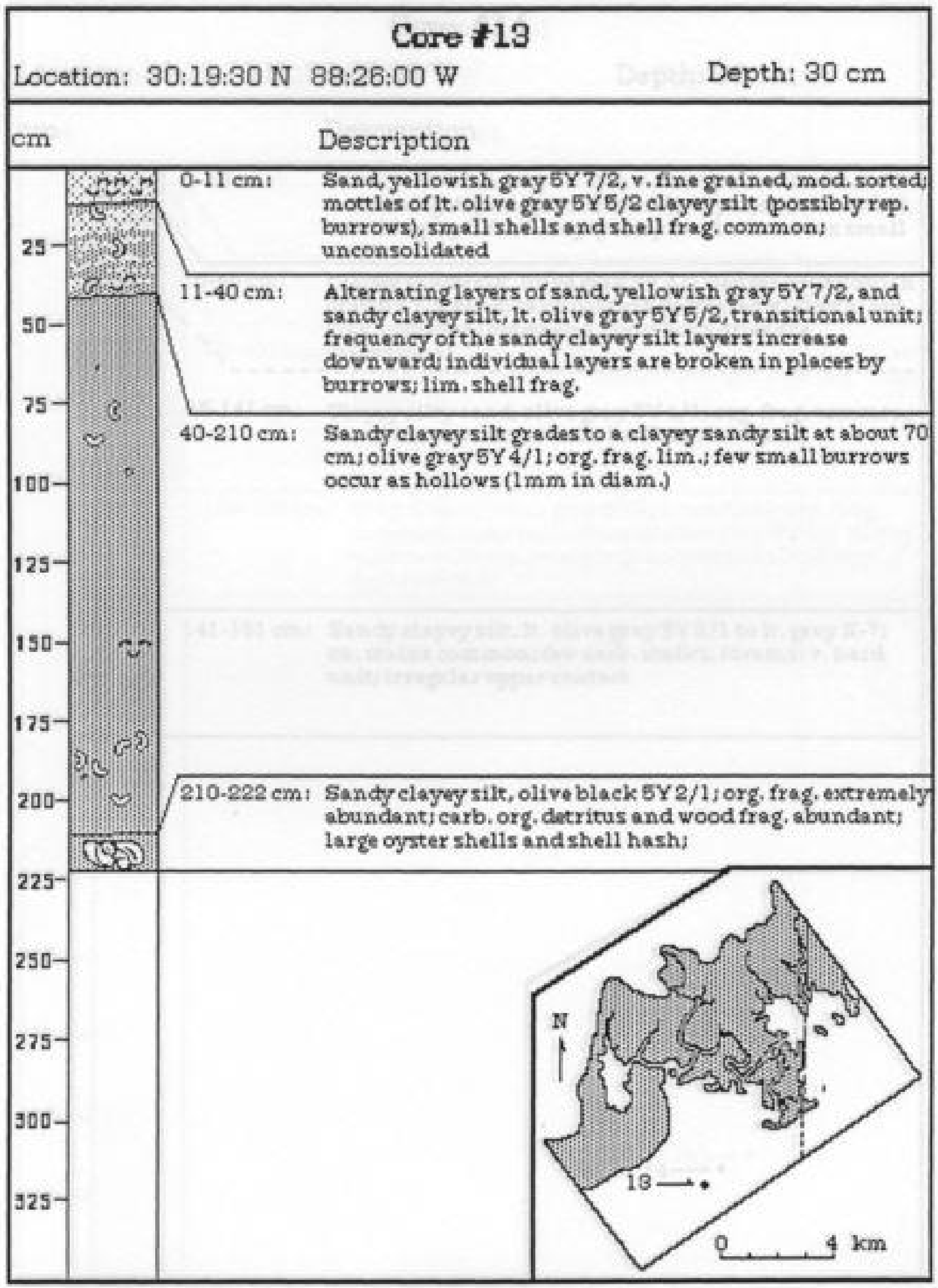


Figure A.17 Kramer sediment core 10

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations



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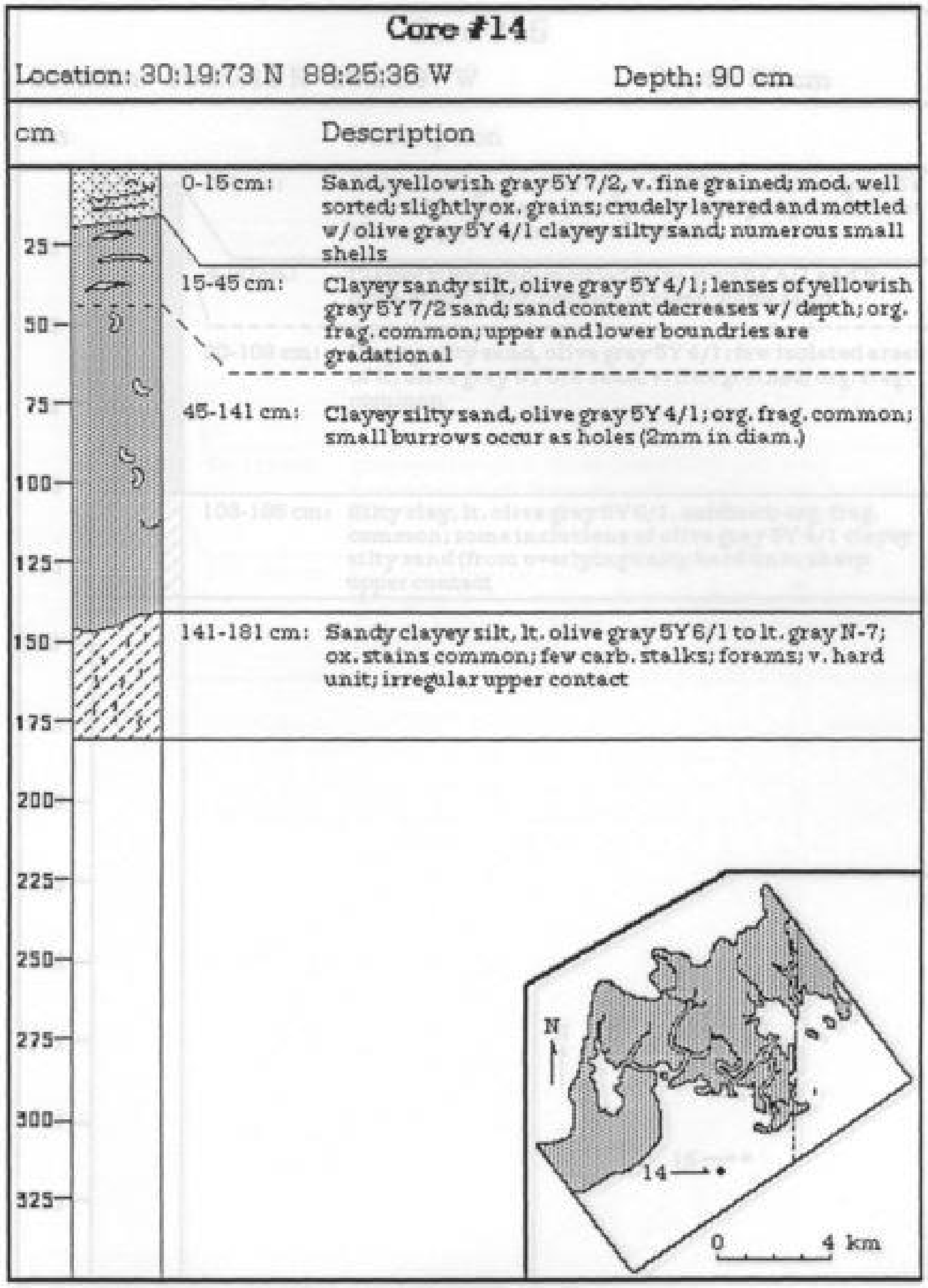

Figure A.19 Kramer sediment core 14

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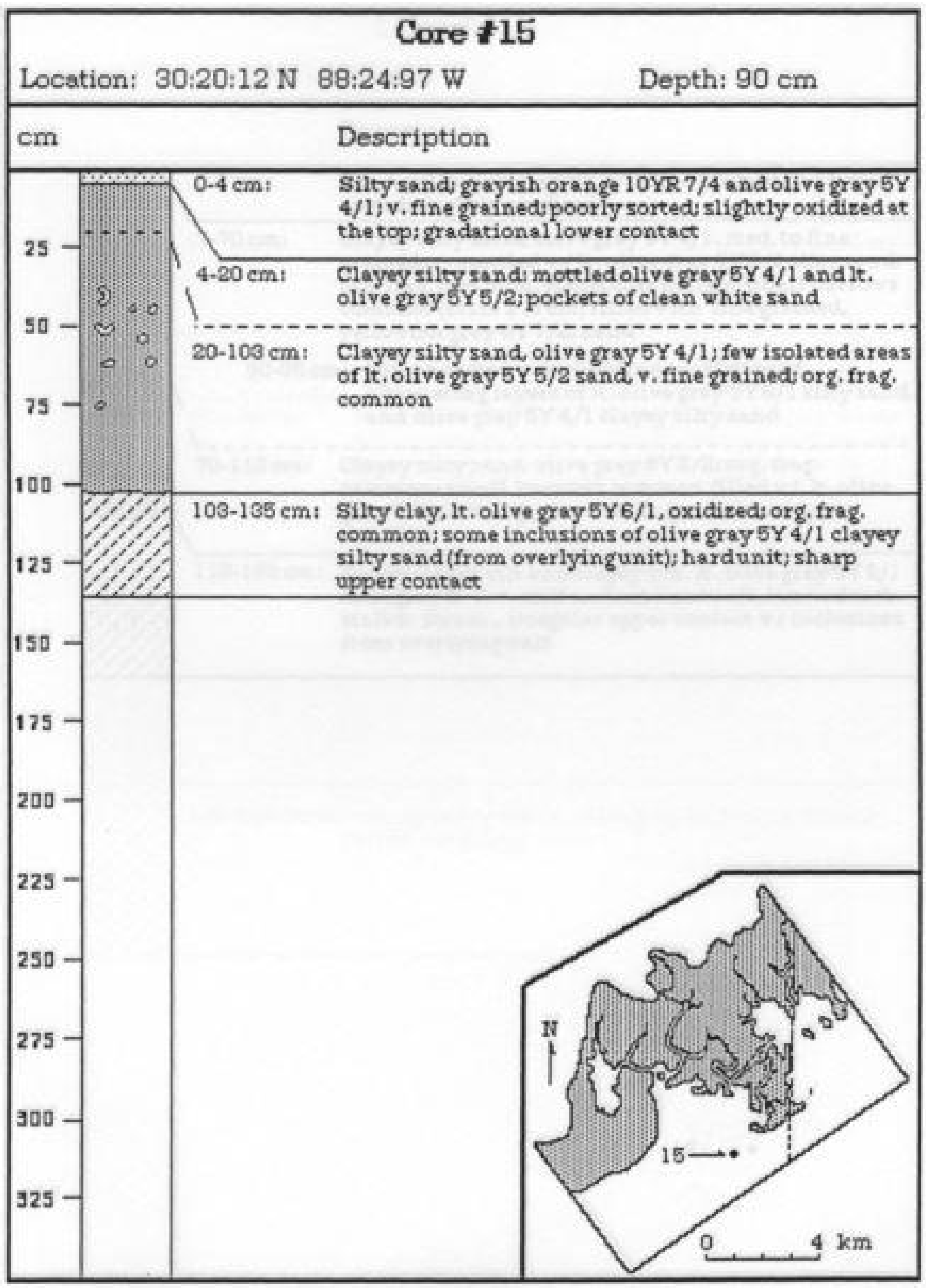
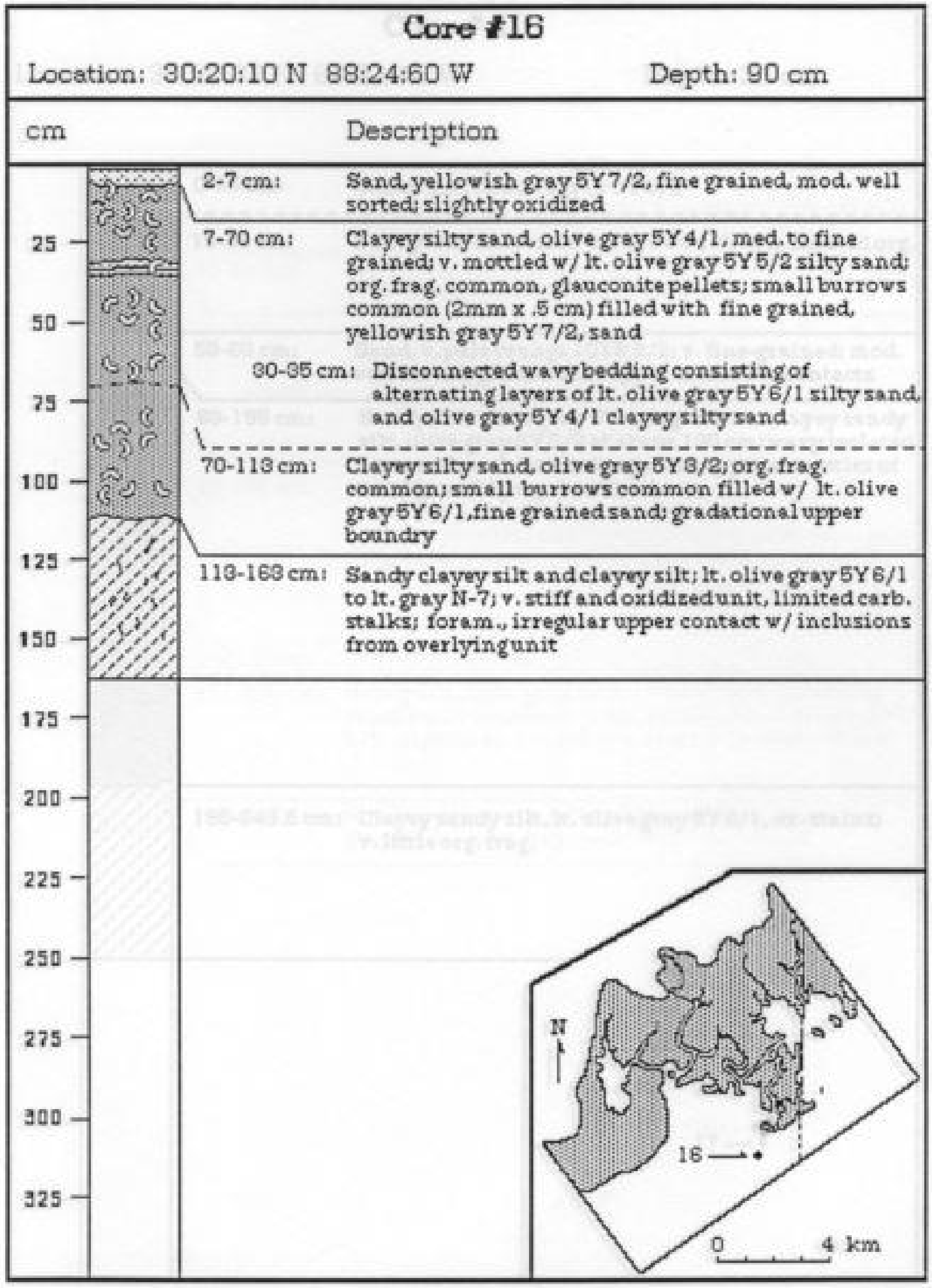


Figure A.20 Kramer sediment core 15

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations



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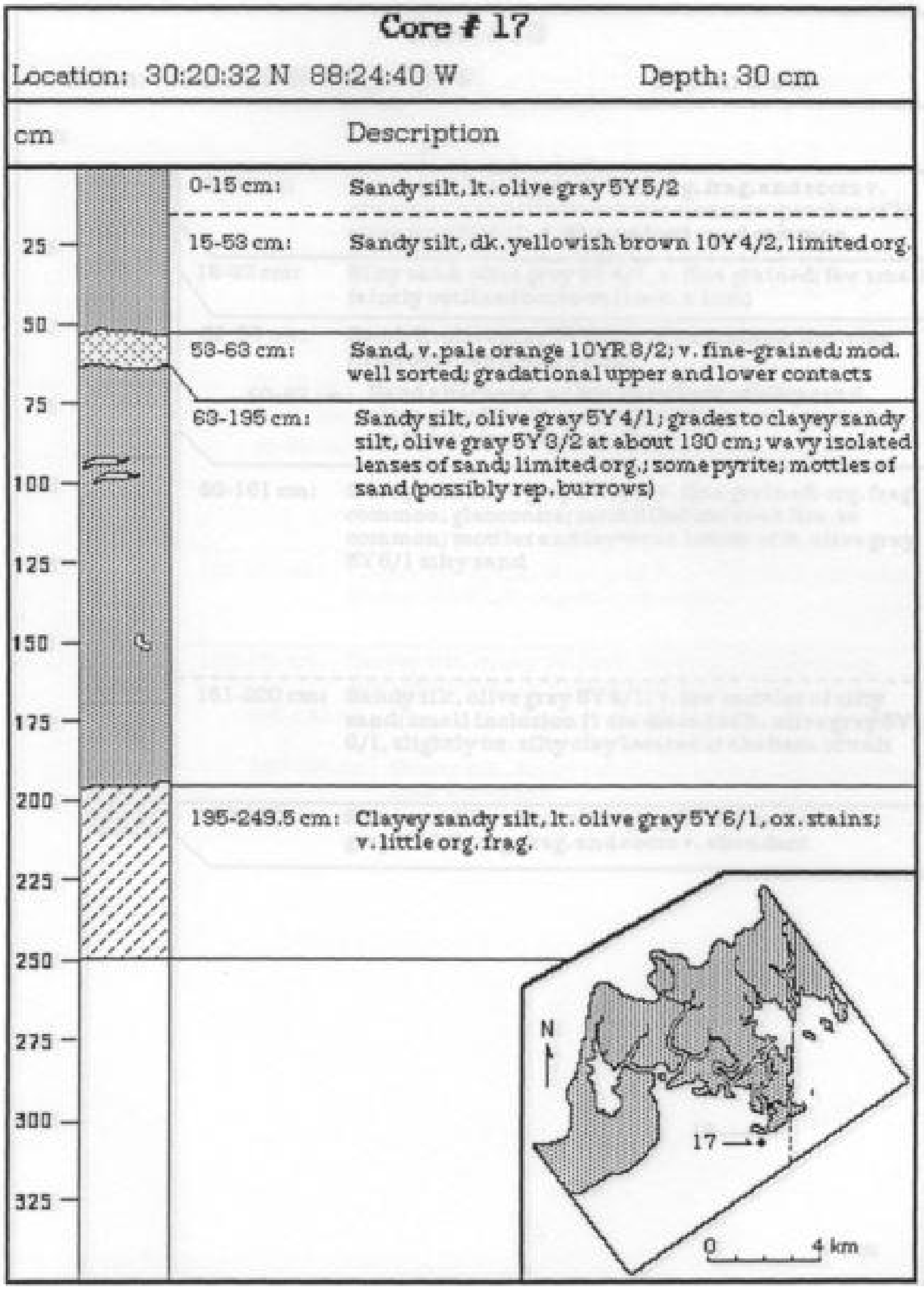
Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations



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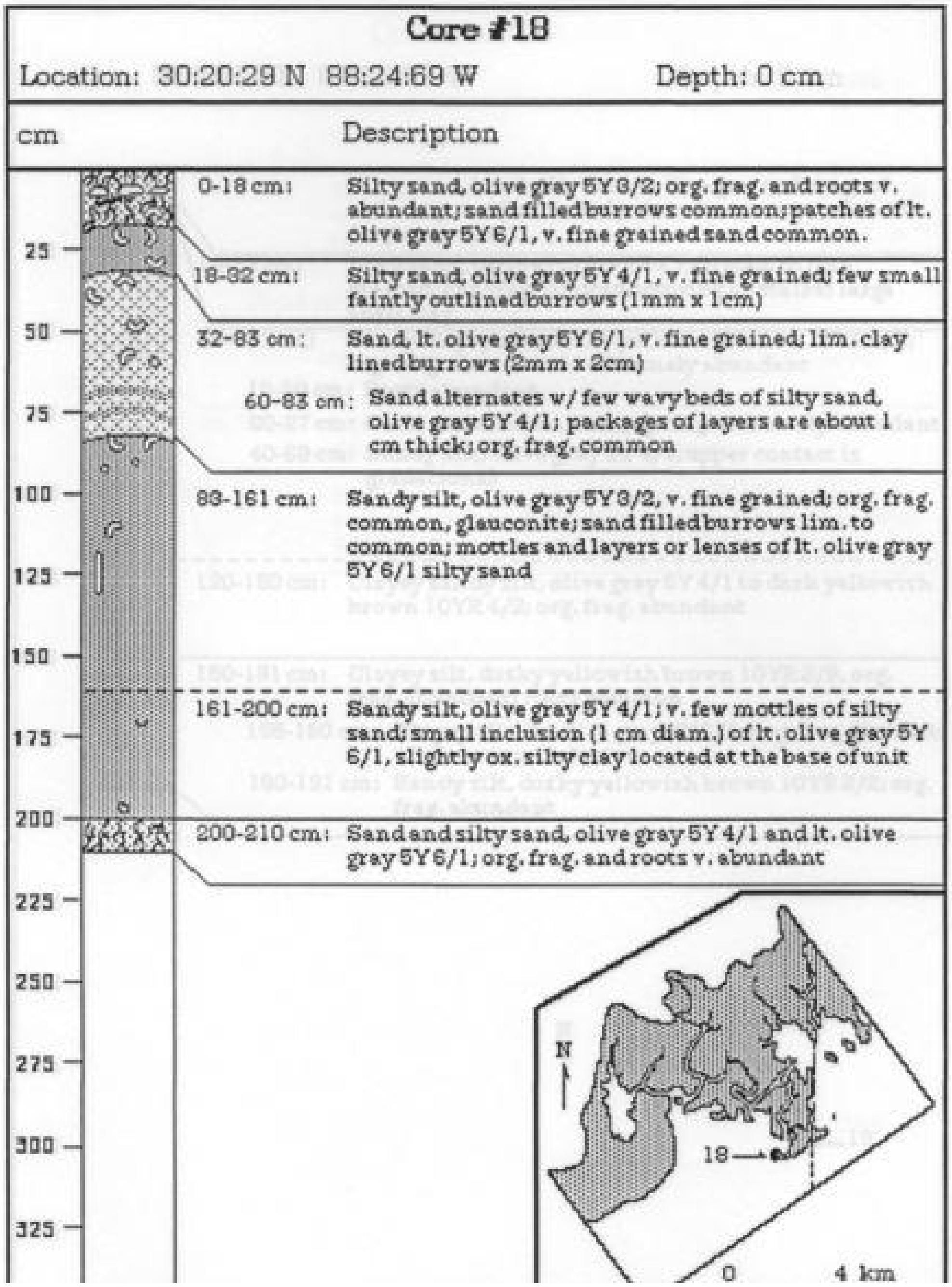

Figure A.23 Kramer sediment core 18

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

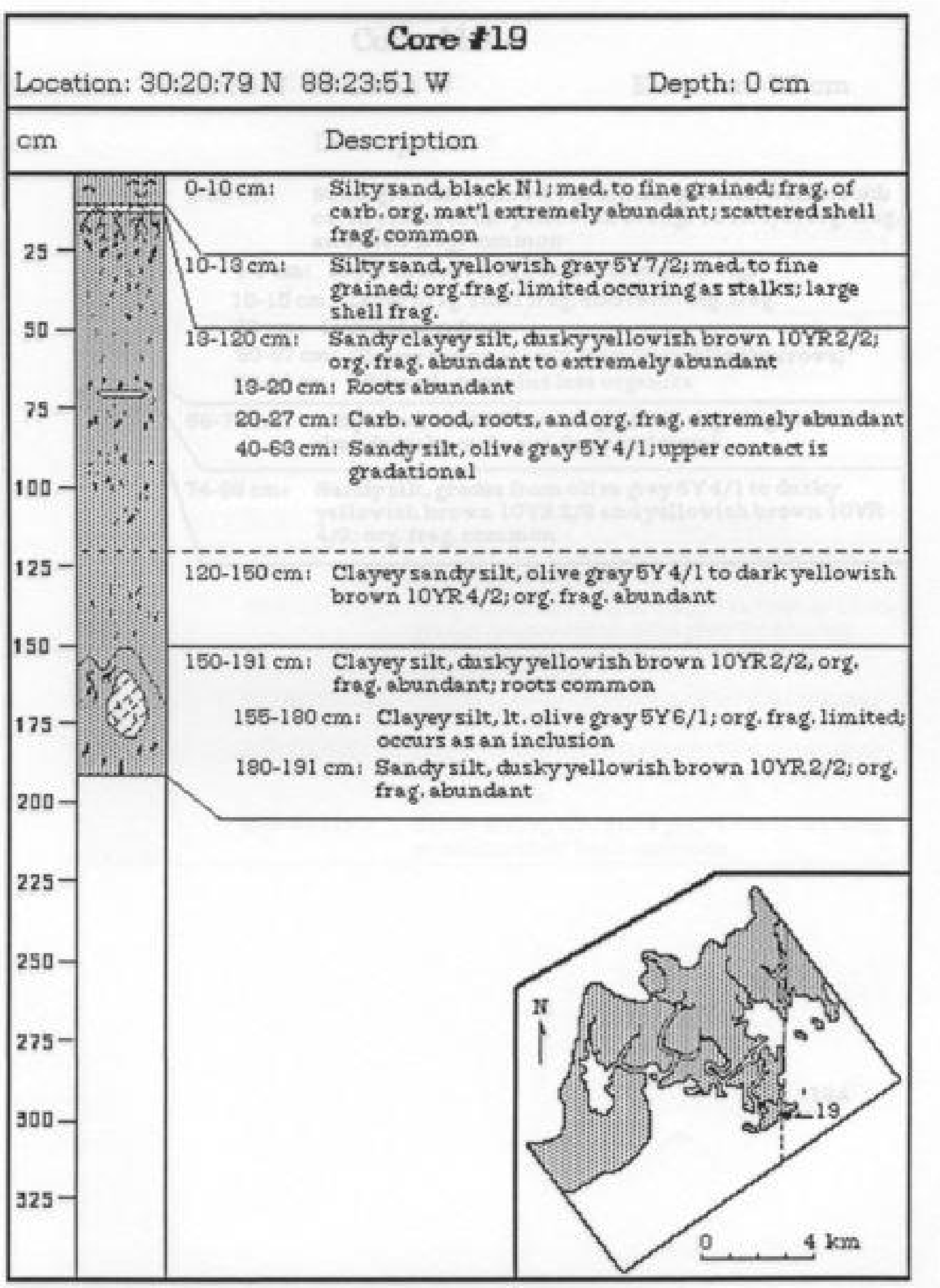

Figure A.24 Kramer sediment core 19

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

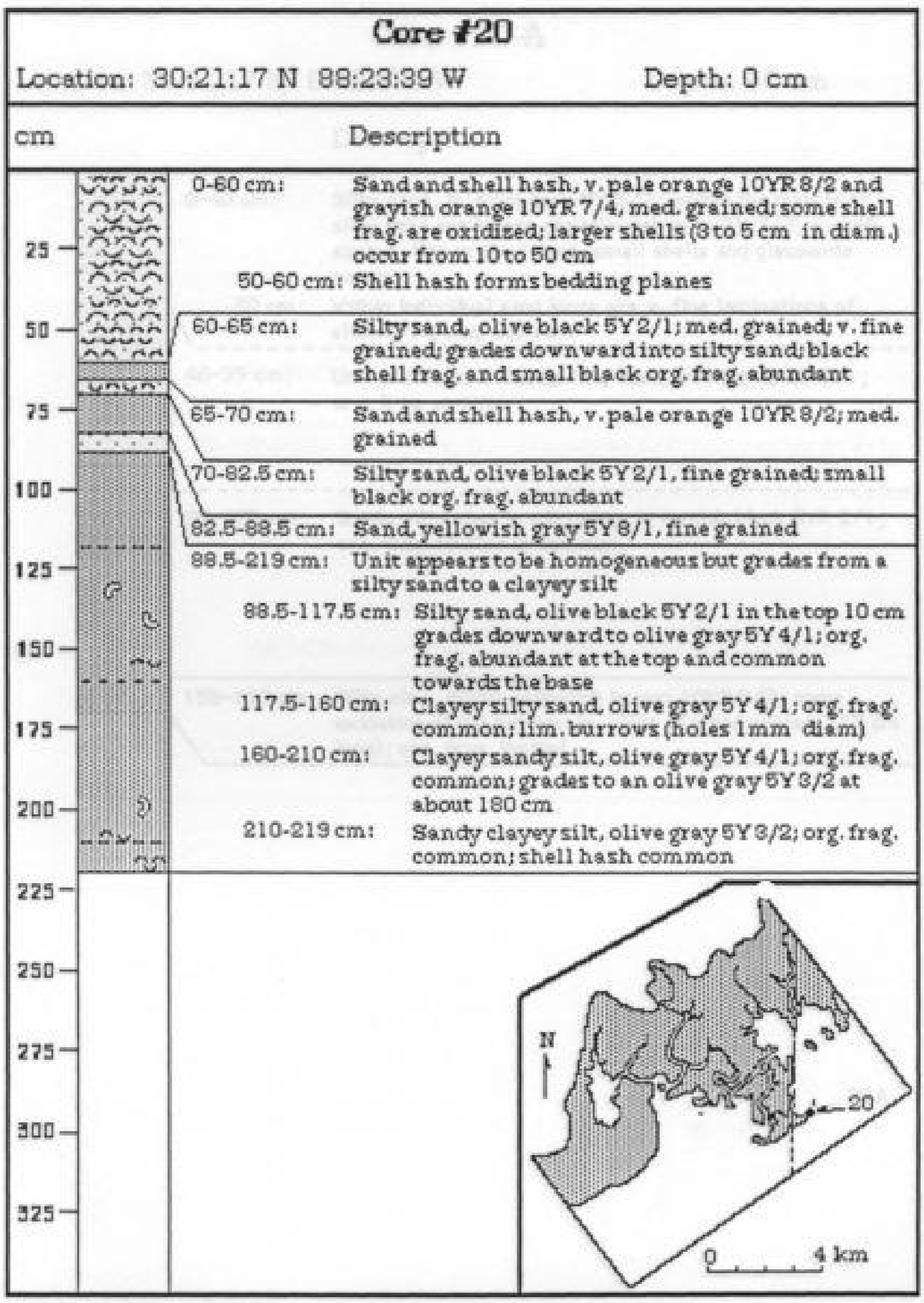

Figure A.25 Kramer sediment core 20

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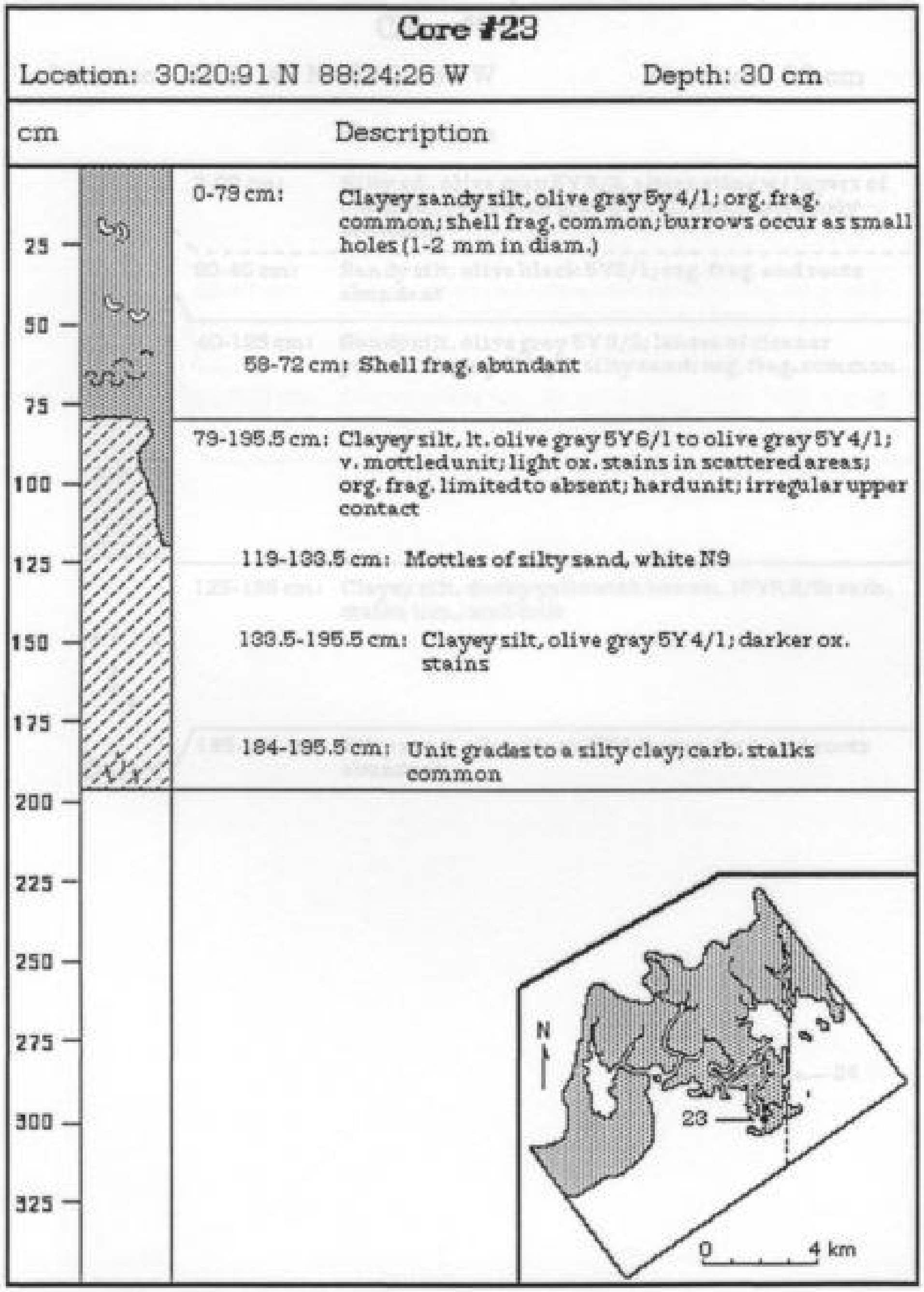

Figure A.26 Kramer sediment core 23

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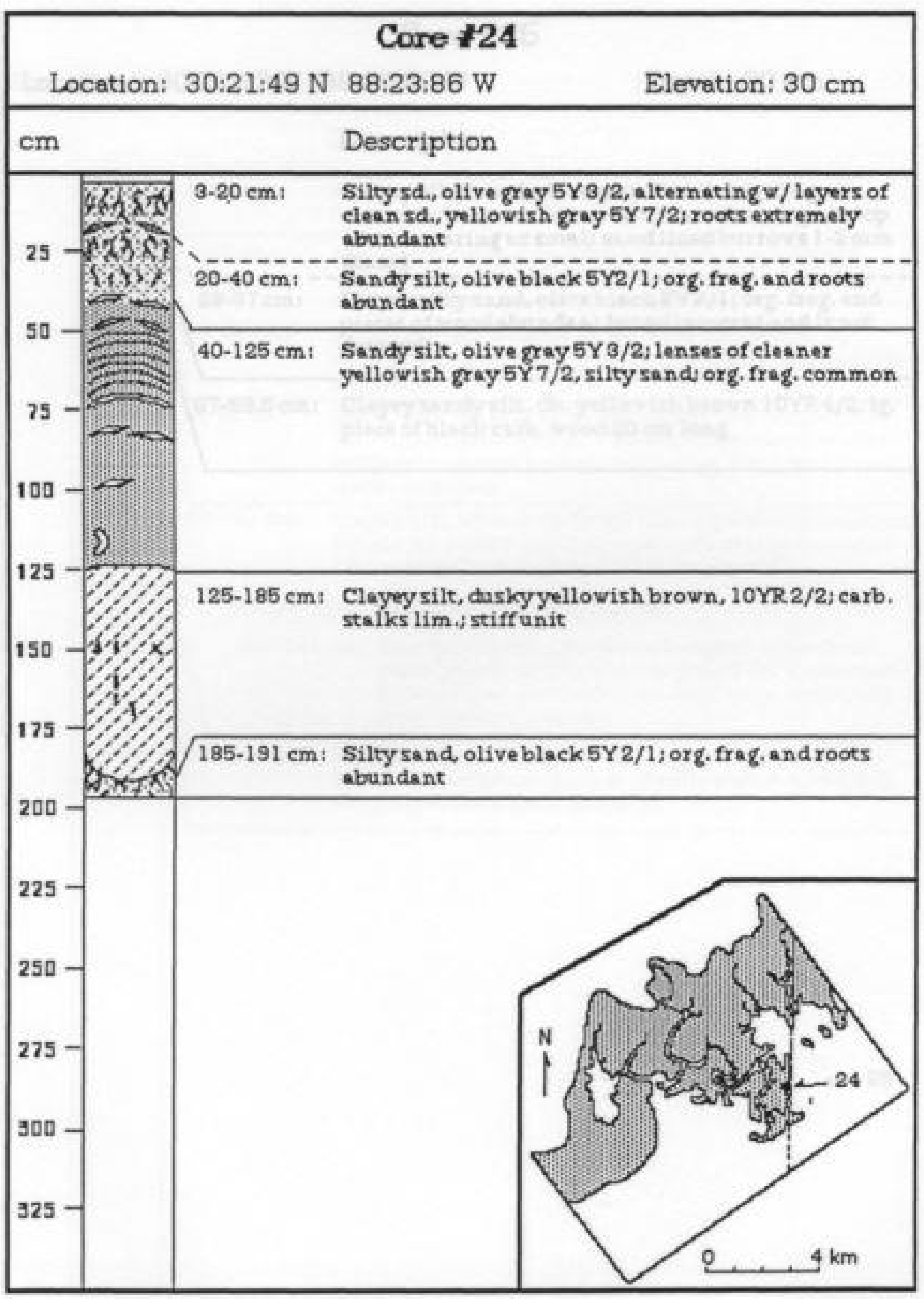

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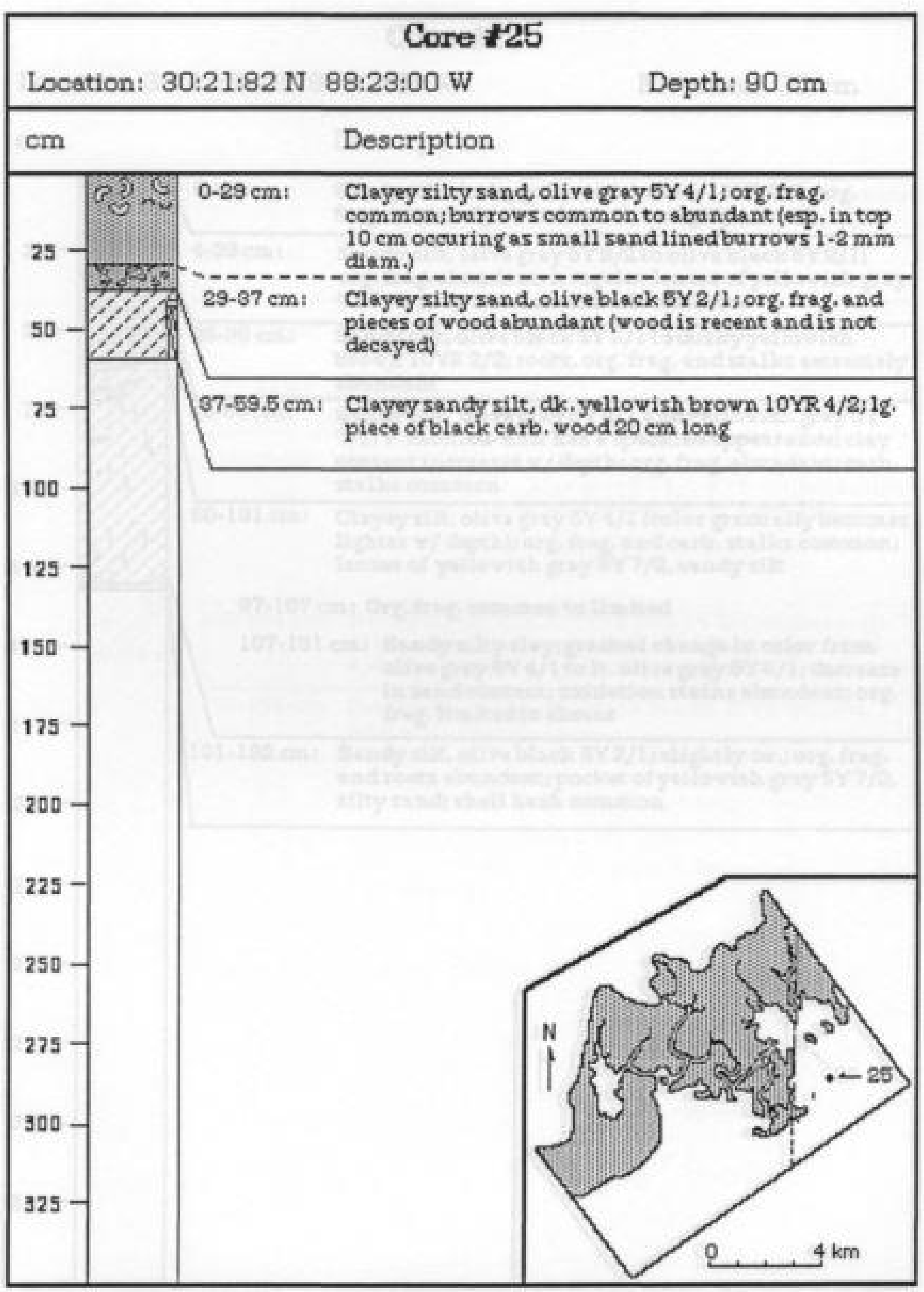

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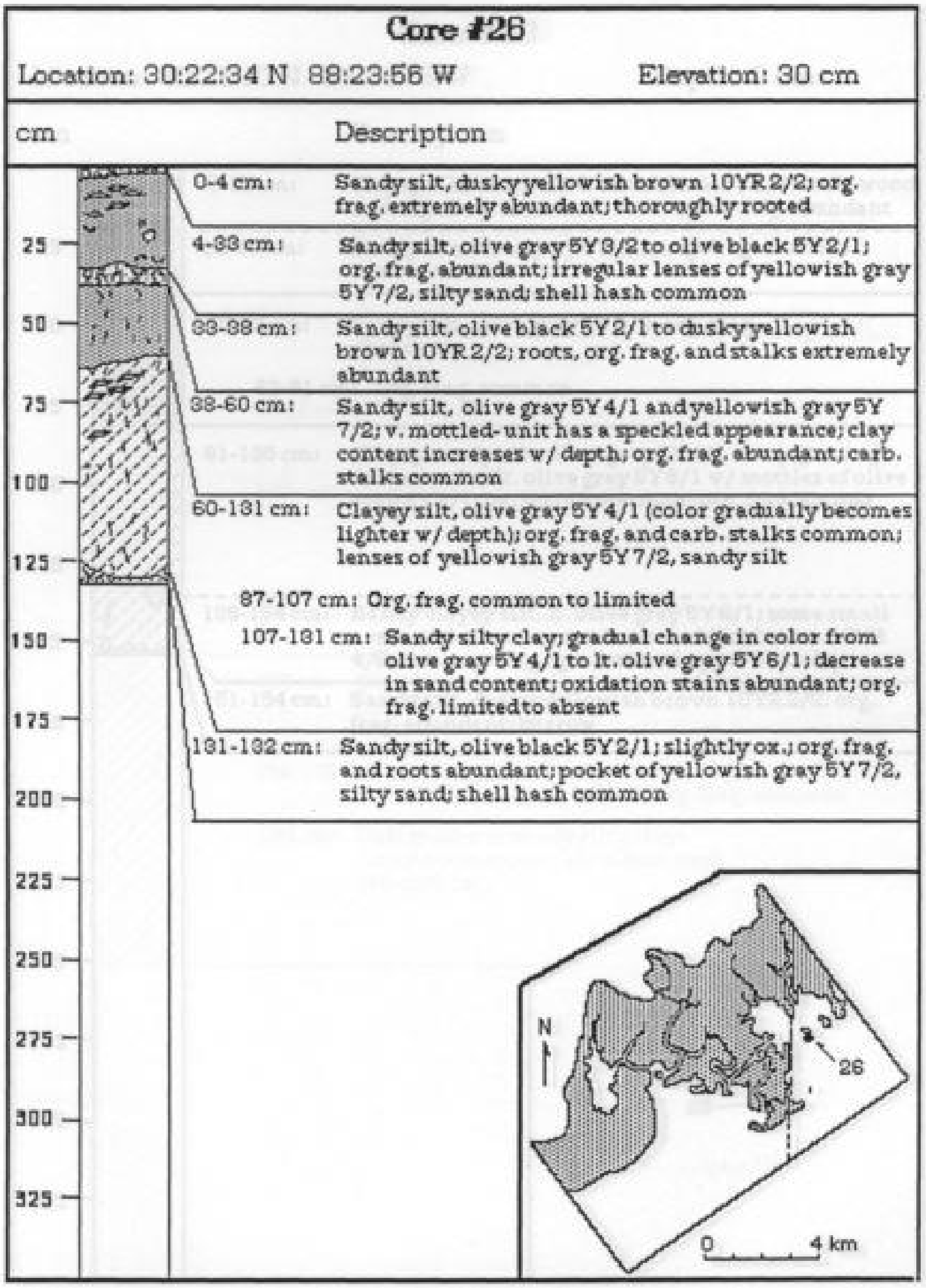

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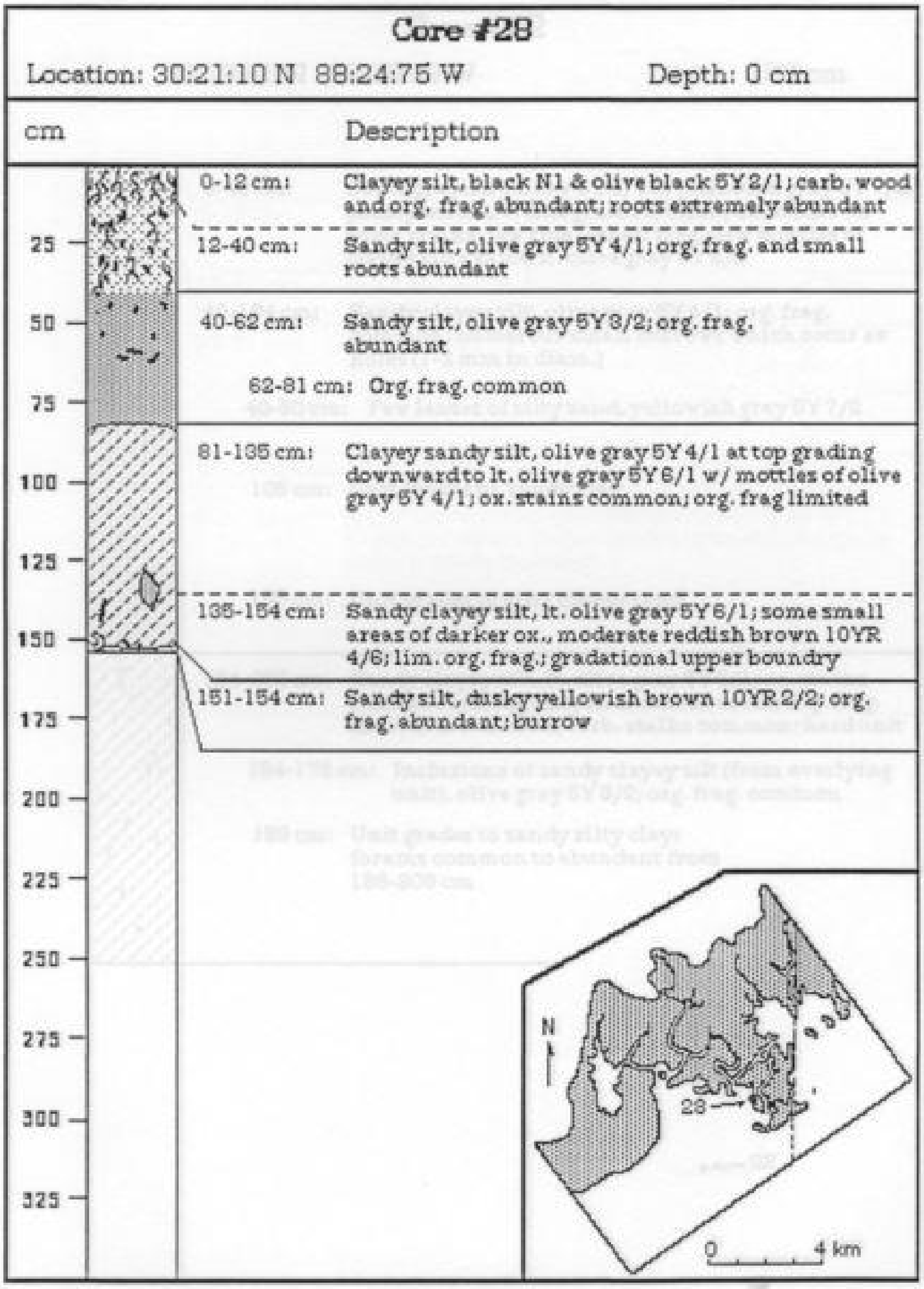
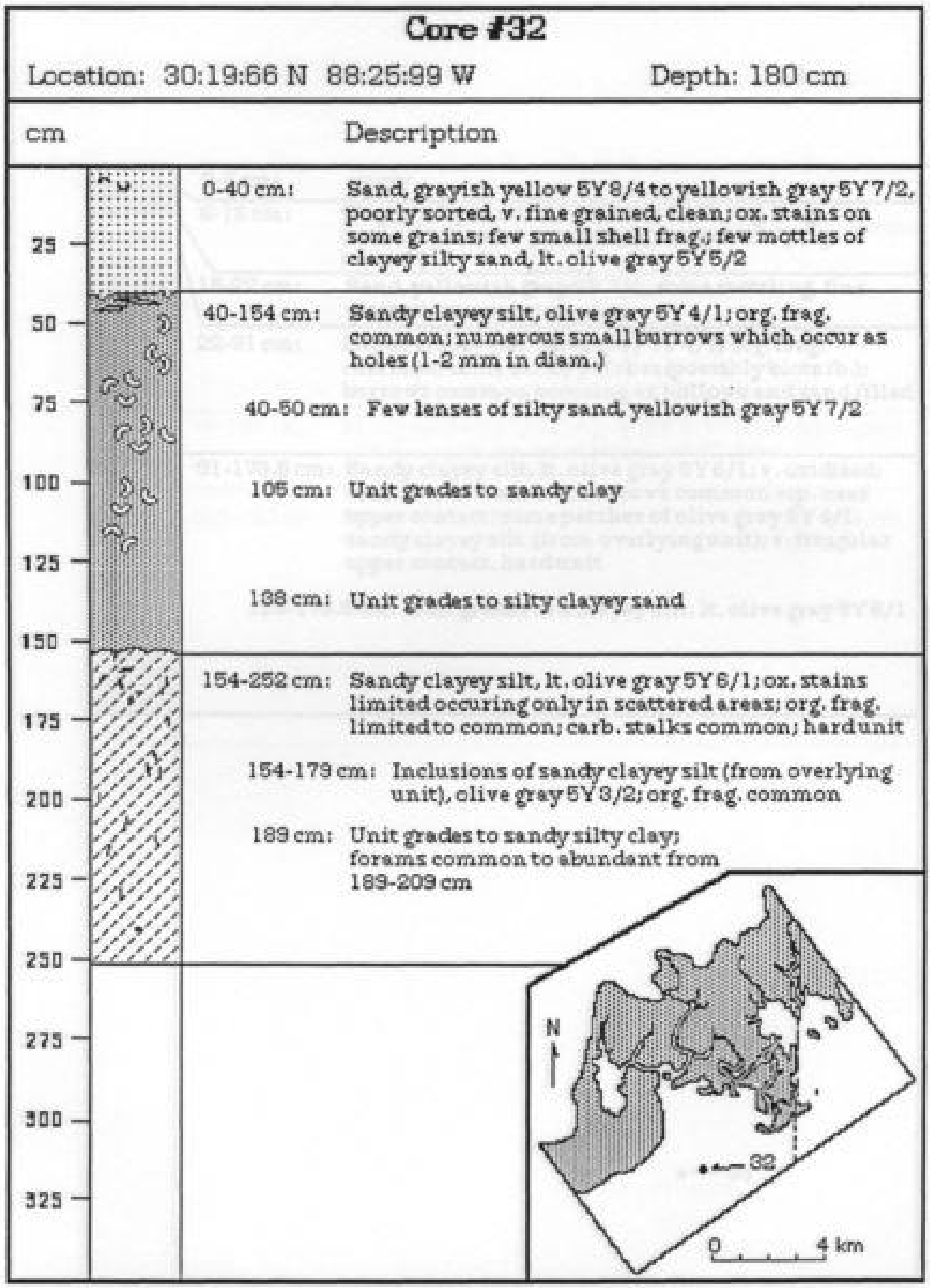


Figure A.30 Kramer sediment core 28

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations



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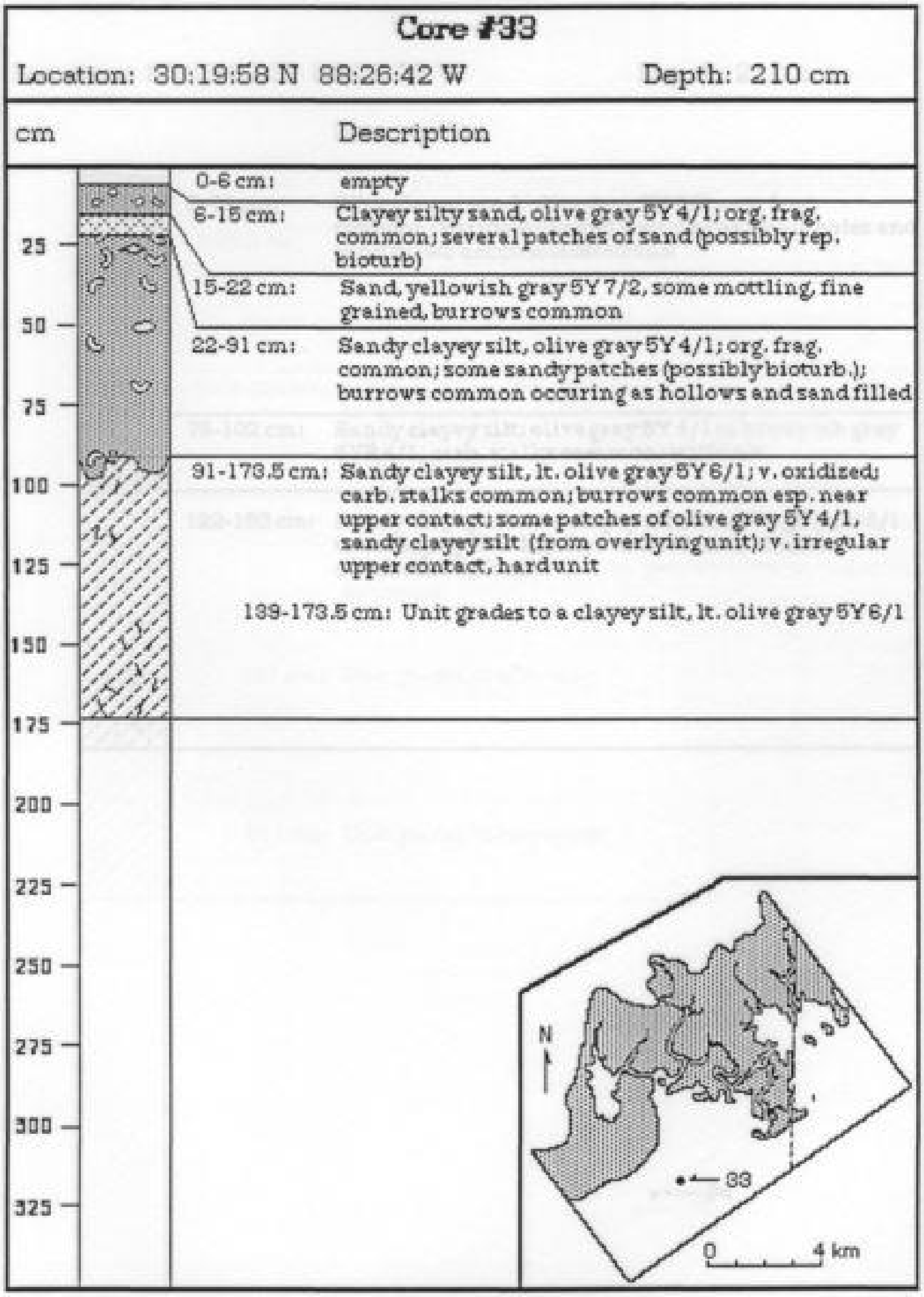

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Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

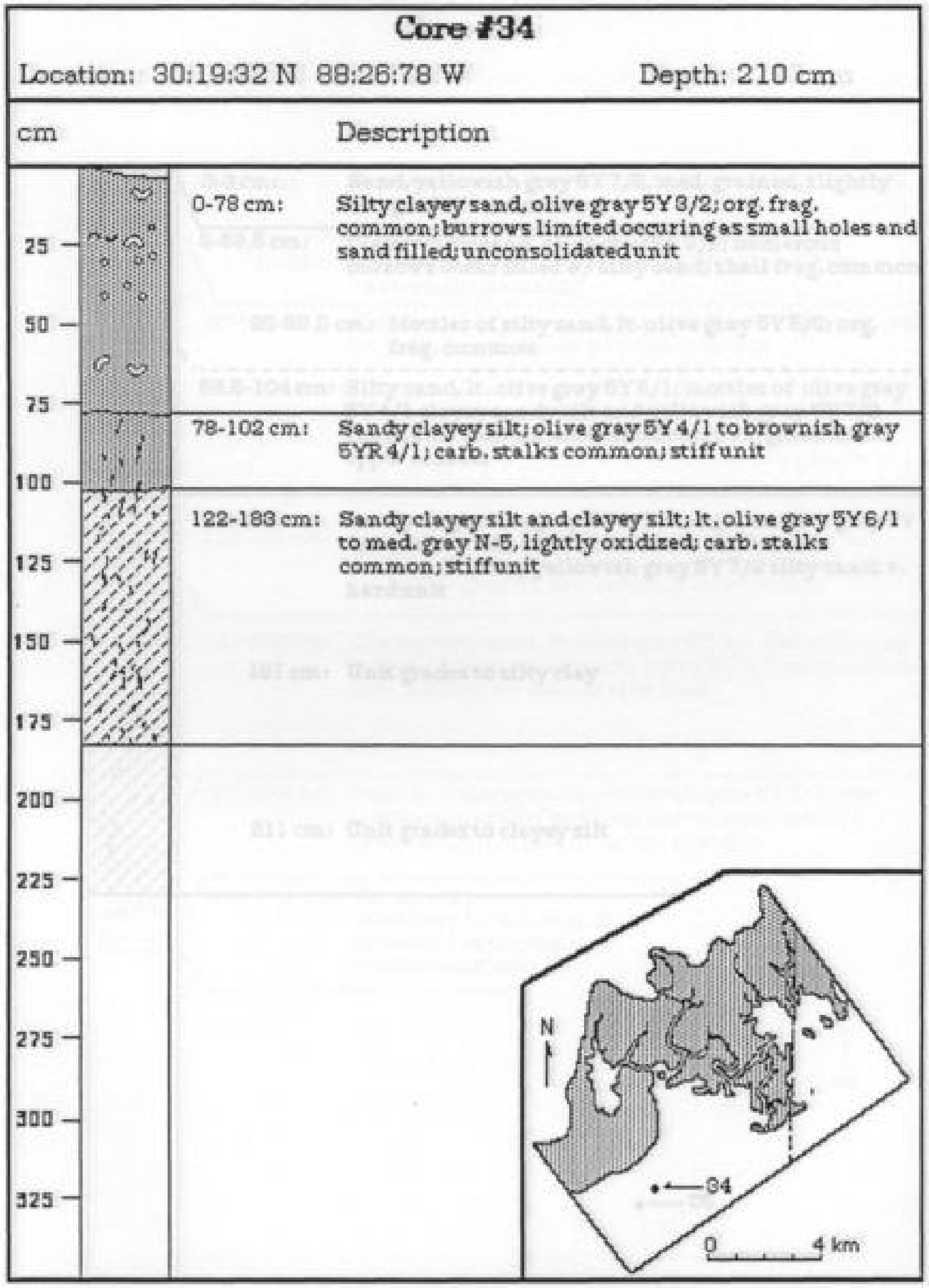

Figure A.33 Kramer sediment core 34

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

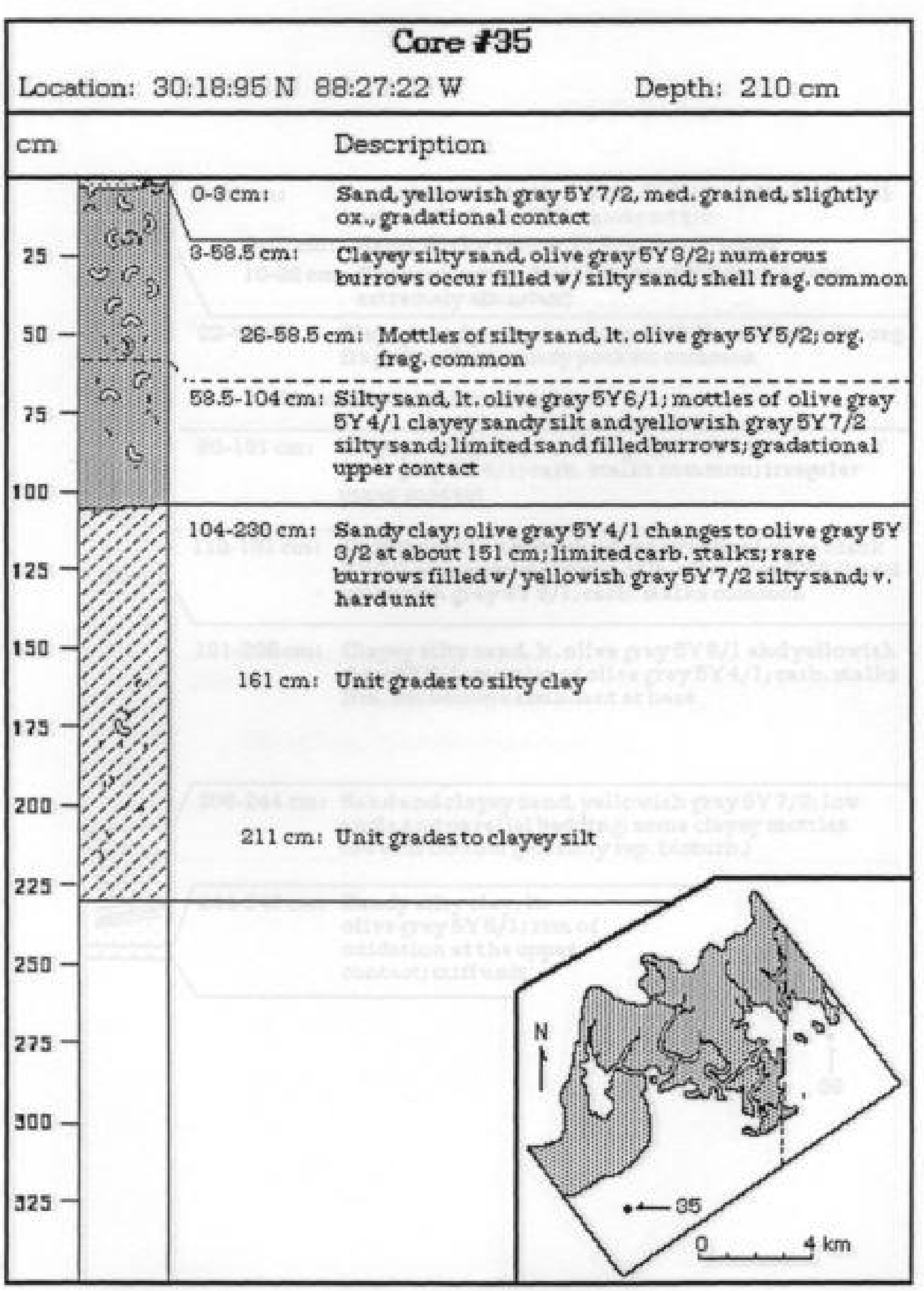

Figure A.34 Kramer sediment core 35

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

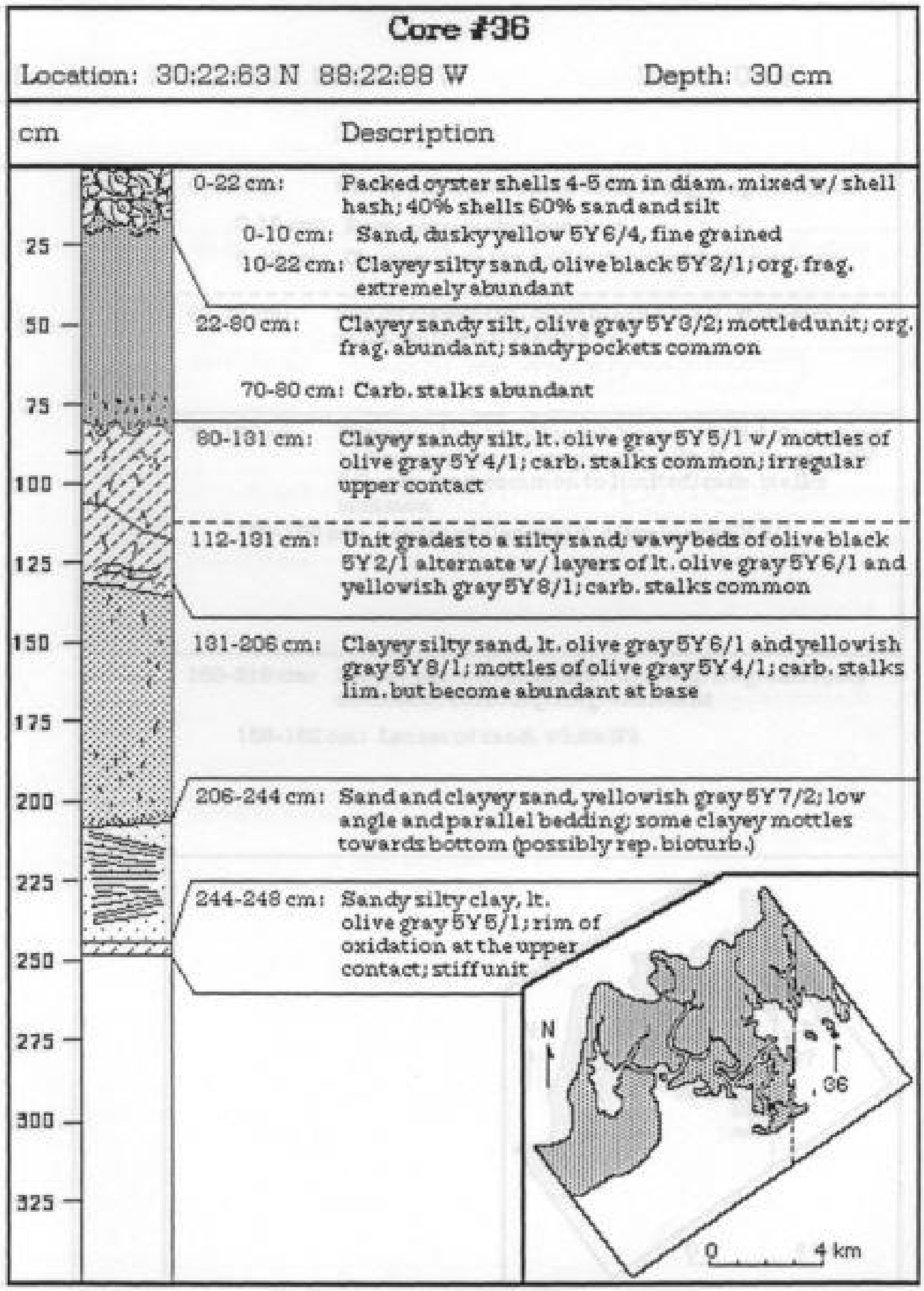

Figure A.35 Kramer sediment core 36

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

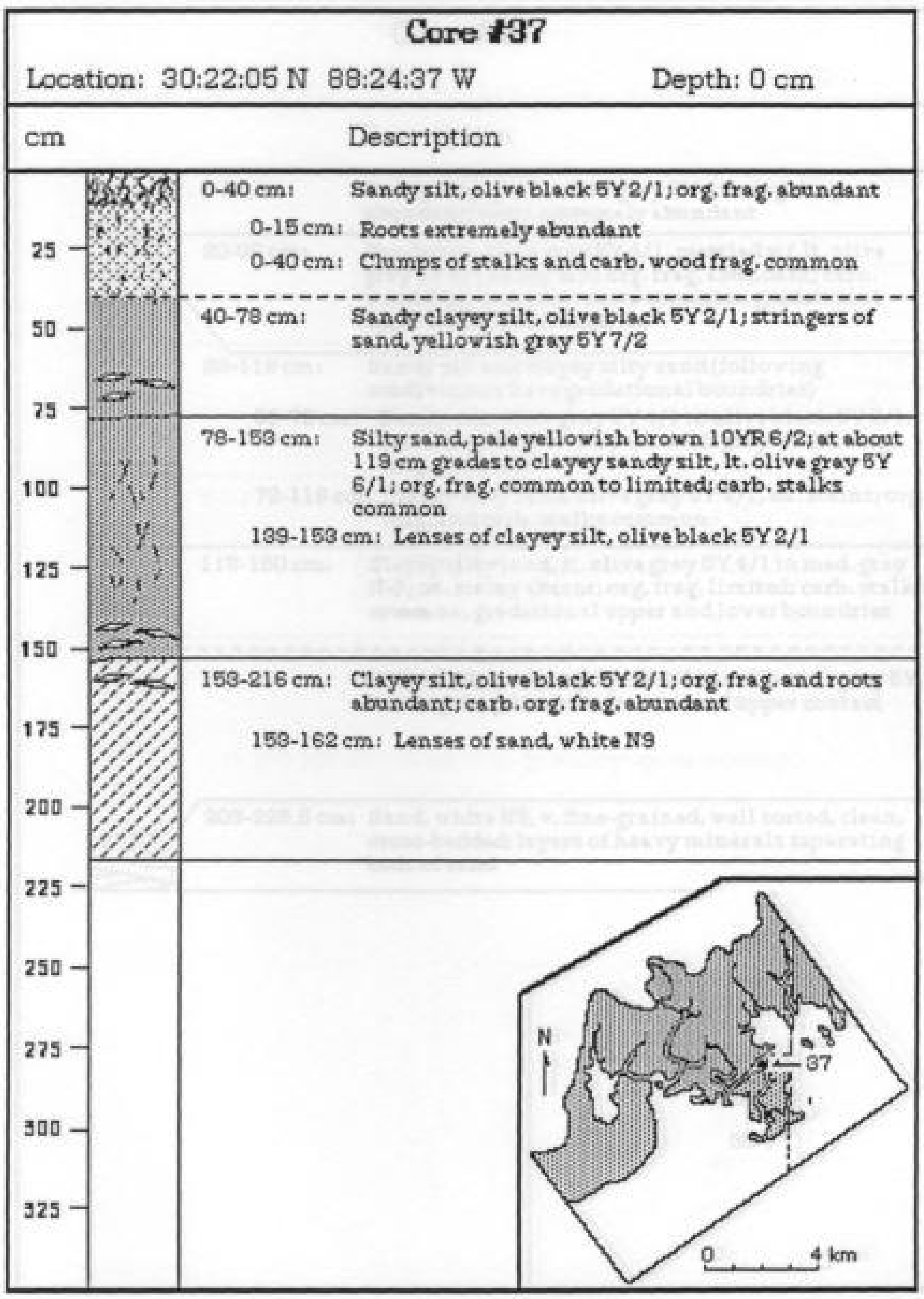

Figure A.36 Kramer sediment core 37

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

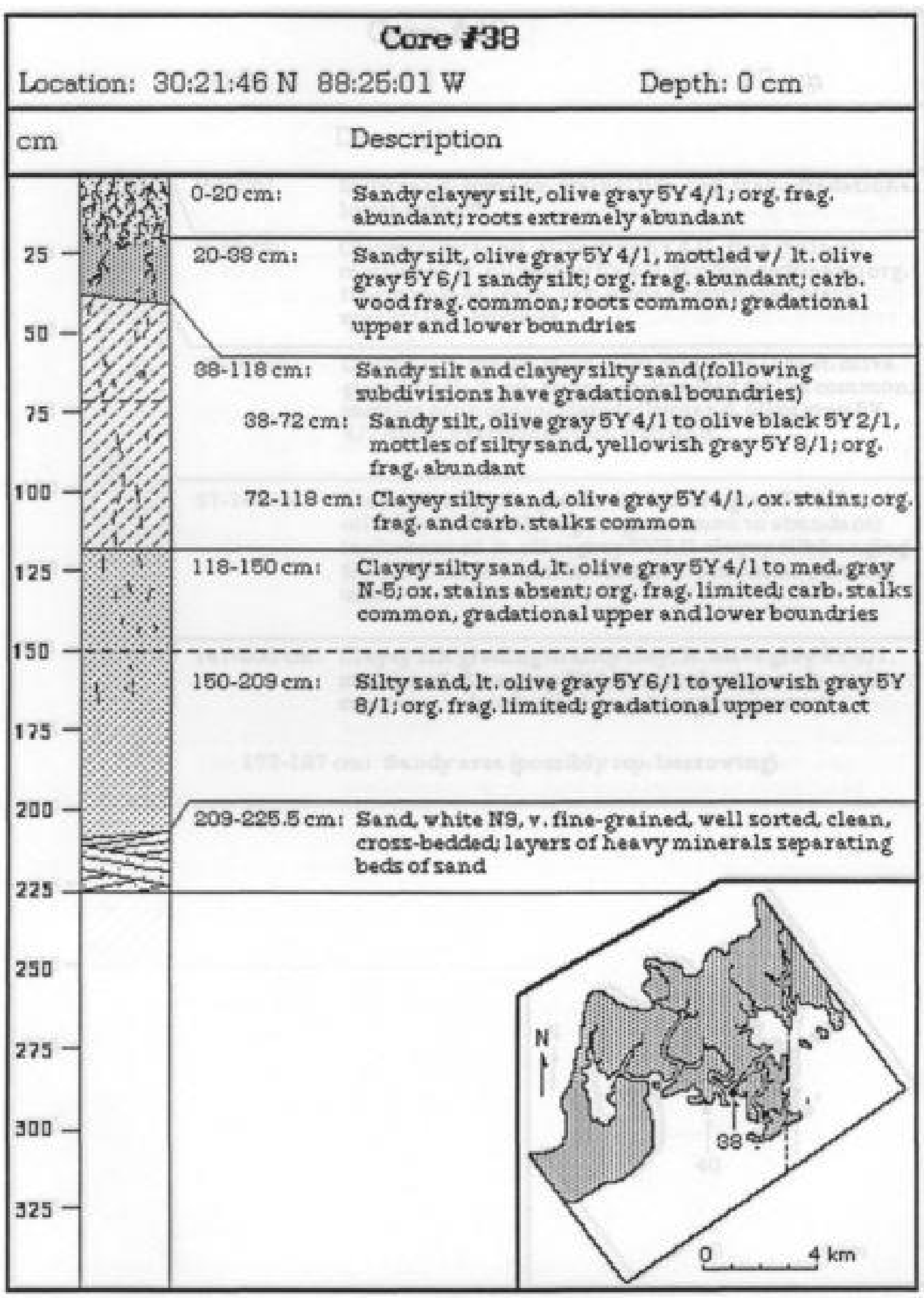

Figure A.37 Kramer sediment core 38

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

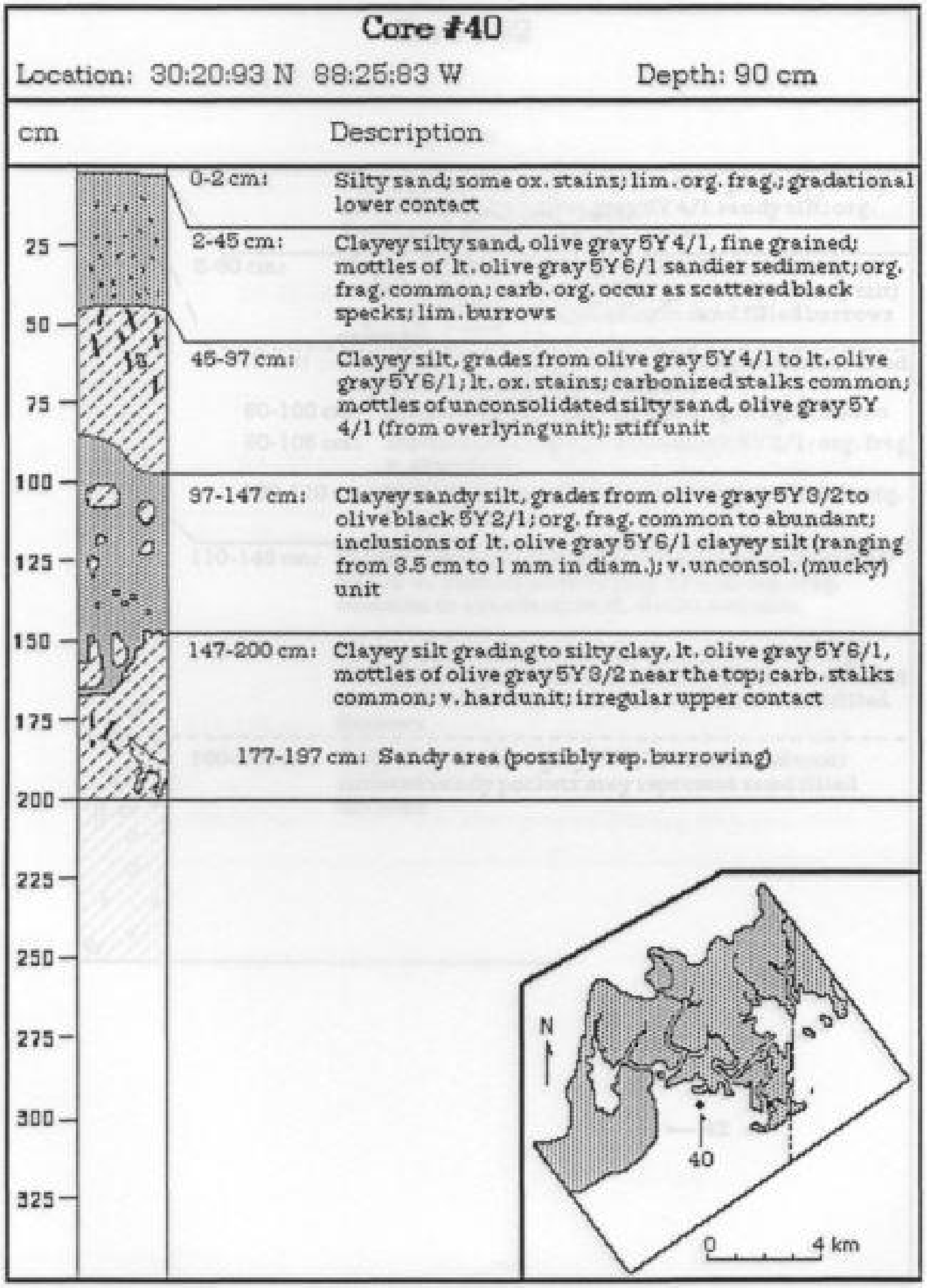

Figure A.38 Kramer sediment core 40

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

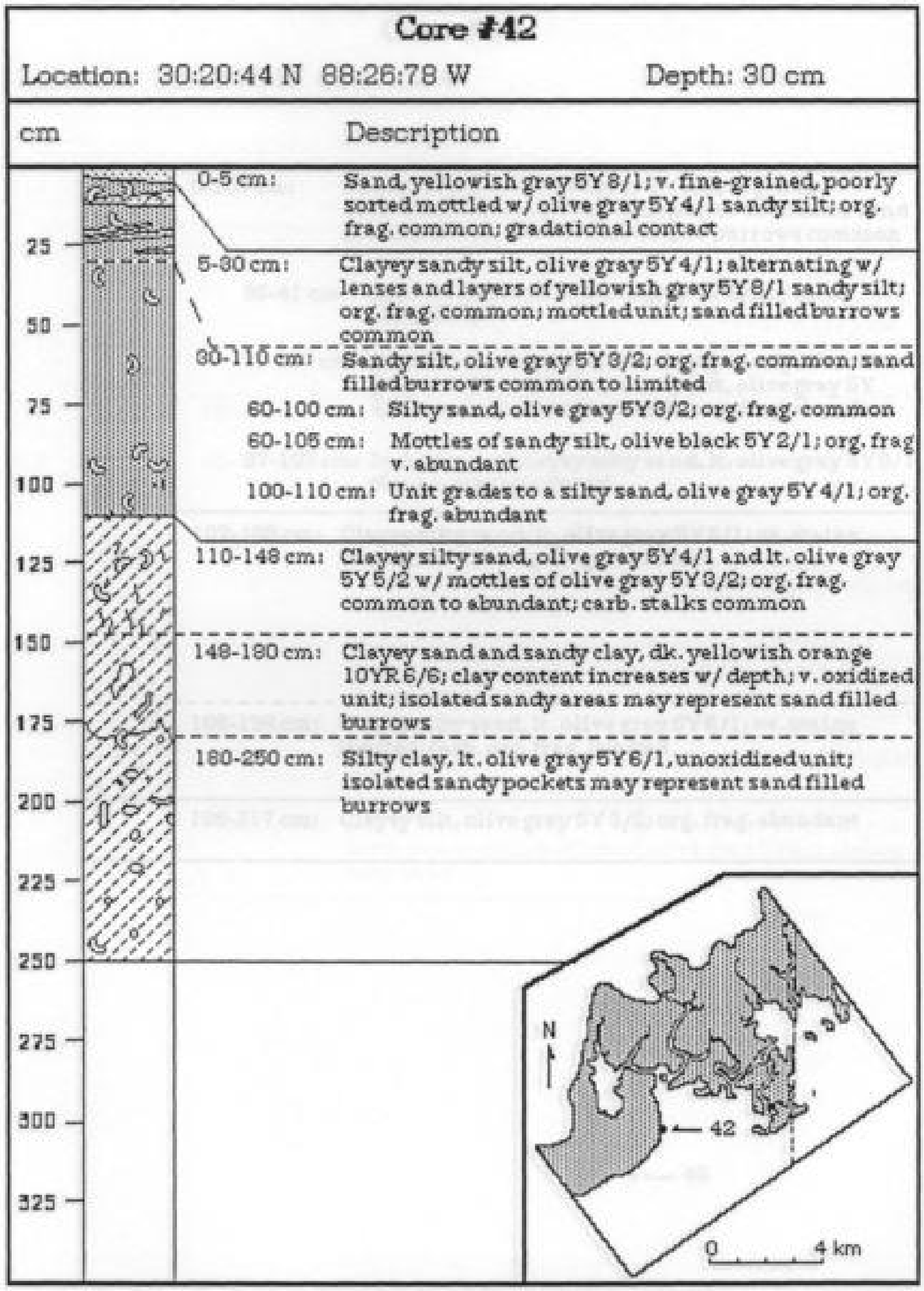

Figure A.39 Kramer sediment core 42

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

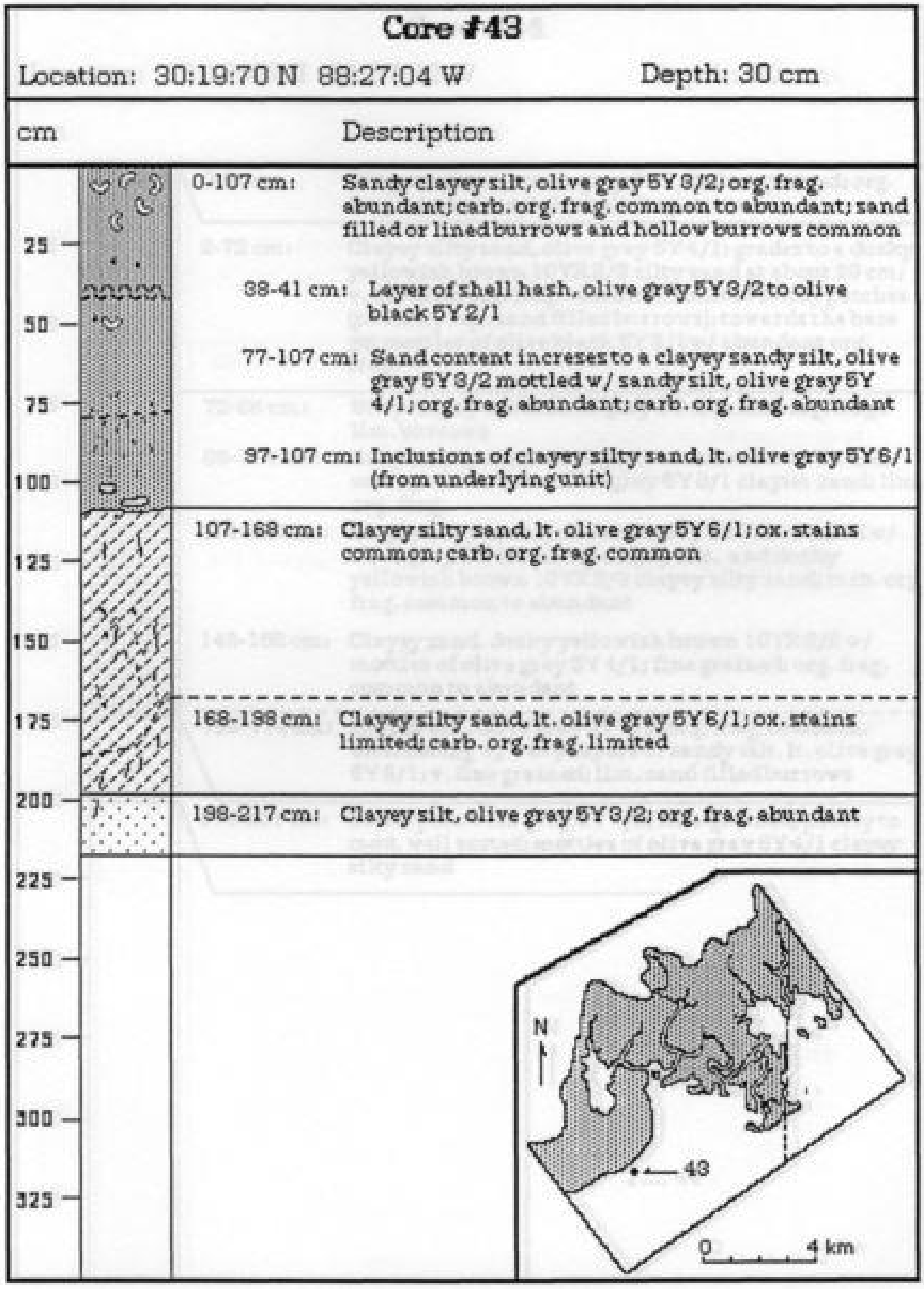

Figure A.40 Kramer sediment core 43

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

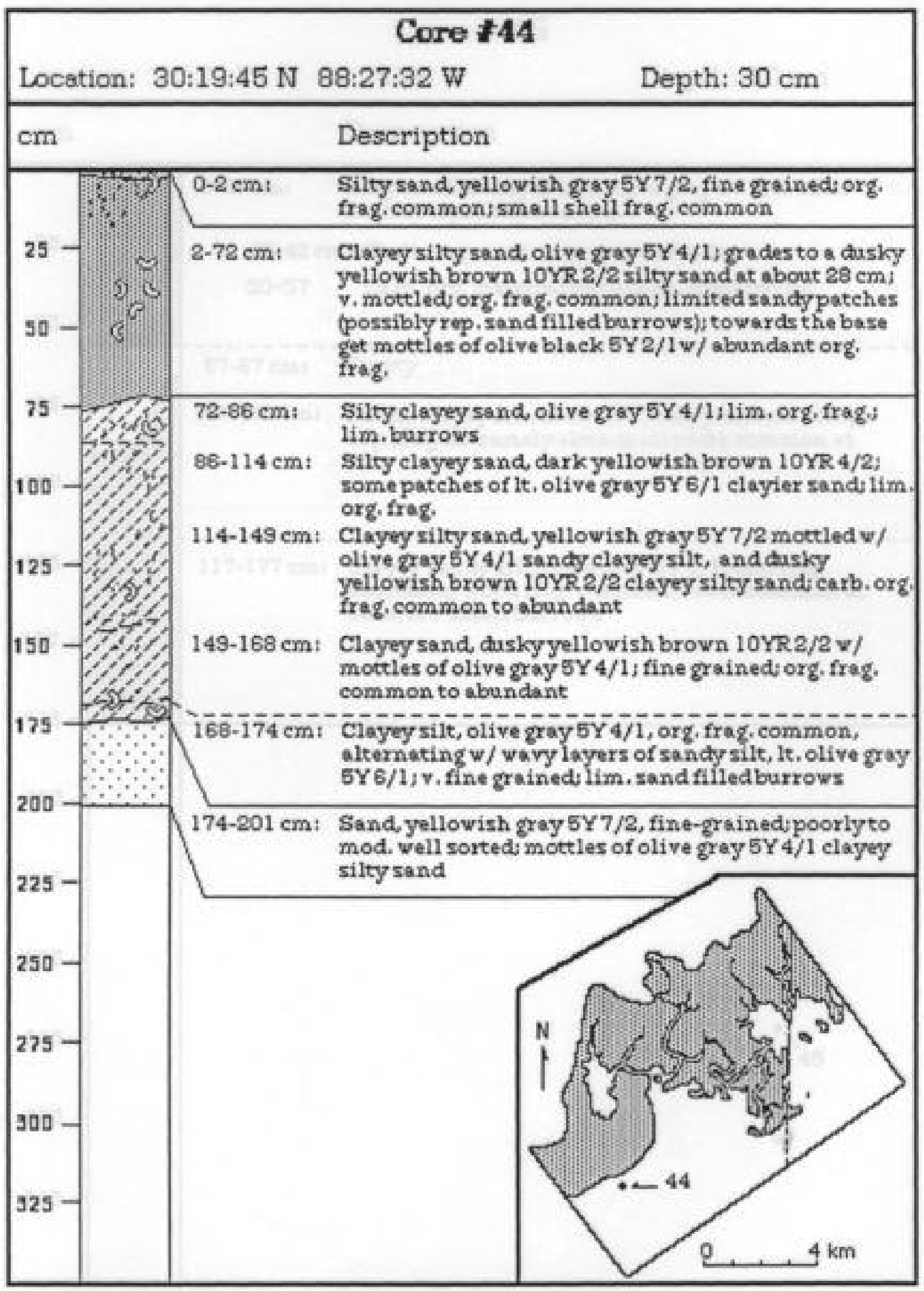

Figure A.41 Kramer sediment core 44

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

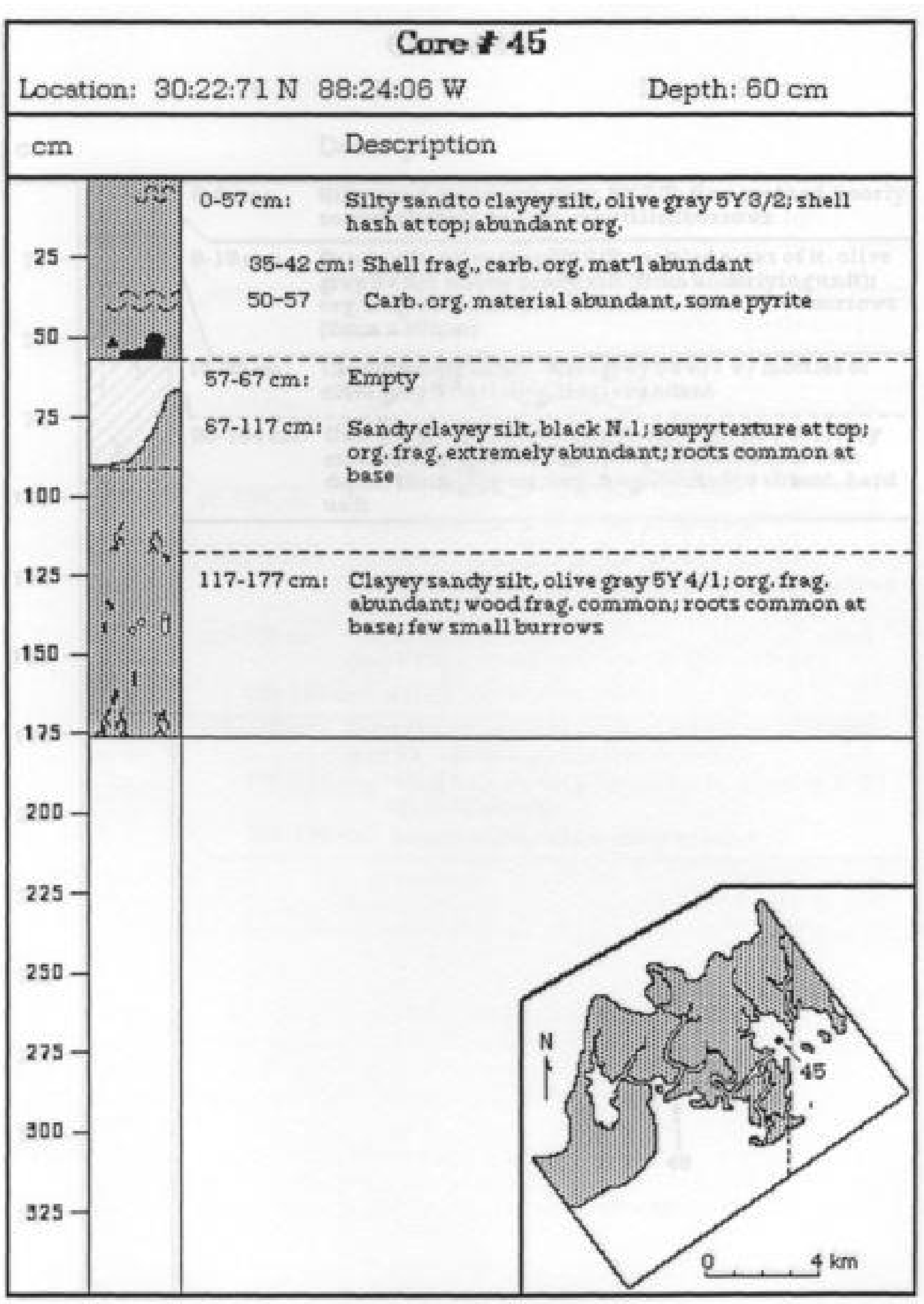

Figure A.42 Kramer sediment core 45

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

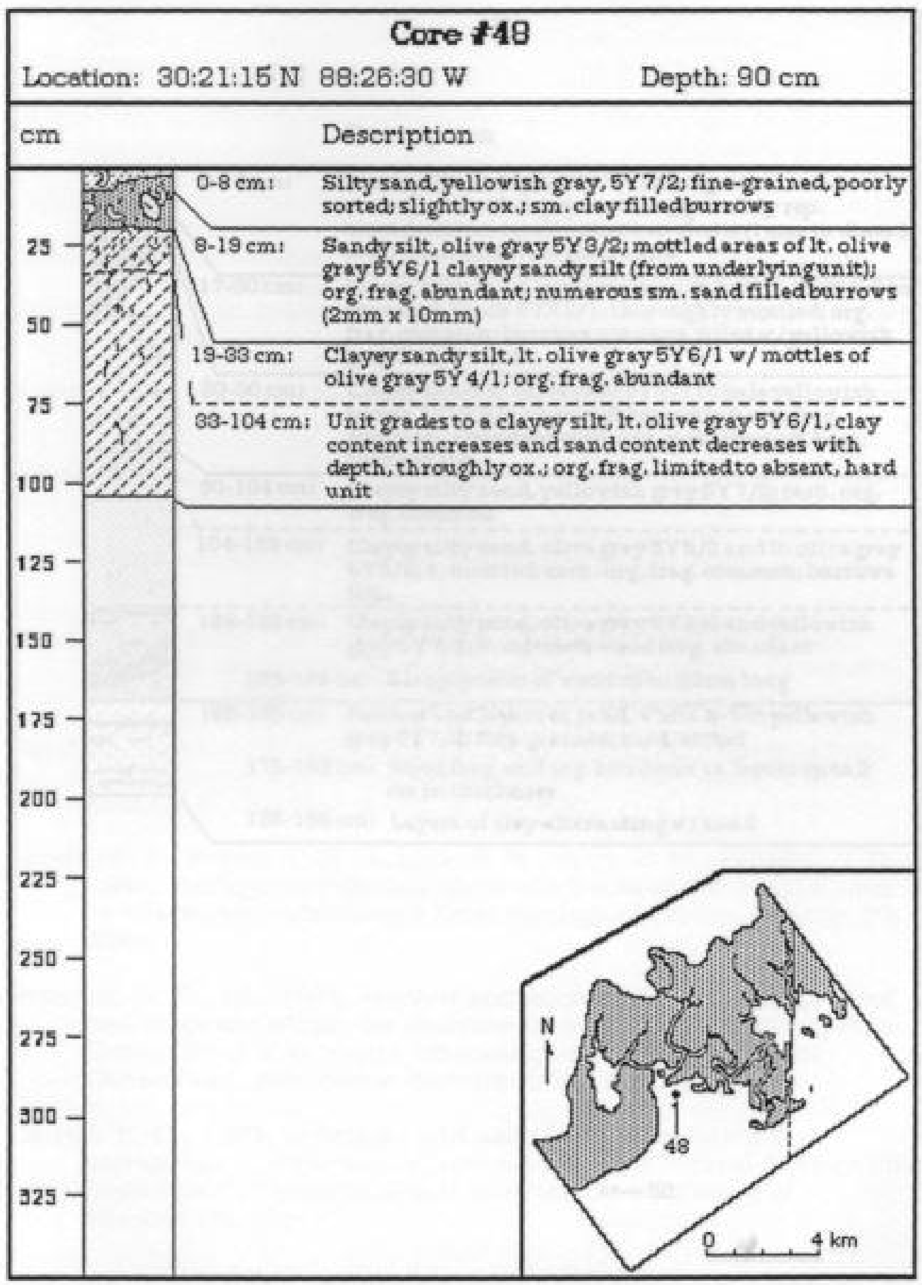

Figure A.43 Kramer sediment core 48

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

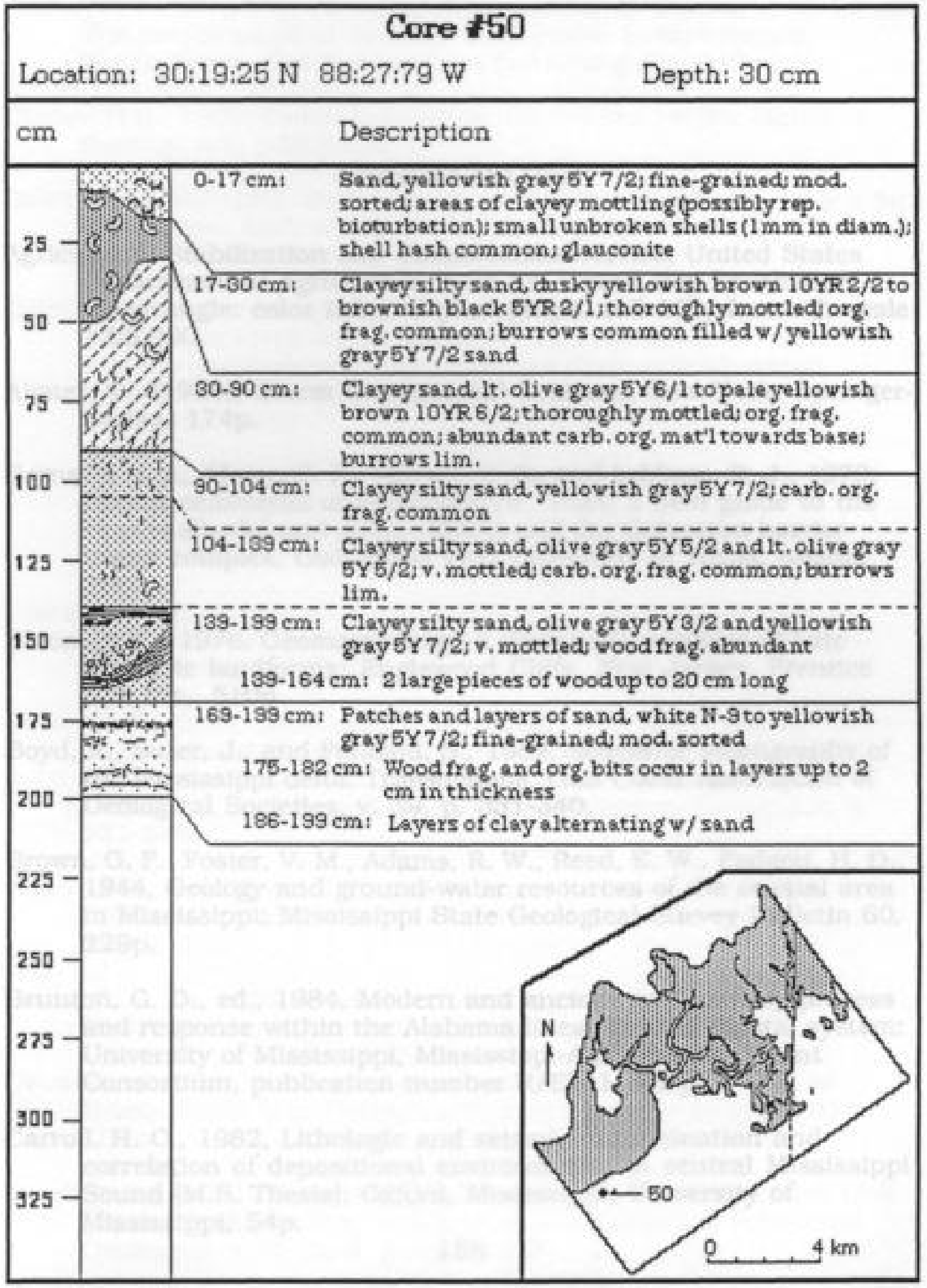

Figure A.44 Kramer sediment core 50

Shallow core was collected within the study area however they did not extend far enough through the subsurface to ground truth lower formations

Shoreline Change

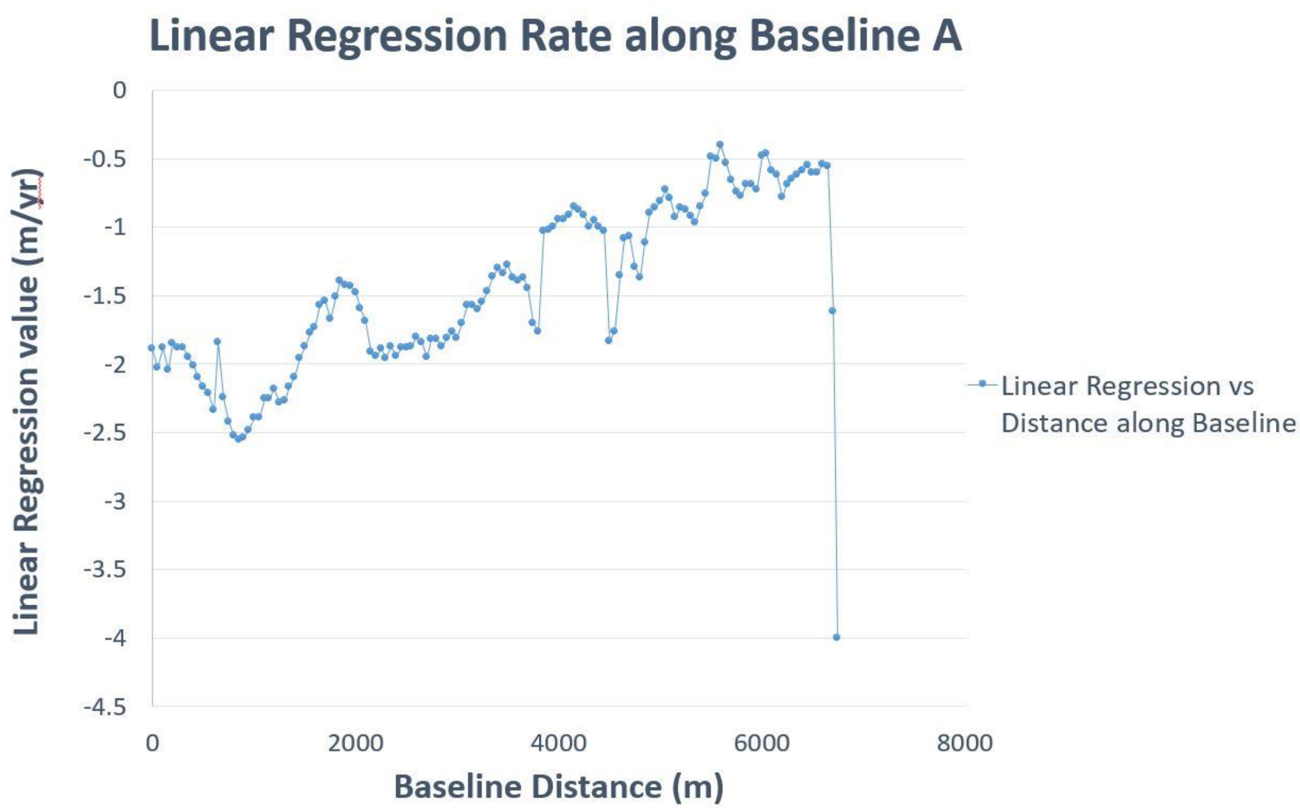

Figure A.45 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for western most portion of the study area

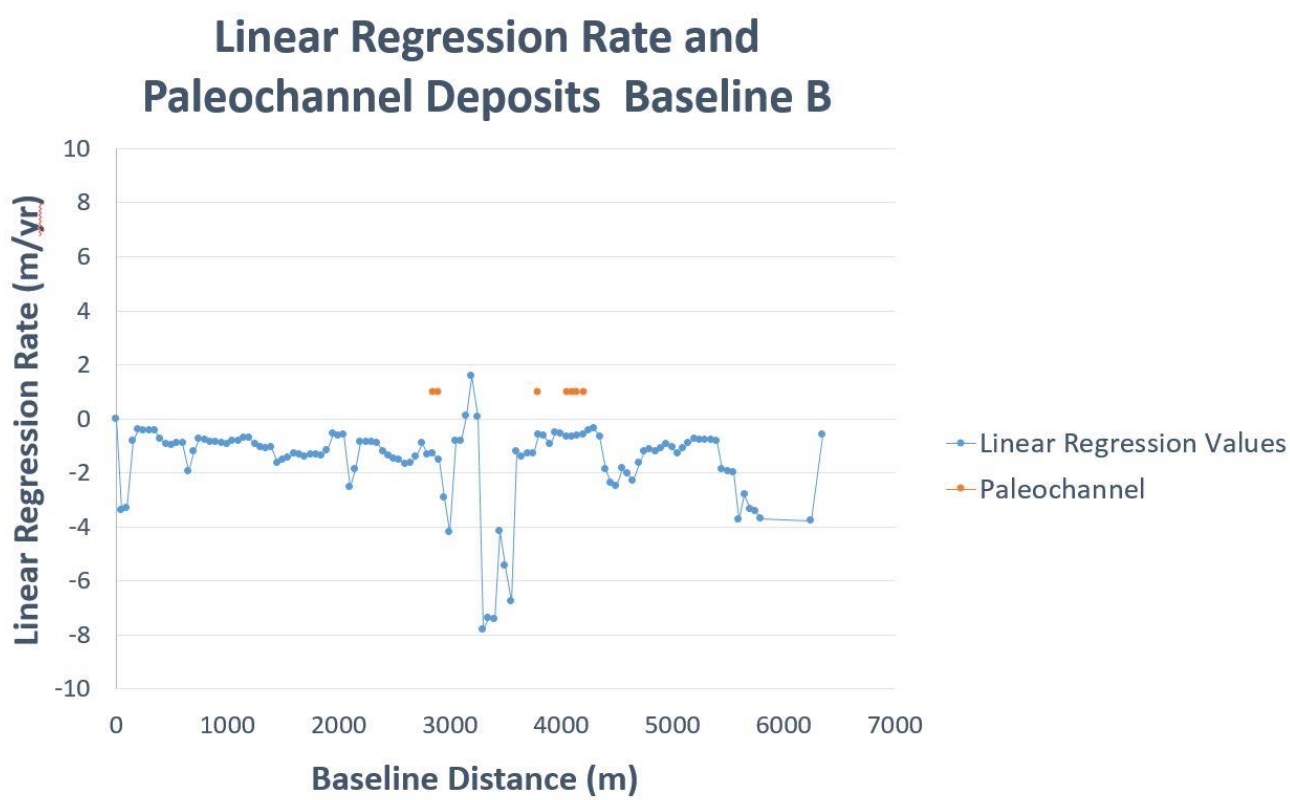

Figure A.46 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for area backing Pointe Aux Chenes Bay

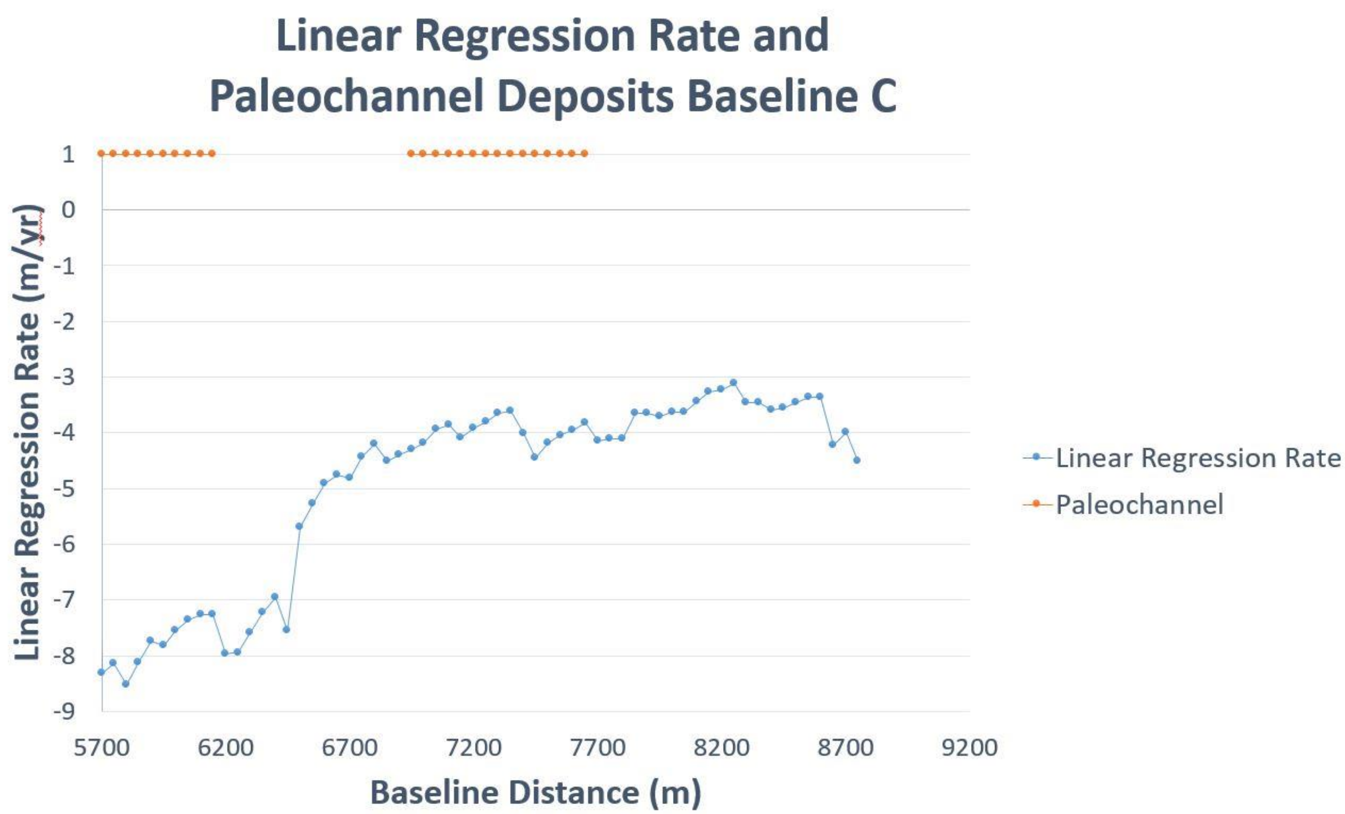

Figure A.47 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for the Grande Batture Islands and the sea facing shore of the protruding deltaic headland

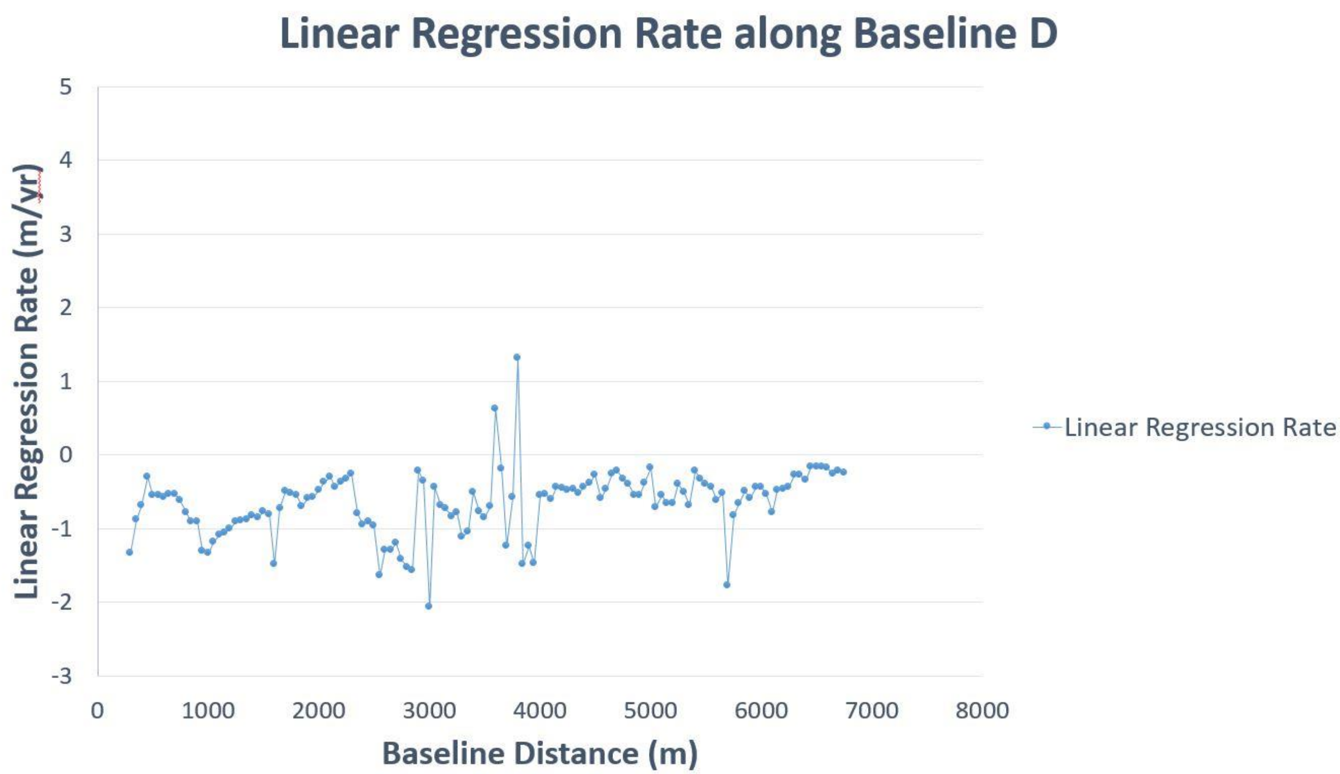

Figure A.48 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for the eastern shore of the protruding deltaic headland

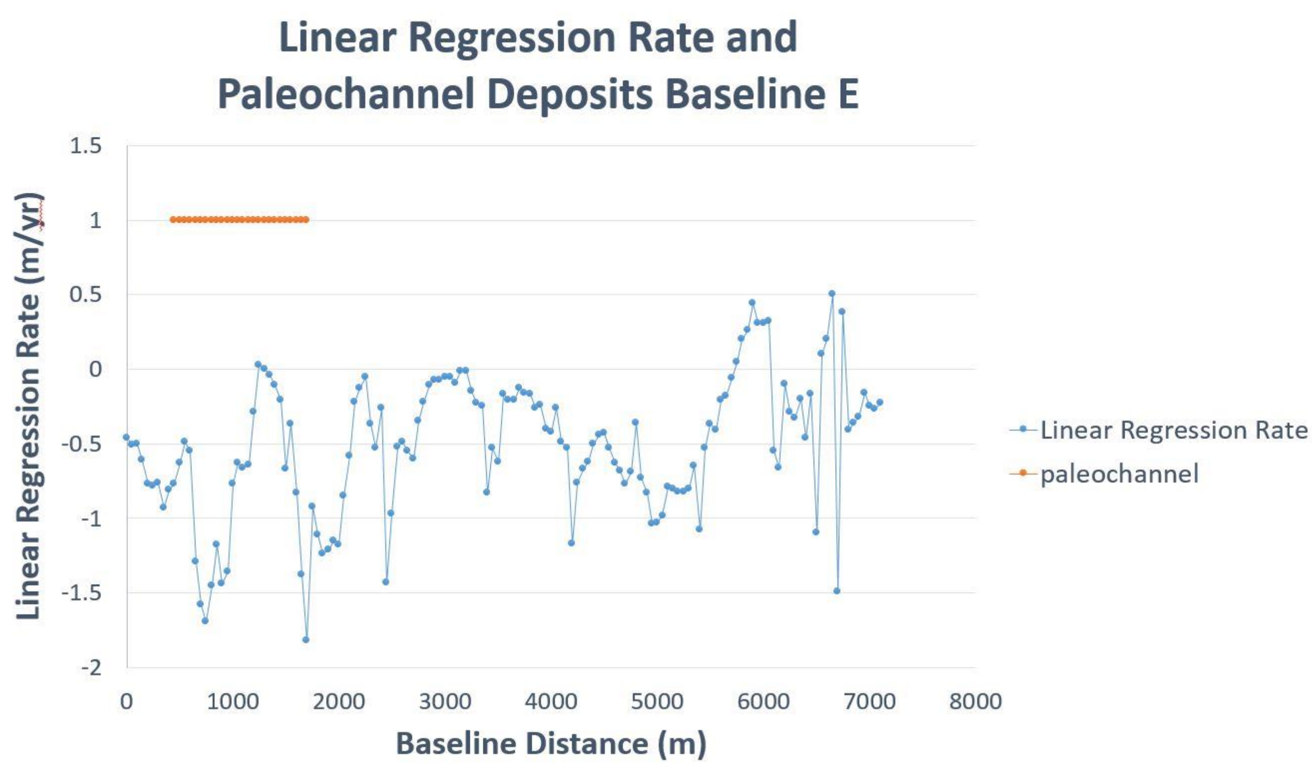

Figure A.49 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for western most portion of the study area

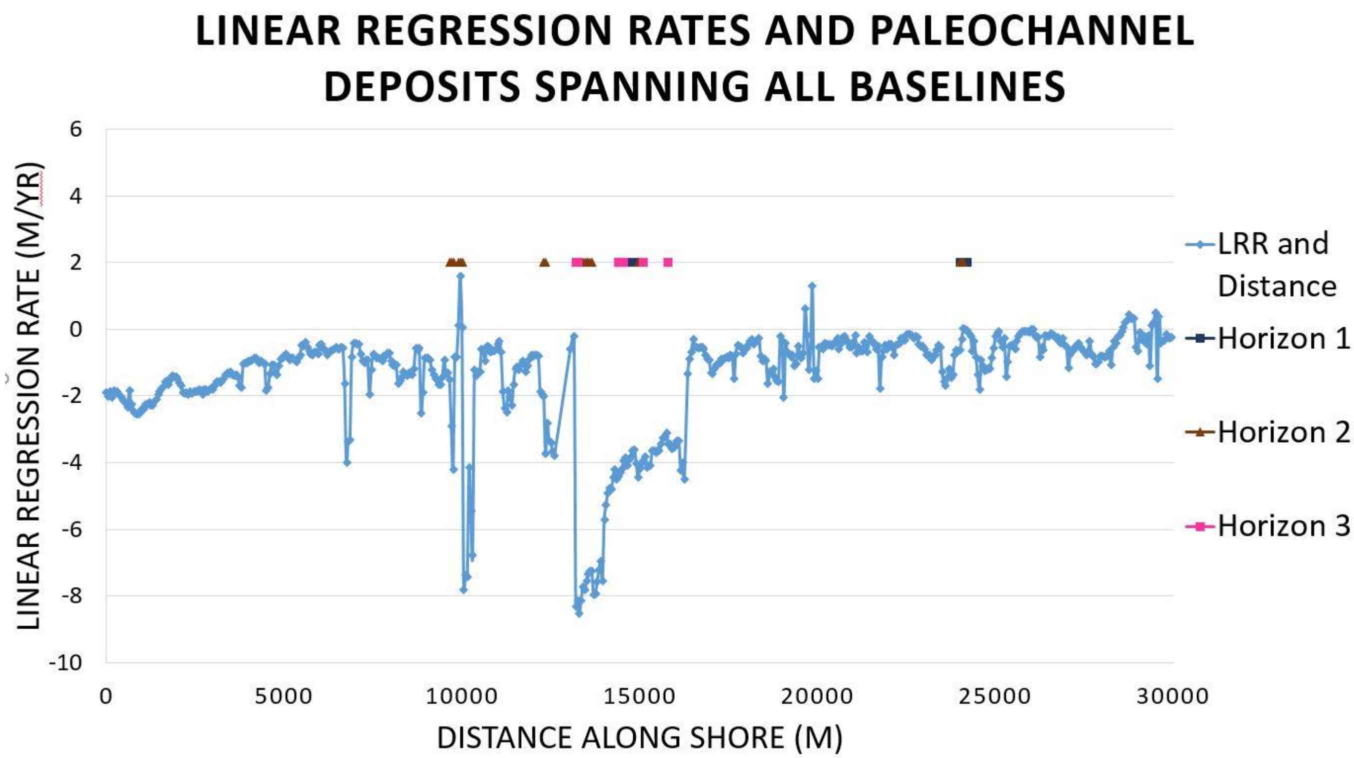

Figure A.50 Linear regression rate of shoreline retreat

Displays shoreline retreat rate in m/yr for entire length of study area

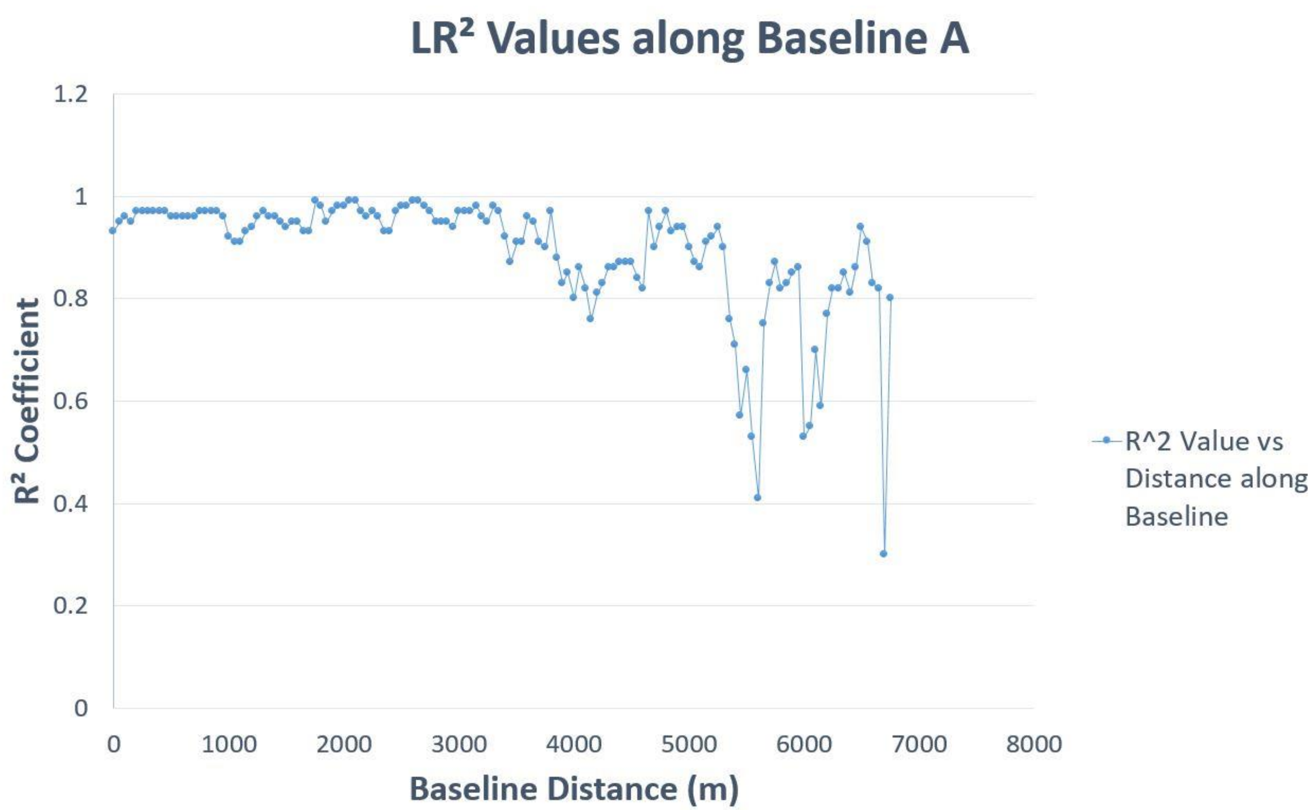

Figure A.51 Variation of shoreline change over time

Displays variation of shoreline change for western most portion of the study area

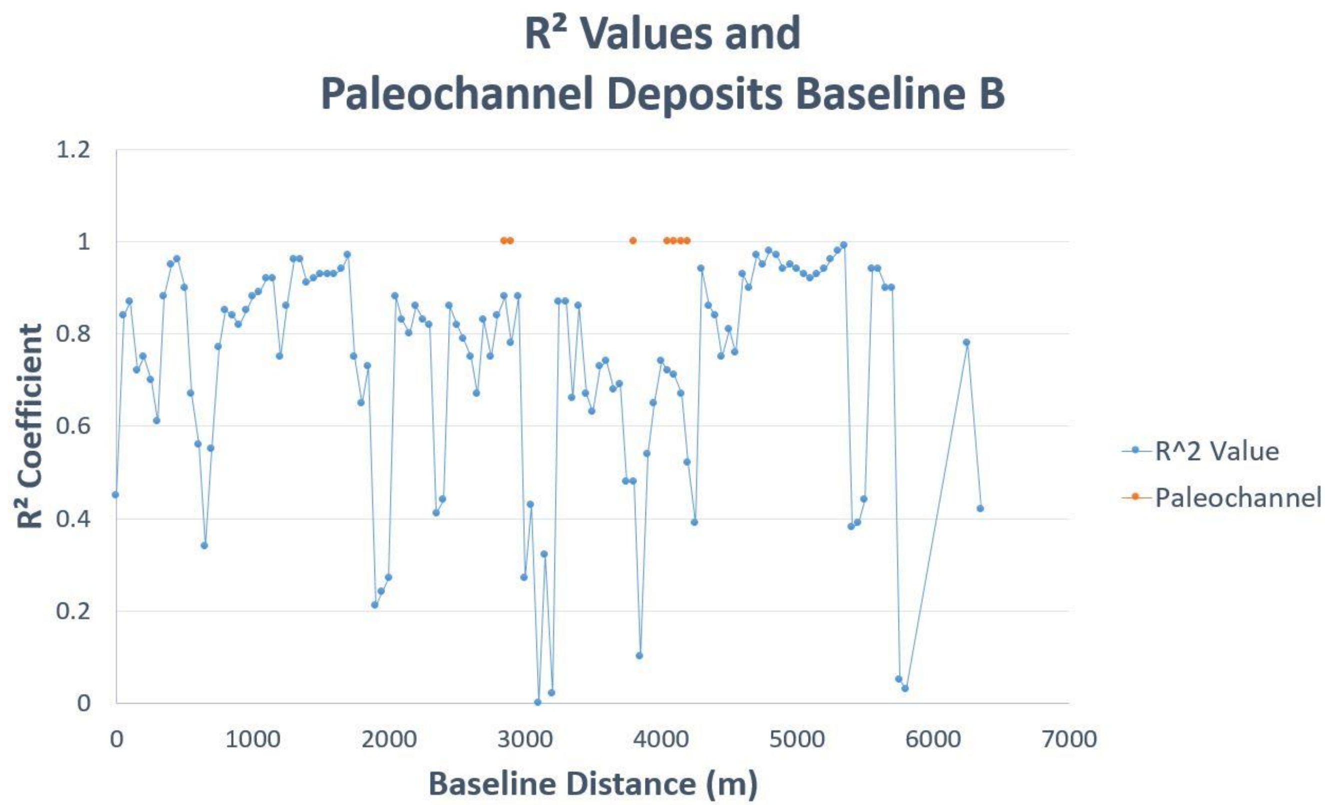

Figure A.52 Variation of shoreline change over time

Displays variation in shoreline change for area backing Pointe Aux Chenes Bay

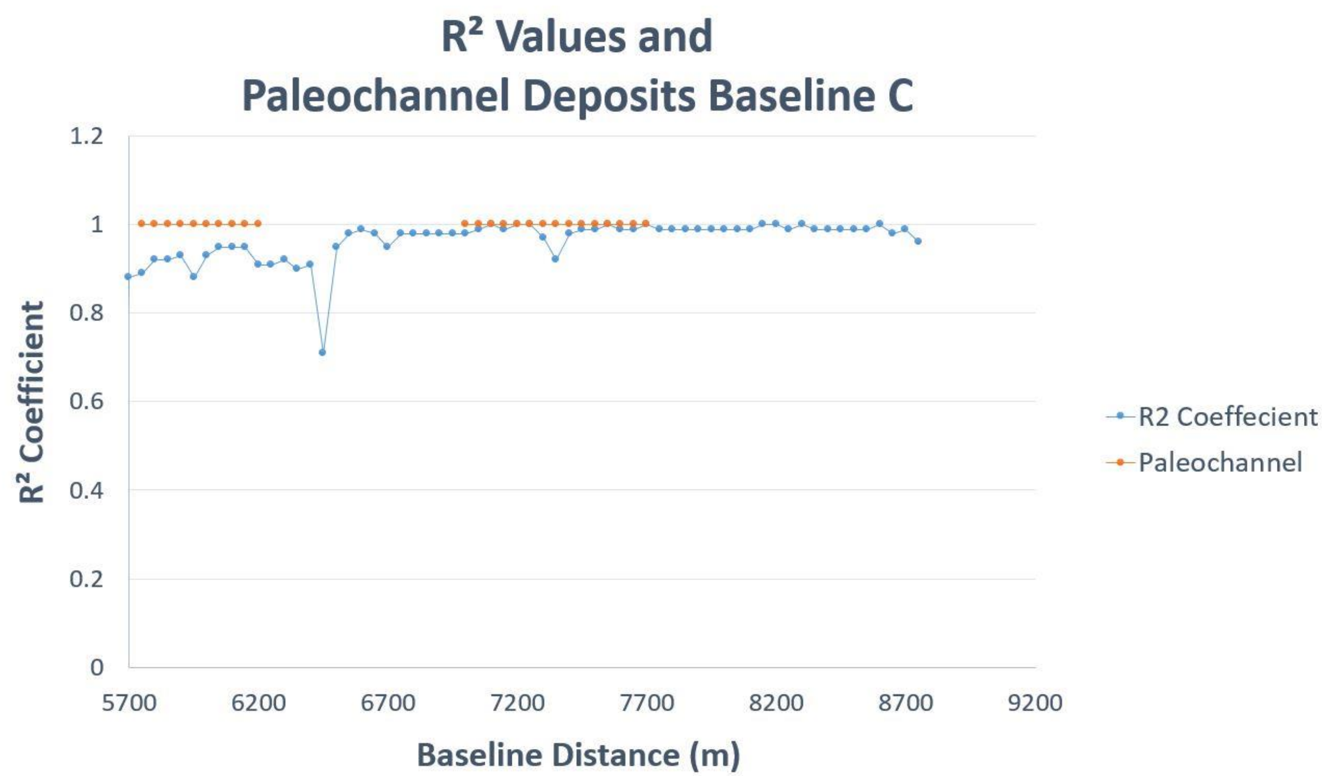

Figure A.53 Variation of shoreline change over time

Displays variation in shoreline change for the Grande Batture Islands and the sea facing shore of the protruding deltaic headland

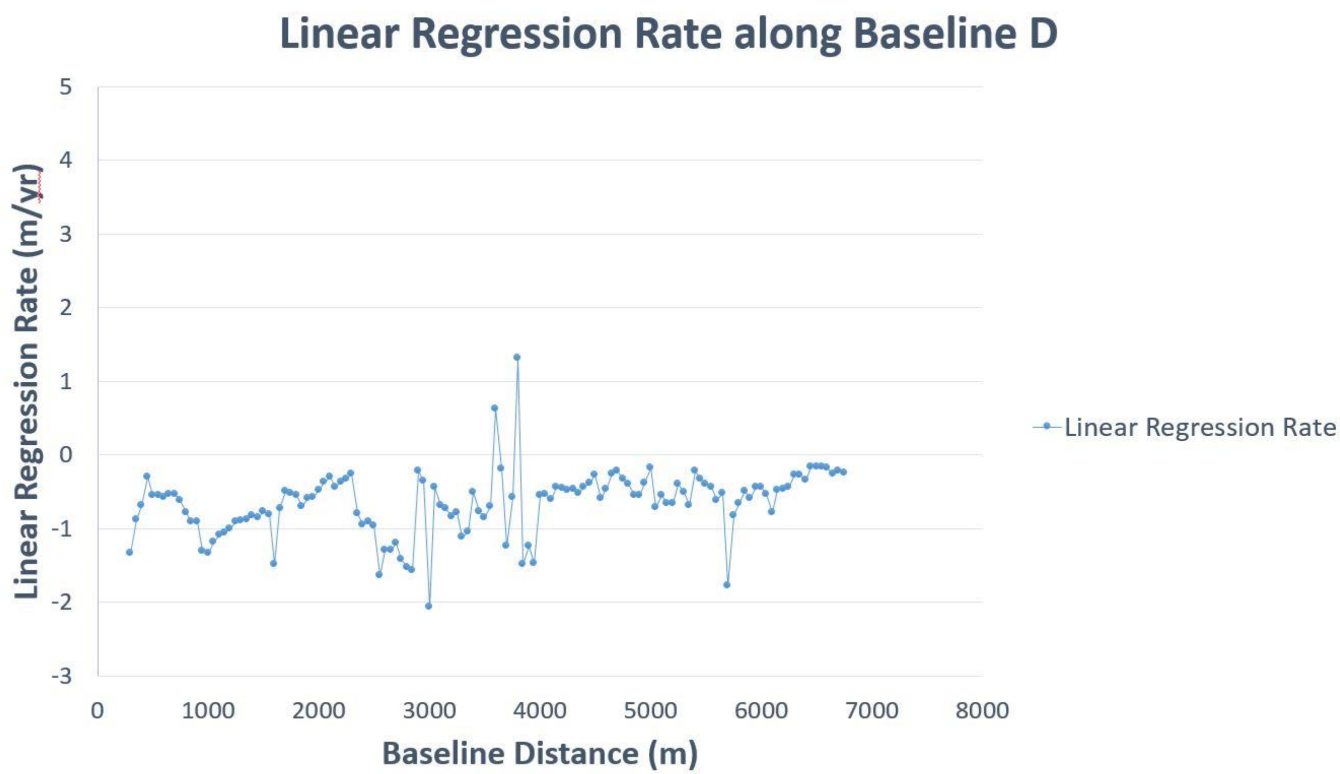

Figure A.54 Variation of shoreline change over time

Displays variation in shoreline change for the eastern shore of the protruding deltaic headland

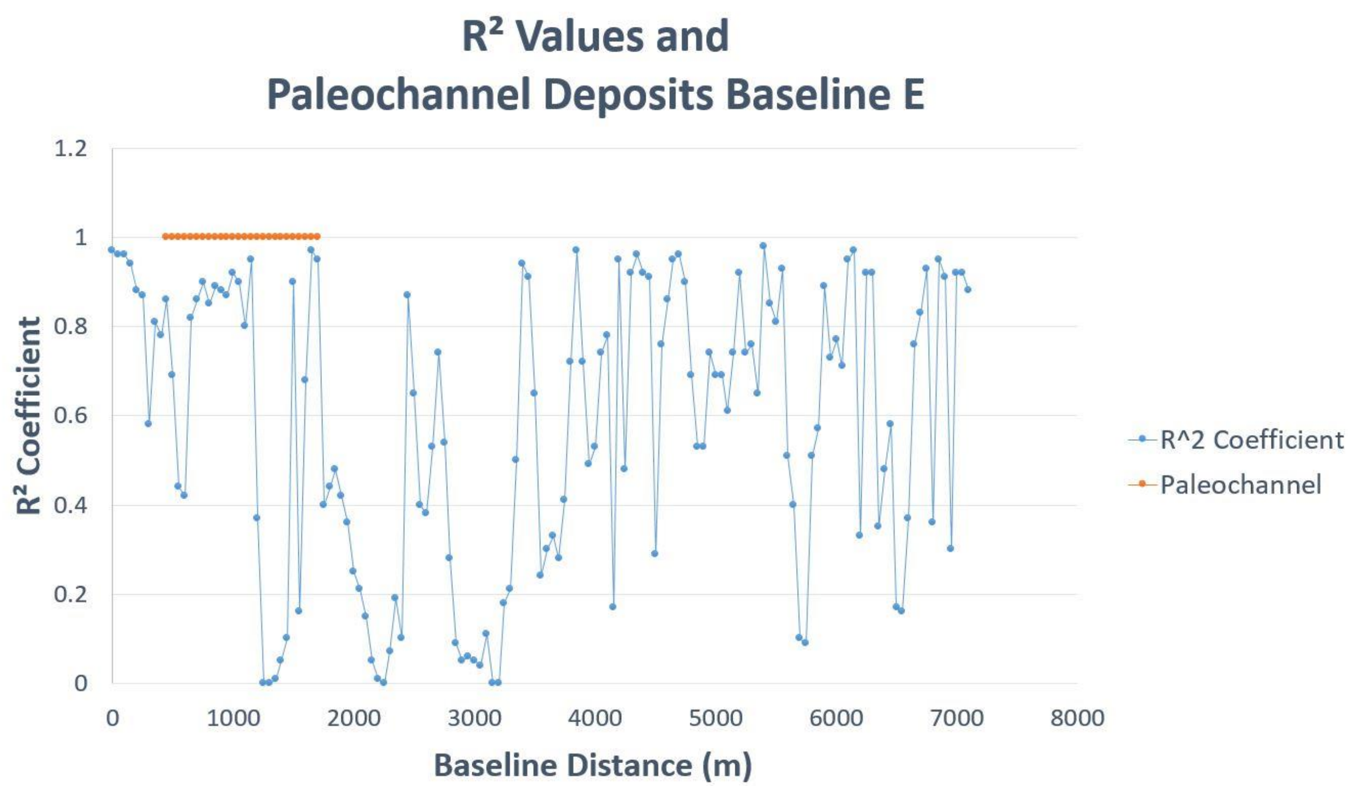

Figure A.55 Variation of shoreline change over time

Displays variation in shoreline change for eastern most portion of the study area

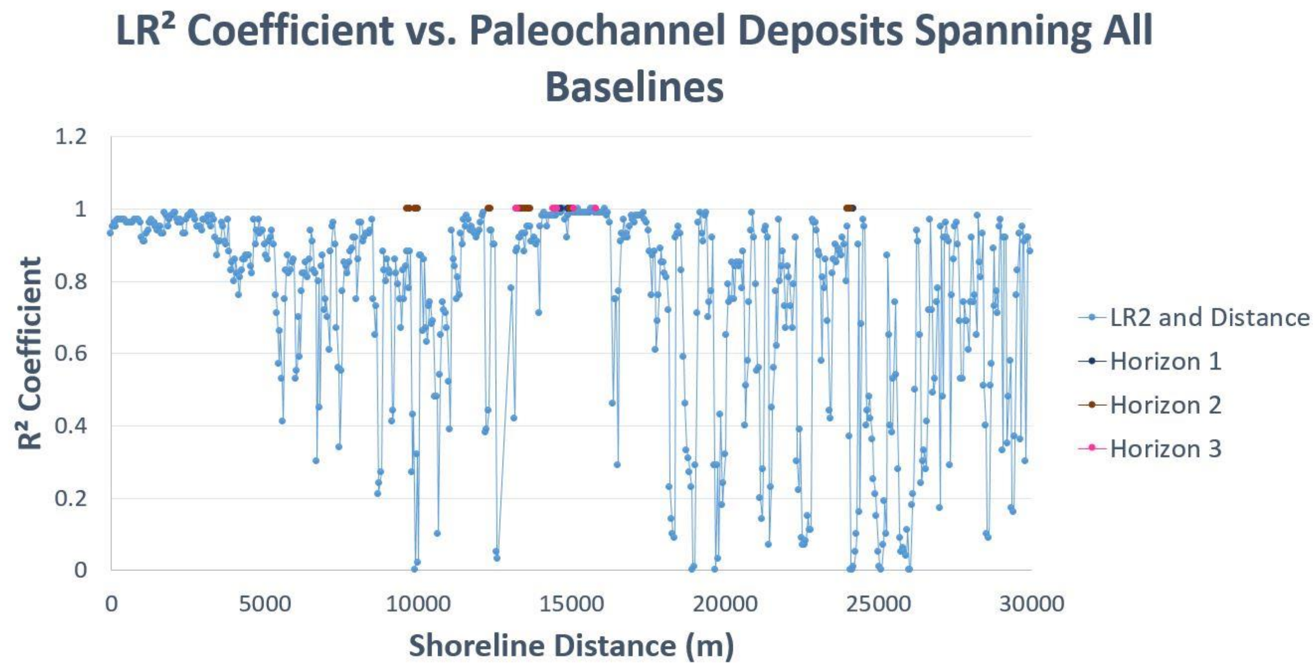

Figure A.56 Variation of shoreline change over time

Displays variation in shoreline change for entire length of study area