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Sand Body Geometry of the Wax Lake Outlet Delta Atchafalaya Bay, Louisiana

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SAND BODY GEOMETRY OF THE WAX LAKE OUTLET DELTA ATCHAFALAYA BAY, LOUISIANA

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ABSTRACT

Deltas forming in Atchafalaya Bay, Louisiana, are the result of delta switching by the Mississippi River. The larger Lower Atchafalaya River delta has been heavily manipulated by dredging for navigation, but the Wax Lake Outlet delta is largely undisturbed and an excellent example of a 'bayhead' delta. Combining stratigraphy, aerial photography and digital terrain model data sets, the developmental history of this delta is presented. The Wax Lake Outlet delta is comprised of a typical upward-coarsening sequence, although its prodelta unit is extremely limited. Its plan-view form is typical of deltas developing in low-energy, unstratified, shallow basins. Early developmental processes were identified by Roberts and van Heerden (1992). Development through the 1980s involved the maturation of distributary channels. From 1989 to 1994, the majority of sediment was retained seaward of the delta proper, due to the efficiency of the distributary system. Greatest sand body thicknesses were found on the upstream portions of delta lobes, but not necessarily at points of bifurcation. Estimates of sand body volume range from 129 to 139 x 10^6 m^3. A small area of the Atchafalaya River delta investigated for comparison also contains an upward-coarsening sequence but with upper and lower coarse-grained bounding units generated by dredging activity. Comparison of the Wax Lake Outlet delta to other Mississippi deltas reveals some similar processes of development despite differences in settings. The Wax Lake Outlet delta has shown a lower rate of infilling compared to subdeltas of the Mississippi River Balize delta due to the relative immaturity of the Atchafalaya. Growth curves based on terrain model data predict an area of 111 km^2 (at and above 0.0 NGVD) by the year 2000, which falls within the range of values given by the Wells et al. (1982) generic model based on the Mississippi subdeltas.

INTRODUCTION

For the past forty-five years the most recent deltas of the Mississippi River have been building in Atchafalaya Bay, Louisiana, at the mouths of the Atchafalaya River and the Wax Lake Outlet (Figure 1). Their development marks the first time in recorded history humans have been able to witness large-scale delta switching by the Mississippi, a process which formed the major portion of coastal Louisiana (Frazier, 1967; Roberts et al., 1980). As with the historical Mississippi delta lobes, the Atchafalaya Bay deltas will be extremely significant and dynamic areas for several centuries to come.

While these 'sister' deltas share a common source, there are major differences in their present use and past development. The Wax Lake Outlet Delta has been left virtually undisturbed from its natural state, and represents a beautiful example of a Mississippi River bayhead delta. In contrast, the Atchafalaya Delta is being heavily manipulated and managed for navigation and wildlife habitat, using dredging and dredged material placement as the primary tools for meeting management needs. The stratigraphy of the Wax Lake Outlet delta and much of the Atchafalaya delta has not been documented, and this lack of information presents a major gap in the knowledge base that is crucial for making sound management decisions and reaching management goals in this important area.

The value of Louisiana coastal wetlands, to the state and the nation, has been well documented (Boesch et al., 1994; van Heerden, 1994; Templet and Meyer-Arendt, 1988; Mendelssohn et al., 1983). Over the past 60 years Louisiana has been losing its coastal wetlands at rates as high as 42 sq. miles/yr as a consequence of both human activities and natural coastal subsidence (Britsch and Dunbar, 1993). The Atchafalaya Bay and its deltas are extremely important because it is here that the largest areas of non-remedial coastal wetland are being created (van Heerden, 1994).

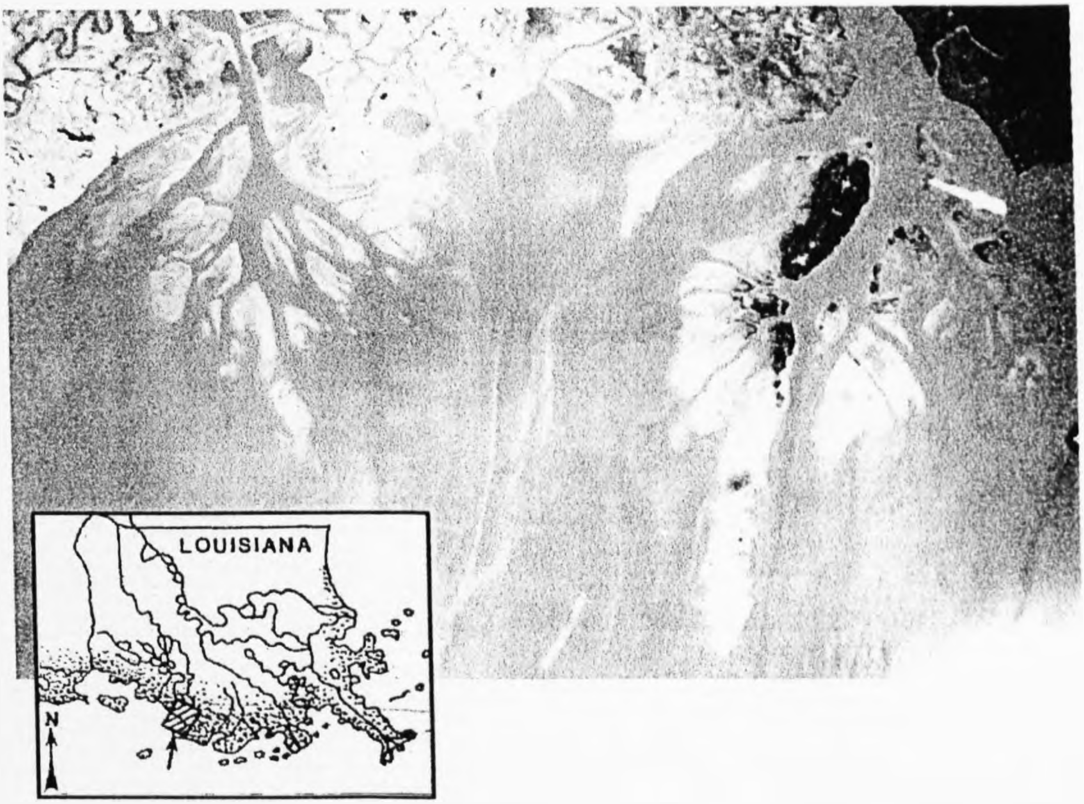

Figure 1. Aerial photo showing the location of Wax Lake (left) and Atchafalaya River deltas in Atchaflaya Bay, Louisiana. Photo taken on December 11, 1992. Inset from van Heerden and Roberts (1988).

One of the tools being used for restoring Louisiana's wetland acreage is the creation of crevasse splays (Moger and Faust, 1991; Louisiana Dept. of Natural Resources, 1993). Splays are delta-like features which form when a crevasse or break in a channel levee allows water and sediment to be diverted to nearby low-lying areas. The Wax Lake Outlet delta system is analogous to crevasse splay systems and thus provides a model for their development.

The objectives of this research have been to examine the development of the Wax Lake Outlet delta, identifying the developmental processes through its stratigraphic and plan view evolution, to map its sand bodies, and to provide estimates of sediment volume and sediment retention through time. Data from the Atchafalaya delta has been included for comparison. The objectives have been met using a unique combination of vibracore stratigraphy, aerial photography, and digital terrain model data sets.

Among the many deltas formed by the Atchafalaya-Mississippi system, there are certain controlling parameters which all have in common, while others are variable among sites. The Wax Lake Outlet delta will be compared to other Mississippi deltas, and the controlling factors responsible for the resulting delta forms will be discussed.

Since the early development of these deltas researchers have been interested in determining their future growth (e.g., Shlemon, 1972; Roberts et al., 1980; Adams and Baumann, 1980). Delta growth trends identified by this research will be used to make predictions for short-term delta growth, and these estimates will be compared to predictions made by previous research.

BACKGROUND

Atchafalaya River and Bay

The basin of the Atchafalaya River is an interdistributary depression defined by deposits of former Mississippi River courses; the Teche to the west and south, and Mississippi and Lafourche systems to the east (Cratsley, 1975). What is now the Atchafalaya River began in the 15th century when a small stream called Pelousas Bayou, near present-day Simmesport, began receiving flow from a former Mississippi River tributary (Latimer and Schweitzer, 1951). Later westward migration of the Mississippi meander belt connected this stream to the river (Latimer and Schweitzer, 1951). The Atchafalaya was documented as a distributary of the Mississippi in 1542 by a monk accompanying La Salle's expedition, but until the nineteenth century it remained a somewhat insignificant stream, choked with debris from the Mississippi and Red Rivers (Latimer and Schweitzer, 1951). After the successful clearance of the stifling log jams in the mid-1800s, the river gradually increased its discharge over the next century to the point where it was poised to become the new Mississippi main course to the Gulf (Fisk, 1952). To prevent this, a control structure was built at Old River in 1963, and the Atchafalaya has since been limited to approximately 30% of the combined Red and Mississippi River flows at 31° N latitude, approximately the division in 1950 (Wells et al., 1982; Wu, 1987).

While van Heerden (1983) noted the presence of a prodelta clay layer associated with an 1839 flood, the period from the 1800s to the early 1950s is generally considered to have contributed to insignificant deltaic sedimentation in Atchafalaya Bay (Morgan et al., 1953; Shlemon, 1972). During this period the Atchafalaya River was increasing its discharge, capturing up to 25% of the Mississippi's flow, but the major portion of the river's sediment load was being deposited in the many lakes (as lacustrine deltas) and other catchments in the basin (Roberts et al., 1980; Tye and Coleman, 1989; Figure 2). Between 1858 and 1950 no major

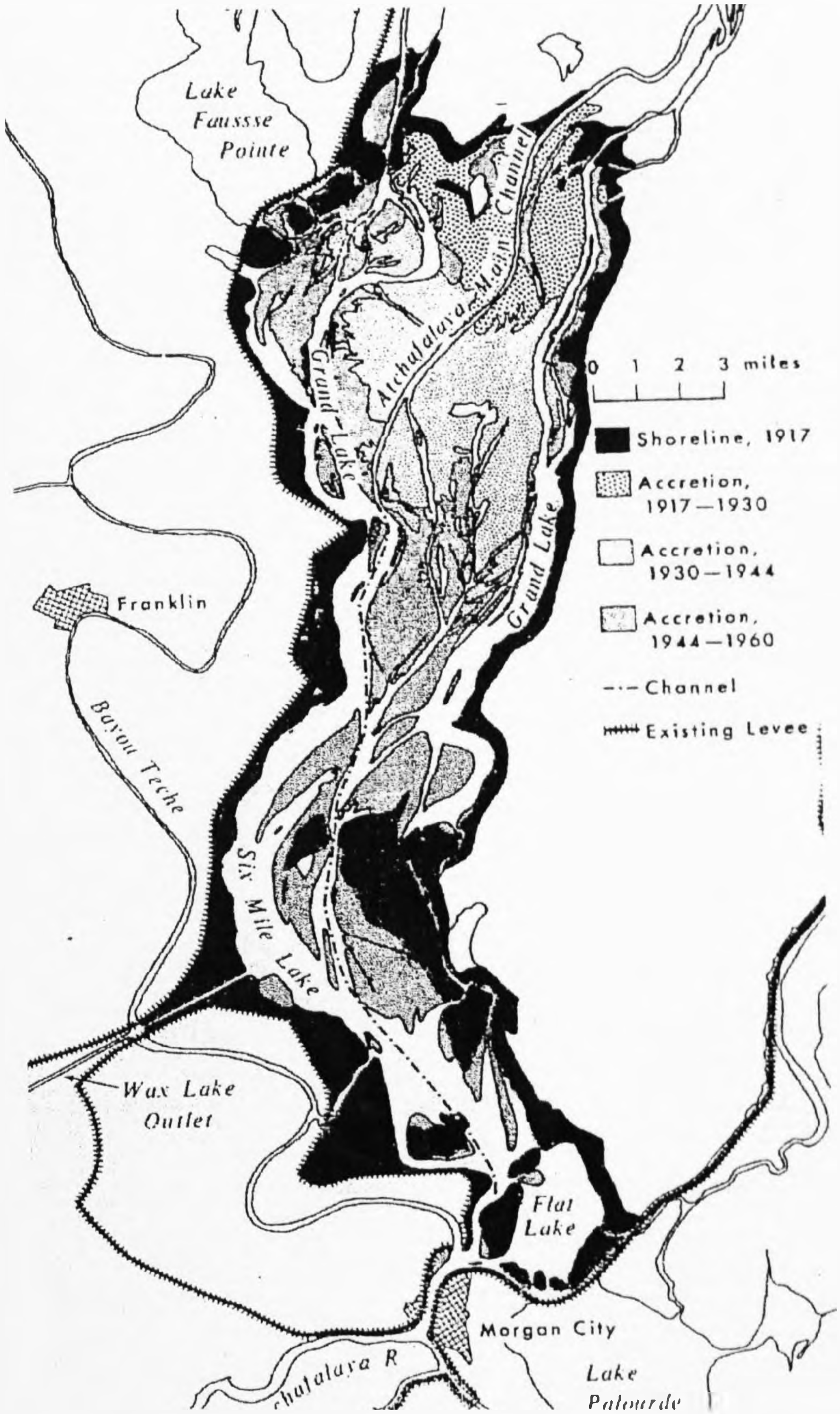

Figure 2. **Lacustrine delta development within the lower Atchafalaya Basin, 1917 - 1960 (From Shlemon, 1972).**

changes occurred in the bay's bathymetry, and it remained at a nearly uniform depth of about 2 meters (Thompson, 1951). Thompson speculated that this was the bay's 'equilibrium depth' representing a balance among the processes of deposition, erosion, compaction and subsidence. It was maintained by the relatively fresh bay waters which did not allow fine sediments to flocculate and settle, and the combination of wind waves and currents which kept sediments in suspension and transported them out of the bay (Thompson, 1951). Prior to the early 1950s, virtually all the sediment discharged into Atchafalaya Bay were clays which were carried out past the Point Au Fer shell reef (Cratsley, 1975). Thompson (1951) reported riverborne surface sediments of Atchafalaya Bay, deposited as a gelatinous mud, consisting of 4% very fine sand, 30% silt, and 66% clay. The thickness of this layer increased from zero in the inner bay, to 1-2 feet (0.3 - 0.6 meters) in the outer bay, to a maximum of about seven feet (2.1 meters) thick at the 12' (3.6 meter) depth contour on the shelf. The seaward thickening of the mud layer was due to flocculation of the material, after mixing with the higher salinity waters on the shelf, which facilitated deposition. It has been suggested that deposition of this mud, which may be considered a marine prodelta unit, began on the shelf in the mid-1800s (Roberts et al., 1980). Although deltaic sedimentation was not significant within the bay, the growing influence of the Atchafalaya River was evident along the Chenier Plain coast to the west. Here, mudflat accretion due to the down-coast drift of river plume sediments was observed beginning in the mid-1940s (Cratsley, 1975; Morgan and Larimore, 1957).

Controls on Sediment Delivery to Atchafalaya Bay

Atchafalaya River discharge is a combination of Mississippi (through the Old River channel) and Red River input. While Old River is the dominant tributary for flow, either tributary may dominate Atchafalaya sediment load at a given time (Mossa 1990). Atchafalaya River suspended sediment concentrations, dominated by silt-clay fractions, have a non-linear

relationship to discharge. Concentrations of silt and clay generally increase sharply as flow increases through lower discharge ranges, then level off with moderate flows, and begin to decrease as flow magnitudes continue to increase (Mossa 1990). The sand fractions of the Atchafalaya's suspended sediment load show a more linear relationship with discharge, increasing in concentration with increasing flow. Total suspended sediment load is maximized prior to the arrival of the highest discharge values (Mossa, 1990). This is thought to be related to erosion and transport of fine-grained sediment stored in the channel during non-flood periods (Mossa and Roberts, 1990). Suspended sediment transport by the Atchafalaya River is highly seasonal, with the greater amounts occurring in the winter and early spring (December through May) and lesser occurring in the summer and fall (June to November; Mossa and Roberts, 1990).

Human manipulation is another factor influencing sediment supply. In the case of the Atchafalaya River, the Old River Control Structure, which regulates input from the parent Mississippi, deprives the Atchafalaya of Mississippi bedload (van Heerden, 1980). Sediment supply from the Red River has also been restricted by locks and dams (G.P. Kemp, pers. comm.; Latimer and Schweitzer, 1951). Additional human activities such as the construction of levees, reservoirs, revetments, cutoffs, and changes in land use, are cited as probable causes for the nonlinear empirical relationship of suspended sediment concentration with discharge observed by Mossa (1990).

The Wax Lake Outlet

The Wax Lake Outlet (WLO) is located in the lower Atchafalaya River basin, approximately 10 miles west of Berwick, Louisiana. Its construction was authorized by the Overton Act of 1936 for the purpose of lowering river stages and shortening flood duration within the lower basin (Army Corps of Engineers, 1938). This Act amended the Flood Control Act of 1928, prompted by the catastrophic flood of 1927 (Army Corps of Engineers, 1938).

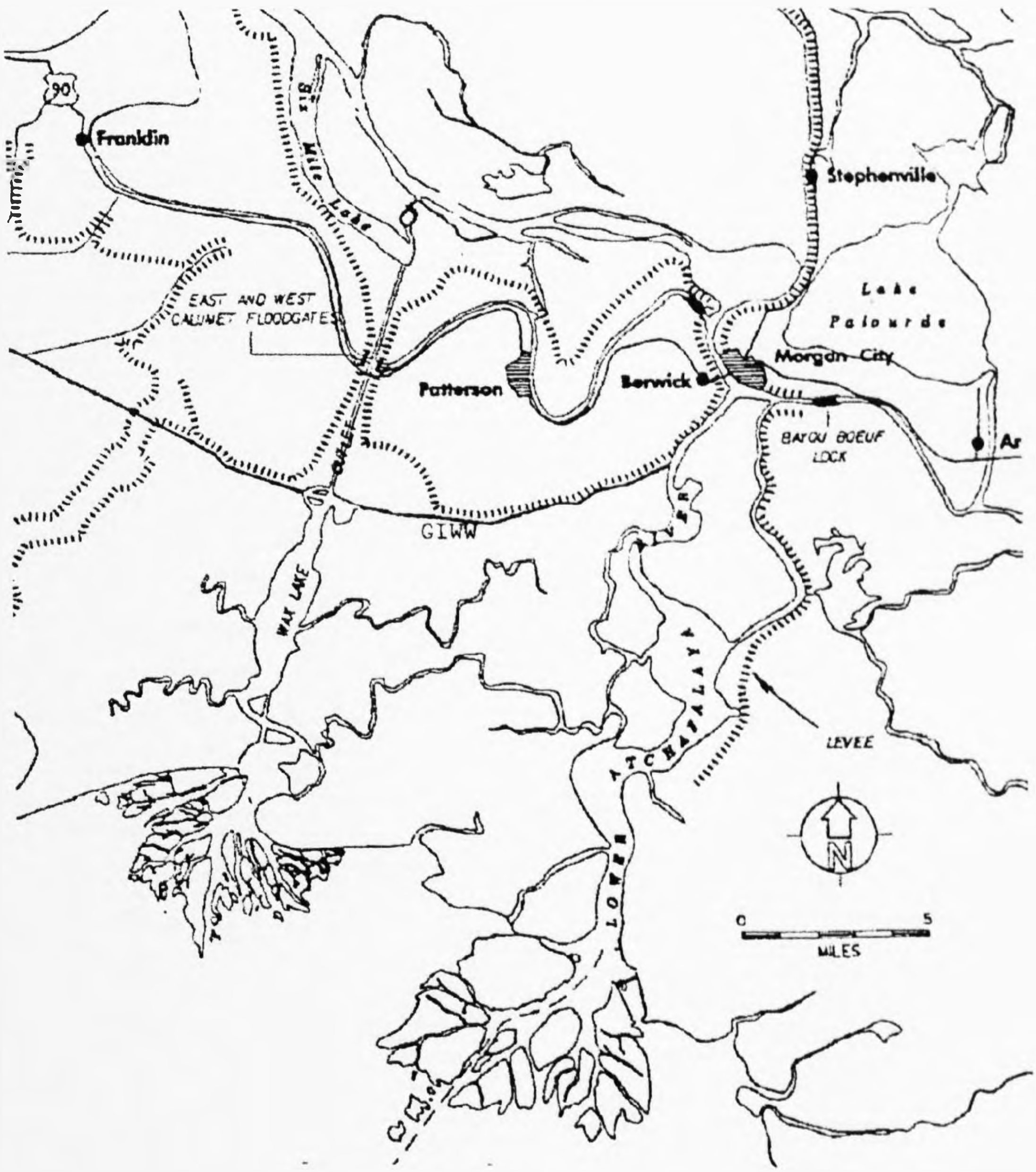

Figure 3. **Map showing the location of the Wax Lake Outlet (modified from Kemp et al., 1995).**

Completed in October 1941, the Outlet extends south from Sixmile Lake, across the Teche ridge, and on to Atchafalaya Bay (Figure 3; Army Corps of Engineers, 1938; Latimer and Schweitzer, 1951). Original bottom widths of the Outlet were 30 to 40 feet, with a depth of 45 feet below mean Gulf level. Guide levees constructed 1000 to 5000 feet to either side of the channel are continuous as far south as the Gulf Intracoastal Waterway (GIWW). Below that, openings are provided at important bayou crossings to allow for local drainage (Army Corps of Engineers, 1938). For a time, a 4-mile long "flood control channel" was maintained running south from New Pass (the Wax Lake Outlet mouth) to the area of the former inner reef shoal (Shlemon, 1972). All dredging in the area, which had been primarily in the northeastern section, ceased in the early 1980s (Roberts and van Heerden, 1992). The Wax Lake Outlet is in effect an artificial crevasse channel of the Atchafalaya River.

Early Deltaic Deposition in Atchafalaya Bay

The decade 1952 to 1962 marked the beginning of increased sedimentation, observed initially in the vicinity of the Lower Atchafalaya River (LAR) mouth (Shlemon, 1975; Figure 4). Rapid deposition of upper prodelta sediments began at this time, consisting of parallel laminated clays and silty clays (van Heerden and Roberts, 1988). Variations in the thickness of the upper prodelta unit and other clues gleaned from sediment cores indicate that a subaqueous distributary channel system was established (van Heerden and Roberts, 1988).

By 1962 the Basin neared its sediment retention capacity (van Heerden, 1983). Around this time, the lower channel of the river was dredged to improve navigation. The increased flow efficiency caused the river to deepen its channel, scouring out previously deposited levee, channel and lake-fill sediments from the basin. Concurrently, it was observed that the composition of the sediment load being delivered to the Bay changed from a predominance of clay and silt, to silt and fine sand (van Heerden, 1983). These sediments were deposited as a distal bar facies, overlying

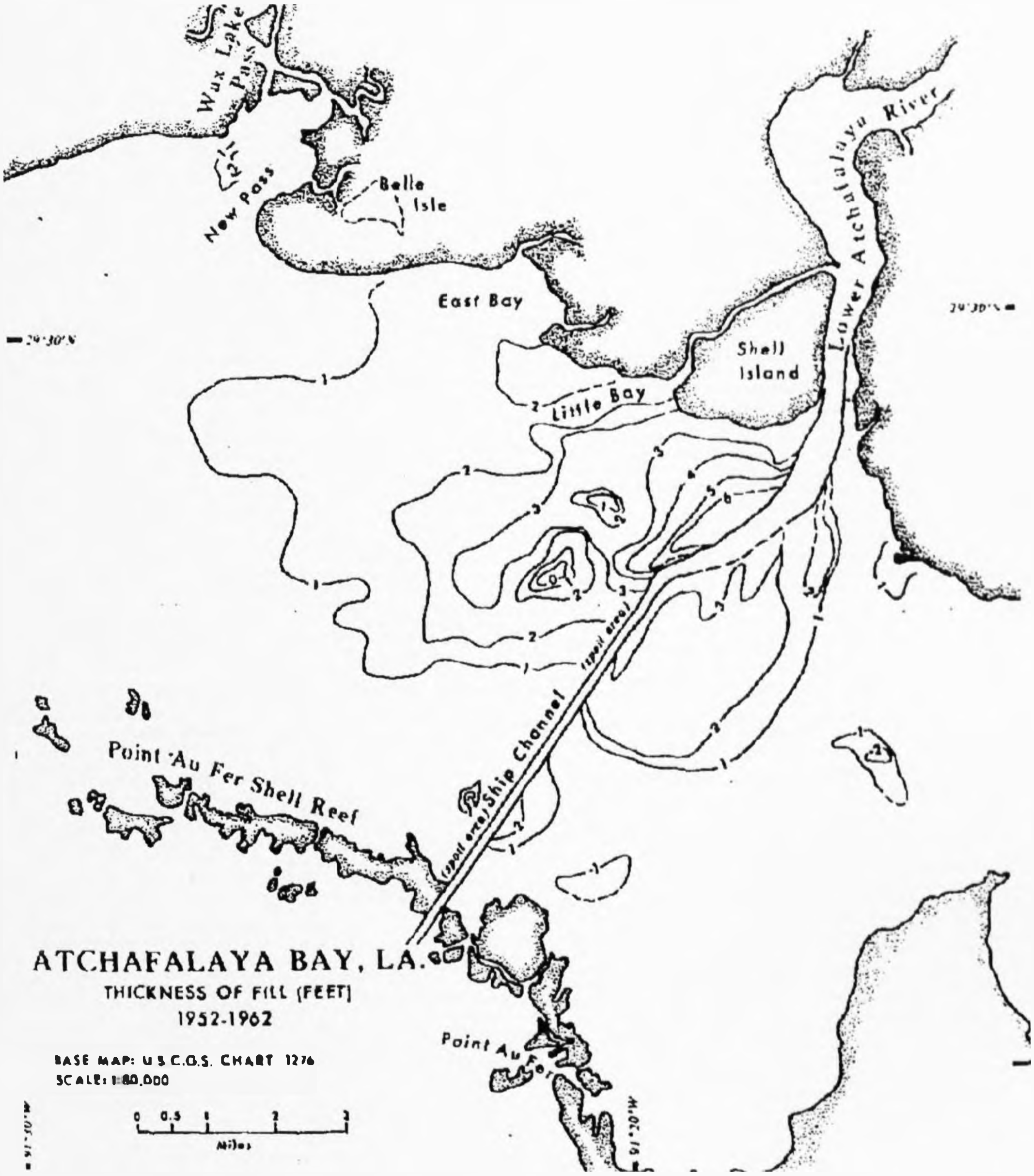

Figure 4. **Isopach map of delta fill thickness in Atchafalaya Bay, 1952 - 1962 (From Shlemon, 1972).**

the finer prodelta units. By 1967, with continued subaqueous growth, distributary mouth bars were deposited on top of distal bar sediments at points of channel bifurcation and along channel flanks (van Heerden, 1983).

In 1972, small shoals became subaerial around the mouth of the LAR. Those on the western side were composed primarily of dredged material generated by navigation channel maintenance, but those on the eastern side were the product of natural deltaic aggradation (Roberts et al., 1980). The following year, 1973, brought an exceptionally high and early flood. Discharge on the Mississippi was so great that the control structure at Old River was undercut, and for seven months that year exceedingly high amounts of water and sediment were delivered to Atchafalaya Bay (G. P. Kemp, pers. comm.; Roberts et al., 1980). As a result, well-developed natural delta lobes became evident on each side of the navigation channel (Roberts et al., 1980). Above normal discharges also occurred the following two years. Scour in the lower reaches of the channel due to those three flood seasons nearly doubled the suspended sediment carried by the river, and most significantly, increased the amount of sand available for rapid delta growth (Roberts et al., 1980). By the end of the '76 flood season, well-developed distributary mouth bars were evident at the mouths of both the LAR and WLO (Roberts et al., 1980).

Developmental Mechanisms

Van Heerden (1980, 1983) investigated the developmental mechanisms and natural depositional facies of the Atchafalaya delta. The focus of those studies was the eastern portion of the delta, which at the time was relatively undisturbed by human modifications. Van Heerden determined that the main processes by which this area had developed were: channel bifurcation and seaward extension of distributary channels, upstream accretion of delta lobes, and lobe

fusion by channel abandonment. The following discussion of these processes is based on the works of Welder (1959), Wright (1977) and van Heerden (1994).

The deltas of Atchafalaya Bay formed under river-dominant conditions, where density differences between the incoming effluent and the ambient basin waters were negligible (i.e., "homopycnal"; Bates, 1953), and where friction with the shallow bed of the receiving basin increased turbulence in the incoming effluent. Research has found that under these conditions, the sediment-laden water issuing from the river mouth enters the receiving basin and begins to spread and decelerate as friction with the bed takes effect. This causes deposition of a portion of the suspended sediment, initially taking the form of a broad arc seaward of the river mouth. Deceleration and lateral expansion increase as receiving basin depth decreases (Wright, 1977). In this way, a feedback loop is begun by which the shoaling caused by sedimentation creates conditions favorable for further deposition. Sedimentation along the lateral edges of the effluent plume, where velocity is reduced by contact and interaction with the ambient basin waters, initiates levee formation. These levees also impede effluent expansion, and through friction with the effluent plume induce continued deposition and levee growth.

Maximum velocity and maximum suspended sediment concentrations occur in the central areas of channel flow (van Heerden, 1994). The sudden deceleration of effluent upon reaching the receiving basin results in the deposition of the coarsest fractions mainly in the central area of the arcuate bar. Deposition on the mid-channel bar, as with the levees, is self-enhancing. As the central bar develops, flow is increasingly diverted around it, and the channel bifurcates. Constricted laterally by the developing marginal levees, the effluent repeats the process of seaward levee extension and bar formation at the mouths of the newly formed channels, possibly promoting further bifurcations.

Typically, a bifurcation results in channels of unequal size. Evidence from the eastern Atchafalaya delta suggests that the channel which becomes the larger, dominant distributary of the parent, is determined by flow asymmetry caused by the tidal cycle (van Heerden, 1994). As the majority of a channel's discharge is directed down the dominant distributary channel, a levee is formed across the minor distributary, which begins the process of abandonment of that channel. Eventually, the abandoned channel will fill with sediments delivered through levee overtopping and tidal incursions. As a result the islands bordering the minor distributary will become fused to form a larger single island lobe.

Sedimentation induced by friction with the levees of a delta lobe leads to changes in both channel and island morphology, particularly in the narrowing of channels by lateral levee accretion, and upstream accretion of the tips of delta lobes (van Heerden, 1994)

The floods of 1973-75 appear to have been a dominating control on the growth mechanisms and resulting facies development of the eastern Atchafalaya delta (van Heerden, 1983). From 1973 to 1976 flood seasons were generally above normal, and delta growth was accomplished through processes of seaward channel extension and channel bifurcation. From 1977 to the early eighties, flood seasons were average to below average, and seaward delta progradation stopped. Growth instead took place by the accretion of sediments on the upstream ends of island lobes, and by channel abandonment, which lead to lobe fusion. Van Heerden emphasized that these two mechanisms - seaward channel extension, and lobe fusion and upstream growth - occurred as separate stages, early and mature, respectively. Tye (1986) reports similar phases of development for the Atchafalaya's Lake Fausse Pointe delta.

In the Mississippi Balize (birdfoot) delta, the major sand bodies are the distributary mouth bar ("bar finger") deposits (Fisk, 1961; Coleman and Gagliano, 1965), and in the Baptiste Collette subdelta, the thickest sands are channel fill and reworked distal sand sheets (Bowles,

1987). In contrast, van Heerden determined that the coarsest sediments (fine sands) in the Atchafalaya were found primarily in the subaqueous and subaerial natural levees. The greatest sand body thicknesses were found on the upstream portions of the delta lobes. The levee environment makes up as much as 40% of the Atchafalaya deltaic sequence (van Heerden, 1983). This was attributed to the floods of 1973-1975, which occurred relatively early in the delta's development. Levees accrete during flood events as turbid waters overtop existing levees and deposit sediments; distributary mouth bars primarily build by deposition of bedload sediments. The early floods flushed silts and sands into the bay so quickly that levees were deposited at the expense of the distributary mouth bar facies. If the seasonal floods had been more average in magnitude during those years, van Heerden (1983) suggested that the distributary mouth bar facies may have been more significant.

Like the Atchafalaya delta, the delta at the mouth of the WLO also began its subaerial development with the flood of 1973, but its growth pattern takes a much different shape (Roberts and van Heerden, 1992; Figure 5). This is because prior to 1980, Wax Lake and surrounding water bodies upstream of the bay were acting as sinks to the Outlet's sediment supply. The delta's growth spurt following 1980 indicates that these upstream systems had sufficiently filled (e.g. Fisk, 1952;Tye, 1986), to the point that they allowed more coarse sediments to reach the Bay. In contrast to the eastern Atchafalaya Delta, the processes of channel elongation, lobe fusion and upstream growth have occurred simultaneously (Roberts and van Heerden, 1992). This indicates a more efficient retention of sediments by the WLO delta system (van Heerden, 1994).

Lower Atchafalaya River Navigation Channel

There is a long history of dredging for navigation from the mouth of the Lower Atchafalaya River (LAR). Prior to the 1970s a 12- x 200-foot channel was maintained in

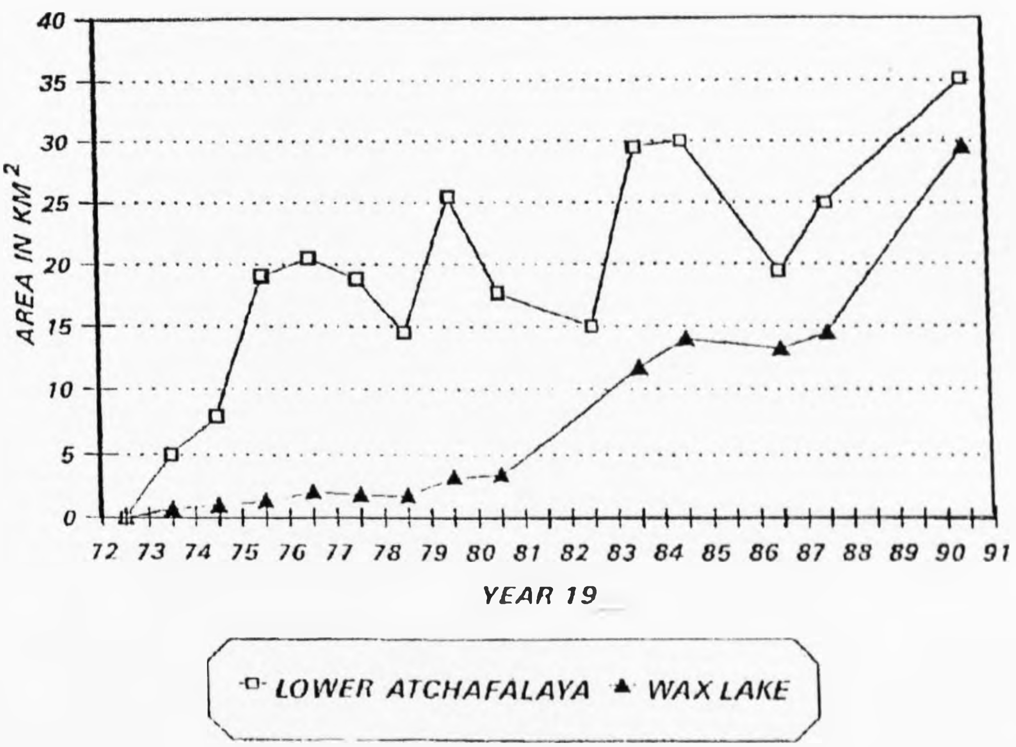

Figure 5. **Atchafalaya and Wax Lake delta growth curves (from Roberts and van Heerden, 1992a).**

approximately the same location as the present navigation channel (Shlemon, 1972). In 1974 the Army Corps of Engineers deepened the channel under authorization of the River and Harbor Act of 1968 (Penland et al., 1996). The present 22-ft deep channel bisects the delta, bound on both banks by dredged deposits and subaqueous bars (Cunningham et al., 1996). It is nearly twice as deep as the deepest natural channels in the delta. Consequently, it is very efficient at conveying sediments through the bay and discharging them onto the shelf (van Heerden, 1994). This has had a significant impact on the delta's sediment retention, severely reducing the system's land-building capability.

The effect of the navigation channel is seen when comparing the growth curve of the LAR delta to that of the WLO (van Heerden, 1994). During high flood years sediment is transported out of the main channel and through the delta's distributaries, contributing to land growth. During low flood years, the efficiency of the navigation channel dominates sediment discharge, reducing sediment supply to smaller channels. As a result, no net land accretion occurs (van Heerden, 1994). In effect, the navigation channel acts as a mature distributary imposed upon a juvenile delta. In natural settings, such a channel would not have developed until the delta had infilled much of the surrounding receiving basin, and even then would probably not have become as deep (van Heerden, 1994).

Maintenance of the current channel requires the removal of an estimated 2 to 3 million cubic yards of sediment each year (Anonymous, 1991). After nearly two decades of point-discharge disposal along the sides of the navigation channel, a new technique was adopted in 1992 whereby the dredged material was placed in shallow water areas in configurations and elevations designed to mimic natural delta lobes (van Heerden, 1994). Several large lobes have since been created, which have been rapidly colonized by vegetation and wildlife.

The management goal in creating artificial delta lobes was to provide marsh habitat for waterfowl, but original stacking heights were set deliberately high, with the expectation that the material would de-water and compact after deposition, and subside to marsh elevations (generally considered to be 0 to +2 feet above Mean Sea Level (MSL)) (van Heerden, pers comm , Penland et al., 1996). While actual original stacking heights were not given, Penland et al (1996) report maximum elevations of two recent islands as 5.39 and 3.91 feet above mean sea level They stated, "Unless significant compaction occurs, the current elevation may be too high for true marsh development in this area and soil type" (Penland et al . 1996) Another component which would contribute to subsidence of the dredged deposits is the compaction effect of the sand packet on the underlying prodelta clays, as seen in the bar finger sands of the Mississippi River delta (Fisk, 1952) At the initiation of this project, it was unclear to what extent this process was occurring.

Dredged material disposal features accounted for 67% of the total subaerial land of the Atchafalaya Delta in 1994 (Penland et al . 1995) The significance of this fact is that management of the delta has reached the point where human manipulation, rather than the river processes, is the major mechanism for creating and forming the land in the delta (G P Kemp, pers. comm).

The Wax Lake Outlet Weir

The WLO was originally designed to carry 20% of the discharge for the 'project flood' of 1.5 million cfs (U S Army Corps of Engineers, 1995) Shlemon noted in 1975 that the gradient advantage of the Outlet channel, which provides a 21 km shorter route to the Bay than the LAR, was causing the Outlet's cross-sectional area to increase and that of the LAR to decrease. Over time, the WLO increased its flow capture to the point that it would carry 30% of the project flood, and up to 45% of average flows (those less than 550,000 cfs) (U S Army

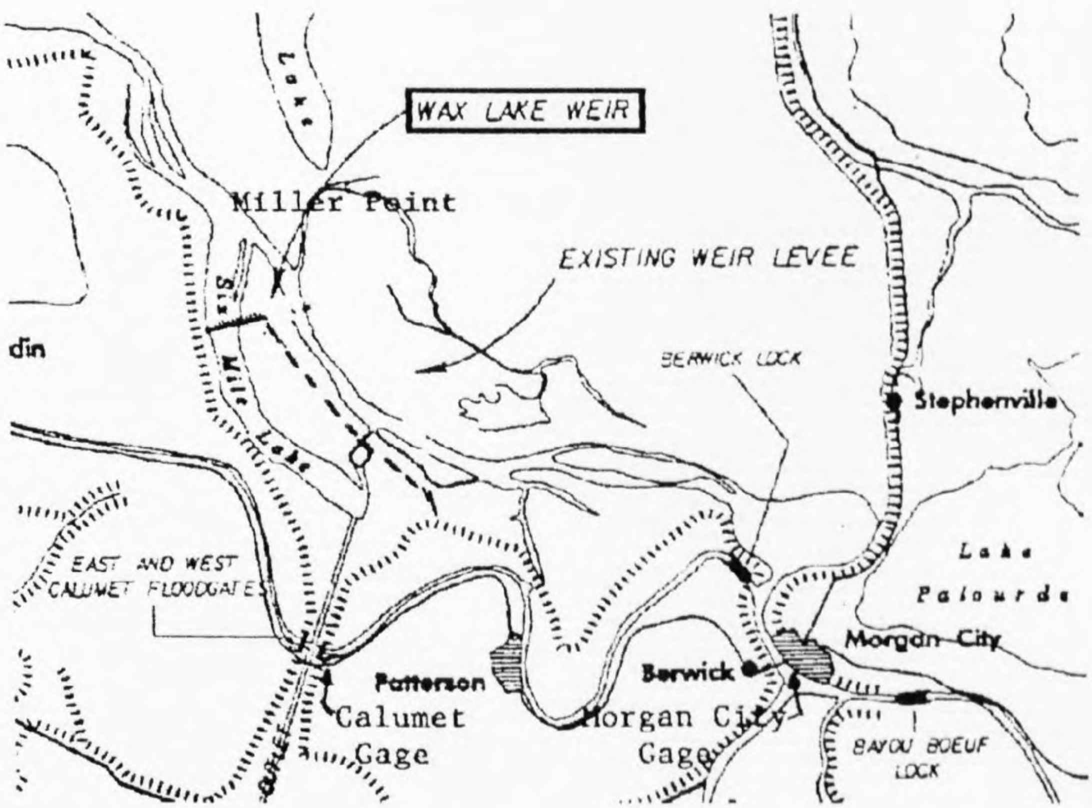

Figure 6. **Location of the Wax Lake Outlet Control Structure (WLOCS; from Kemp et al., 1995).**

Corps of Engineers, 1995). It was projected that flow capture by the Outlet would continue to increase, further reducing the capacity of the LAR, and decreasing the overall capacity of the WLO-LAR system to safely carry the project flood (U.S. Army Corps of Engineers, 1995). In short, it became clear that the manmade Wax Lake Outlet was causing an inadvertent avulsion of the Atchafalaya River. In an attempt to rectify this, a weir, the Wax Lake Outlet control structure (WLOCS) was installed above the entrance to the Outlet in Sixmile Lake, in 1987-1988 (Figure 6). Its purpose was to force more discharge down the LAR, in the hopes that the channel would scour itself to acceptable depths, and to hold the WLO to 30% of Atchafalaya discharge during average flow periods (Kemp et al., 1995).

Changes brought about by the weir, investigated by Kemp et al. (1995), were found to include:

1. Decreased flow proportion down the WLO. Discharge allotted the WLO was relatively depleted in bedload, and in general a disproportionately low concentration of sediment down WLO per cfs discharge. Return flow from the LAR to the WLO through the GIWW contributed large volumes of water, but virtually no bedload.

2. Increased volume of bed material (fine sand) transported down the LAR channel, leading to the deposition of large volumes of sediment which otherwise would have been carried down the WLO, or been deposited in adjacent basins. In general, velocities in the LAR channel at discharges less than 500,000 cfs were not sufficient to cause scour of the bed or to transport bedload.

3. Reduction of the WLO channel above the weir by approximately 10%. This was most strikingly evinced by the deposition of approximately 2 million cubic yards of material, in the form of a levee, in Sixmile Lake on the approach to the WLO. This feature divided the channel into two parts; a main eastern channel, and a levee flank/overbank area west of the levee crest.

Problems with increased river stages around Morgan City prompted the removal of the structure in 1994, and the attempted return to pre-weir conditions (U.S. Army Corps of Engineers, 1995). Kemp et al. (1995) predict that the trend of increasing flow capture by the WLO will not increase indefinitely. Eventually, bedload will be transported down the WLO, and the two channels will fluctuate around equilibrium cross-sections. Over the six years of its existence, the weir acted as a plug at the head of the WLO, making the Outlet channel above the GIWW analogous to an abandoned channel, which receives significant discharge and sediment input only during high water periods (Kemp et al., 1995).

METHODS

Subsurface Sampling and Analyses

In October 1995, a set of ten sediment vibracores was collected from the eastern and central portions of the Wax Lake delta. The cores were collected in 3.5 inch (9 cm) diameter aluminum irrigation pipe, using standard vibracoring procedures (e.g., Smith, 1984; Figure 7). Compaction of the sediment column within the core tubing was measured relative to ground level prior to core extraction. Top-of-core elevations were measured relative to water level using a theodolite and rod or in the case of submerged sites by direct measurement. Elevations were then related to the National Geodetic Vertical Datum (NGVD, the national reference surface established by the National Geodetic Survey in 1929) via the record of the nearby Amerada Hess tide gage (Wolf and Brinker, 1989). Core locations were recorded using a handheld Trimble Ensign™ GPS. Data from an additional thirteen cores previously collected by the Coastal Studies Institute, some of which are reported in Roberts and van Heerden (1992b), were used along with the 1995 cores to construct stratigraphic cross sections of the delta (Figure 8).

Thirteen cores were collected from the Atchafalaya delta (Figure 9). This study area is located in the southeastern portion of the delta, and includes the manmade lobes known as Long, Community, and Horseshoe Islands. These islands are composed of dredged material deposited from 1990-1994; some atop pre-existing low natural delta lobes.

In the lab, opposite sides of the core tubing were cut in half lengthwise using a circular saw. Thin wire was inserted into the cuts and run down the length of the sediment column, cleanly dividing it. The halves of the tubing were then split apart, and the sediment units were described based on physical characteristics such as grainsize, color and visible structures. While one half of each core was kept intact, sheathed in plastic "lay-flat tubing", the other half was cut into sections approximately 28 cm long. These short sections were laid facedown on a specially

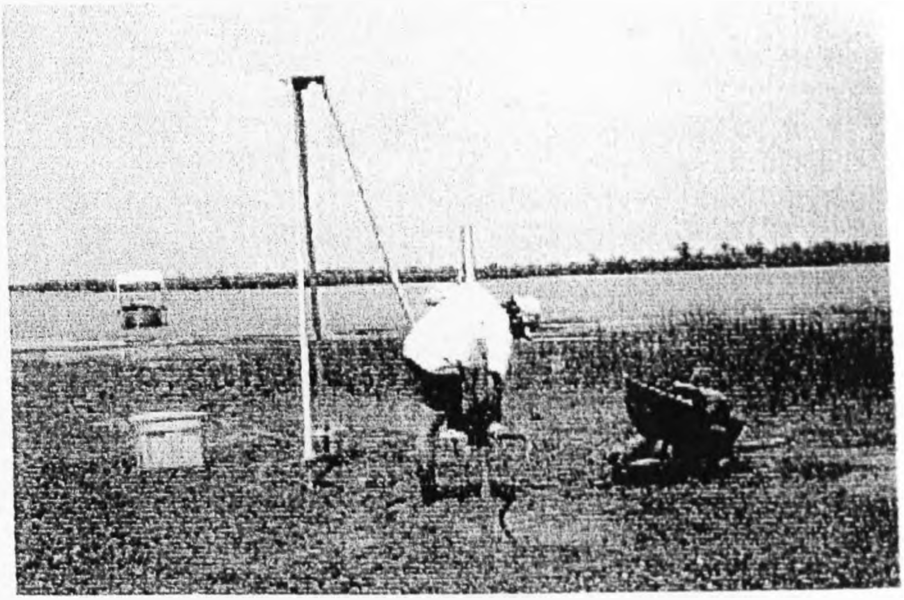

Figure 7. **Standard vibracoring procedure.**

Figure 8. Wax Lake Delta vibracore locations, "WL" indicates cores collected for this project, "R" indicates those collected in 1992.

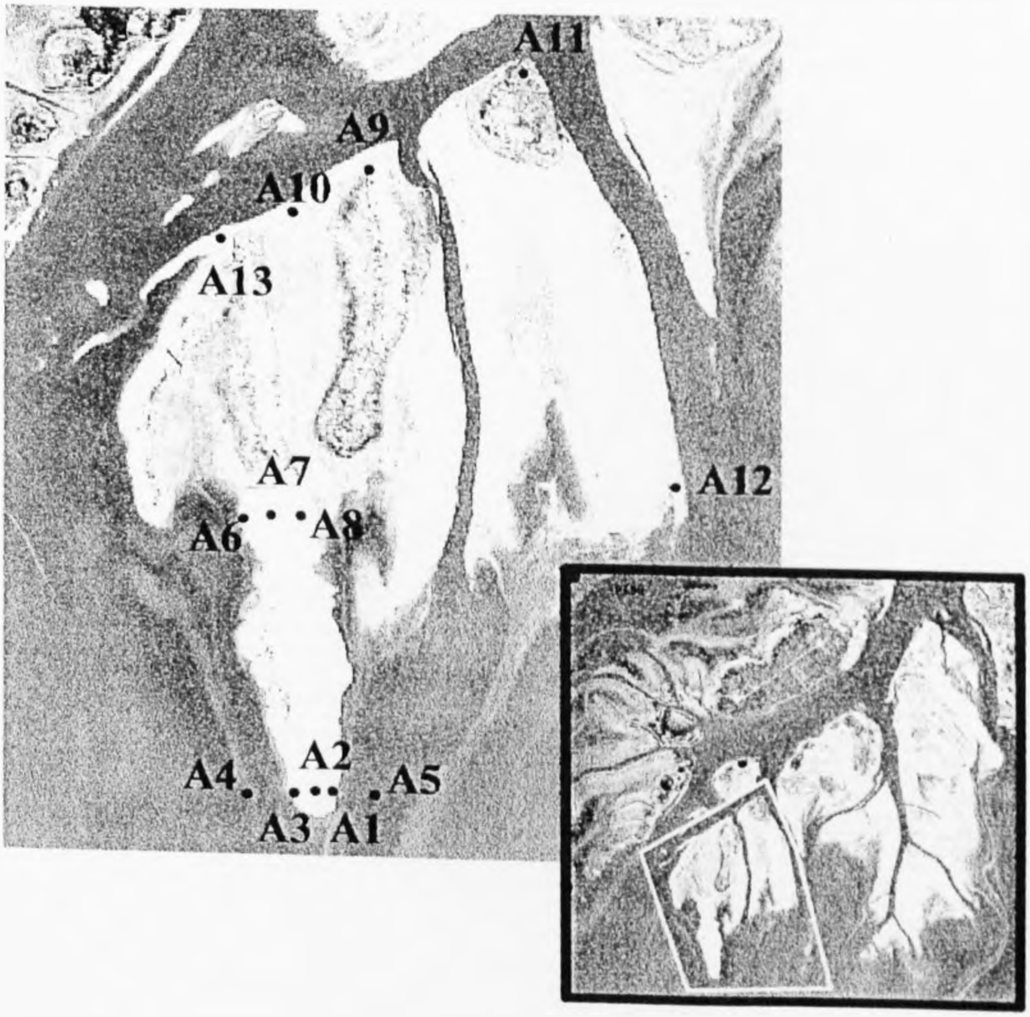

Figure 9. **Atchafalaya Delta study area and core locations. Aerial photo taken January 7, 1995, 0.1' estimated water level.**

designed surface that allows a uniform 1-cm slab to be sliced from each section. These slabs were photographed by X-ray radiography using standard methods (Roberts et al., 1976). The undisturbed halves of selected cores were photographed using Tungsten film, and all were stored for later observation and sampling.

Vibracore Compaction/Decompaction

During the vibracoring process and prior to extraction from the ground, sediments in the core tubing underwent compaction varying from 3.2 to almost 28 percent of total penetration depth. Previous work (Bowles, 1987) considered compaction of 10 percent or less to be negligible. Ten of the twenty-three vibracores collected displayed compaction of approximately 10 percent or less. The other thirteen cores were "decompacted" based on the algorithm presented by Kuecher (1994). This algorithm, presented in graphic form, is based on the percent recovery of pushcores taken from various sediment types (Figure 10). The main sediment types presented in the graph are fine sand, silt, clayey silt, very silty to silty clay, clay or fat clay, and peat. To decompact these cores, the major sediment type for each unit (as according to the physical description) was used for deriving the conversion factor to be applied to the unit. For example, if the top 1-meter of a core were composed of silty sand, the y-axis of the algorithm (depth in meters) would be read between 0 to 1.0 meter. Going across the graph, the curve defining the limit of the fine sand field is found to give a value of about 1.1. Therefore, the 1.0 meter sand unit thickness would be decompacted to (1.1 * 1.0 m) 1.1 meters thickness. Then, supposing the underlying unit was silty clay with a compacted thickness of 0.3 m, the y-axis would be read from about 1.1 to 1.4 m, and the silty clay field would give a value of about 1.45. The decompacted unit would be (1.45 * 0.3 m) 0.44 m thick, and represent 1.54 m in depth below the surface. In cases of texturally variable units, for example where sands, silts and clays were

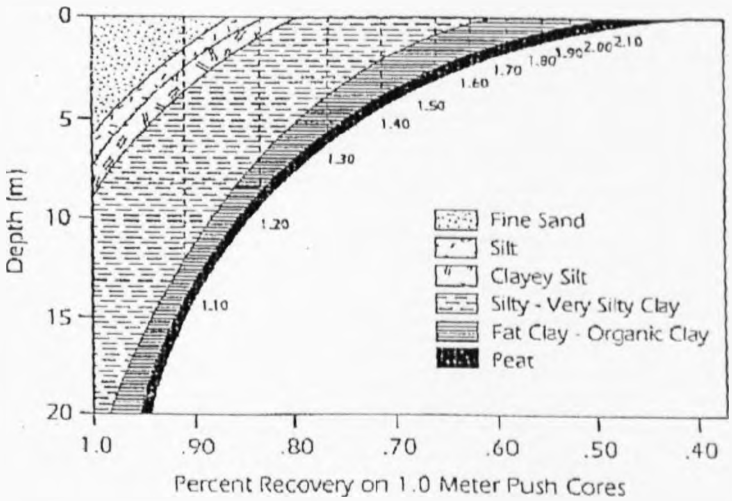

Figure 10. **Kuecher's (1994) decompaction algorithm.**

interlaminated, an interpolated value is used from among those derived for each individual sediment type.

Core Interpretation

The sediment units were grouped into four basic categories corresponding to environments of deposition described by earlier work (Appendix I, van Heerden 1983, Roberts and van Heerden 1992, Bowles 1987, and Kuecher 1994).

To aid in core interpretation, selected samples were analyzed for percent sand by weight. Samples were wet-sieved through a 64-micron screen. The material left on the screen was dried, weighed, then incinerated to remove organics (Davies, 1974), and reweighed. Following removal of organics, the volume percentage of shell material content was visually estimated.

Terrain Models

Digital terrain models were constructed based on the 1981, 1989, and 1994 Corps of Engineers hydrosurveys of Atchafalaya Bay. These surveys consisted of cross bay transects, spaced (600 m) apart along standardized rangelines with a z-value (depth) collected every 30 or 60 m. All z-values were directly or indirectly adjusted to the Amerada Hess tide gage (ACOE tide gage no. 88550). Each survey consisted of two sections: East, covering the Lower Atchafalaya River (LAR) Delta, and West, covering the Wax Lake Outlet (WLO) Delta. Only the Wax Lake Outlet terrain models will be presented here. For the Atchafalaya delta models, see Cunningham et al., 1996. LORAN-C was used for horizontal control of the 1981 survey, while the 1989 and 1994 surveys employed the Global Positioning System (GPS). The accuracy of each survey is probably variable, depending on methodology, equipment, and technology applied to each.

In addition, a digitized version of the NOS navigation chart for Atchafalaya Bay was obtained from Dr. G. Stone of the Coastal Studies Institute, LSU. This chart shows only very

early delta development at the mouth of the Atchafalaya, and none at the mouth of the Wax Lake Outlet. It is composed of data from various years, but may be considered to represent conditions in the bay as of the early to mid 1970s. This dataset was also converted into a terrain surface to provide a bathymetric baseline prior to subaerial delta development.

The terrain models were constructed at Louisiana State University's Computer Aided Design and Geographic Information Systems (CADGIS) Laboratory, utilizing Intergraph hardware and software. The hydrosurvey data files were converted to the Louisiana State Plane coordinate system and placed in design files representing each of the three years. Due to the 2000 ft spacing of the survey range lines, the survey data alone was inadequate to define island shapes and channels. High altitude, color-infrared aerial photography acquired from NASA and USGS was digitized to provide additional bankline and delta lobe information. Dates and water levels relating to the aerial photos are presented below (Table 1). In addition, field data from core locations was incorporated into the models. Cunningham et al. (1996a, b) present a detailed explanation of the processes used in terrain model construction.

Table 1. Dates and water levels for aerial photos used in model construction.

MODEL	DATE	WATER LEVEL (NGVD)
1981	November 16, 1983	+1.0 ft (+0.3 m) estimated
1989	September 19, 1989	+0.6 ft (+0.18 m) estimated
1994	January 24, 1995	+0.6 ft (+0.18 m) estimated

Stratigraphic Transects

Elevation values along transects between cores were based on a combination of measurements taken in the field and those derived from the digital terrain models, using Intergraph Siteworks™ software. The Wax Lake Outlet study area has one dip and two strike transects, while the Atchafalaya area has two dip, and one quasi-strike, transects (Figure 11).

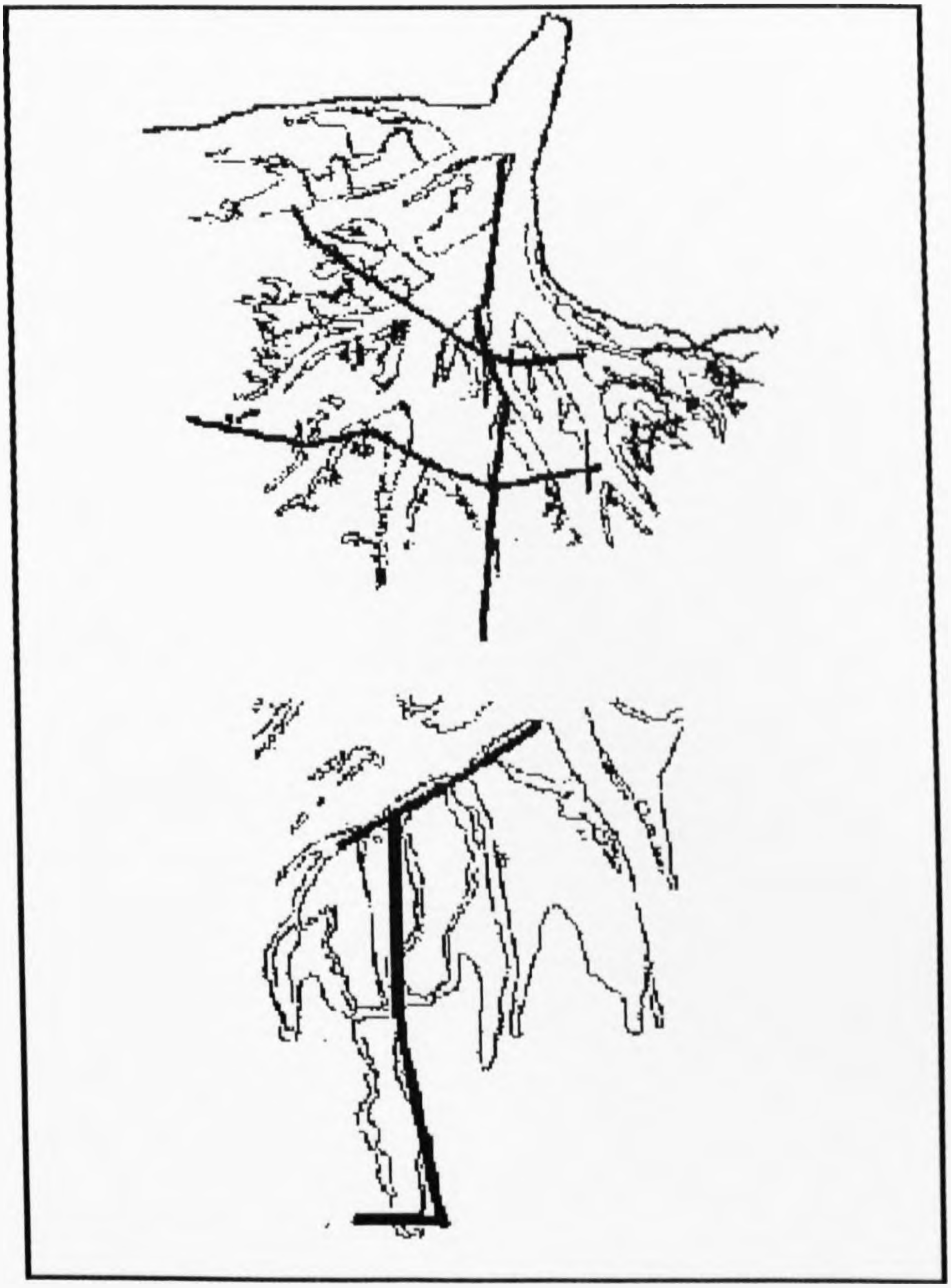

Figure 11. Location of transects in the Wax Lake and Atchafalaya Deltas.

Volume Calculations

One useful feature of the digital terrain models is that the volume of difference of one year's surface values from another may be calculated using Intergraph's Terrain Analyst module. The software gives the output information in two forms. The first is a TIN (Terrain Irregular Network) model, which provides an isopach map of difference values, and the second is a text report of positive, negative and net change values. Difference models were run for the years: 1981 to 1989; 1989 to 1994; 1981 to 1994; and between the navigation chart model surface to 1981.

Sand-rich facies basal elevations were derived from available core data and entered into an Intergraph design file. After transforming this information into a terrain surface, an estimate of the sand volume of the Wax Lake delta was calculated by creating a difference model using this basal surface and the 1994 elevation surface.

Sediment Retention

Mr. Hassan Mashriqui compiled suspended sediment measurements from the Wax Lake Outlet, taken at Calumet, and the Lower Atchafalaya River, taken at Morgan City, from ACOE records. These data were originally reported in tons, but were converted to m^3 using a conversion factor of approximately 1 ton per yd^3 (H. Mashriqui, pers. comm.). The results were grouped according to time intervals corresponding to the difference models. The ratio of net volume gained to volume supplied was calculated to give estimates of sediment retention by the WLO delta lobe.

RESULTS AND DISCUSSION

Sediment Cores

The twenty-three vibracores collected for this project ranged in length from 2.98 m to 5.32 m. Core description logs are provided in Appendix II. On average, cores from the Wax Lake were longer and underwent less compaction than those of the Atchafalaya; consequently, they achieved greater penetration depths on average. The decompaction exercise resulted in reducing the error in all but three of the thirteen overcompacted cores to less than 10 percent (Appendix III). These two cores were WL5 (overdecompacted, +10.3%), A11 (underdecompacted, -15.6%) and A7 (underdecompacted, -21%). The reason for the lack of success with these cores is unclear.

Deltaic Sand Units

The results of sediment sample analysis for percent sand by weight are shown in Appendix IV. Distributary mouth bar, levee, and channel environments are generally those considered to be the major sand-bearing facies in deltas such as the Wax Lake and Atchafalaya (e.g., Coleman (1975), van Heerden, (1983)). Tye (1986) mapped as sand units those containing greater than 25% sand, and samples from the traditional sand facies in both the Wax Lake and Atchafalaya deltas are generally in agreement with Tye's definition. Samples of distributary mouth bar deposits contained an average of 28 percent sand by weight, levee deposits an average of 71 percent, and an active channel deposit from East Pass in the Wax Lake delta contained 30 percent (Table 2).

Terrain Models

The digital terrain models discussed here provide the most recent information on the Atchafalaya Bay deltas. Color grid representation of the navigation chart model surface is

Table 2. **Percent sand data for natural delta facies.**

Delta Facies	# Samples	Average % Sand	Standard Deviation
Levee	19	71	21
Channel	1	30	-
Distributary Mouth Bar	11	28	16
Levee Flank	4	24	16
Interdistributary Bay	4	10	7
Distal Bar	18	7	7
Upper Prodelta	12	3	4

included in Figure 12, with the '81, '89 and '94 model surfaces included in Figure 13, along with the corresponding aerial photographs.

To examine the delta features alone, excluding possible errors encountered along the edges of the models, a polygon was traced around each delta roughly following the -0.6 m (-2 ft) contour line. This elevation was chosen as the minimum elevation for the 'lower intertidal' zone of the delta (Cunningham et al., 1996a), and will be used here to separate each delta proper from the rest of its half-bay model.

The difference models are presented in Figures 14 through 16. A table of values obtained from the difference models is presented in Table 3. "Lobe Area" refers to the area within the delta proper, as described above. "Flank area" refers to the remaining area in each half-by model. As mentioned previously, these change models report the areas and elevations by which the two models differ in elevation (z) values. Where the more recent model "A" (representing conditions at T_2) is higher in elevation than the older model "B" (representing conditions at T_1), the volume is reported as an increase ("+"). Where "A" is lower in elevation than "B", the volume is reported as a decrease ("-"). However, in the intervening years between the two models, processes such as deposition, compaction, subsidence, erosion, and sediment reworking, continued to operate, and it is important to keep these processes in mind and to be aware of how

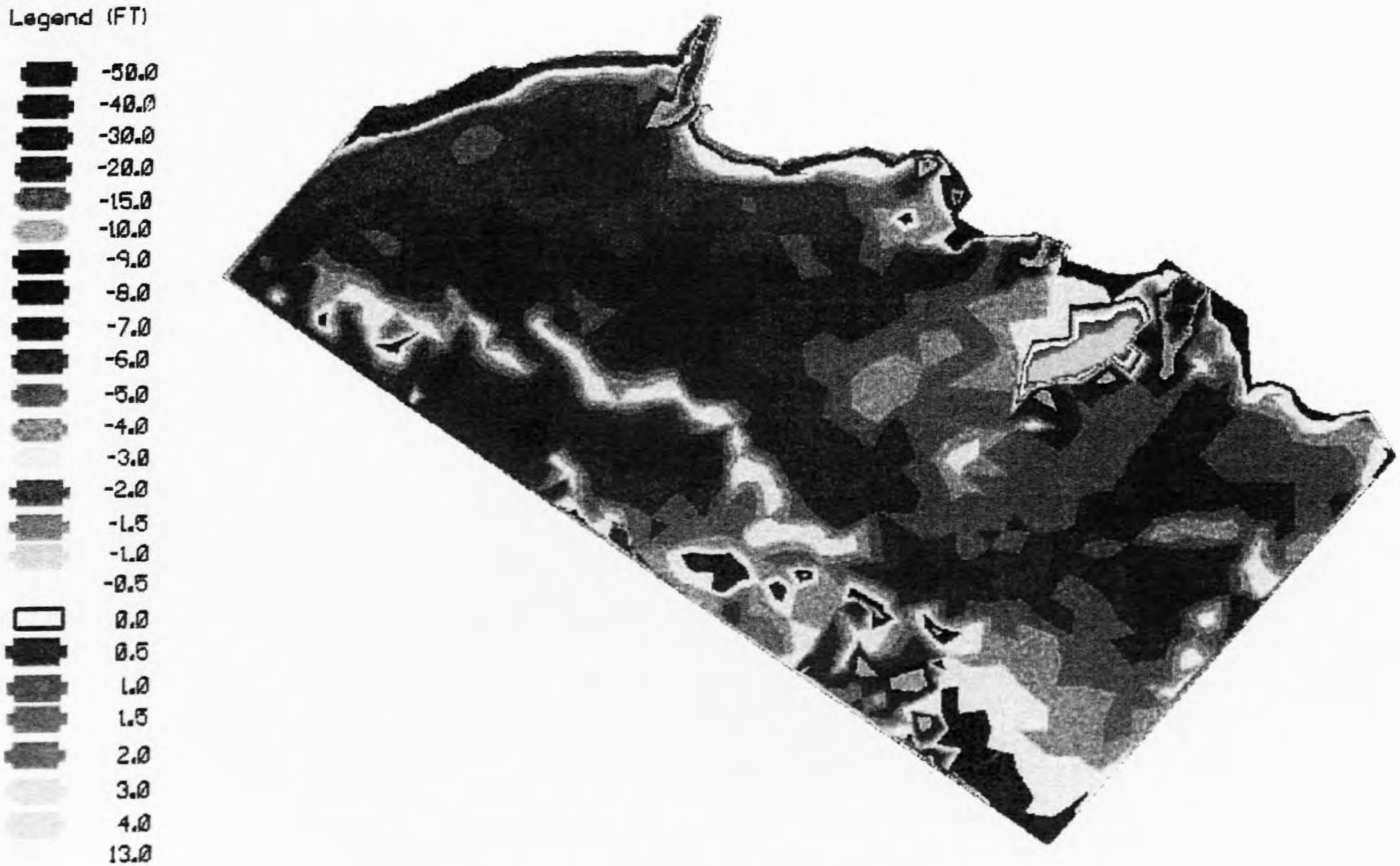

Figure 12. **Navigation Chart terrain model.**

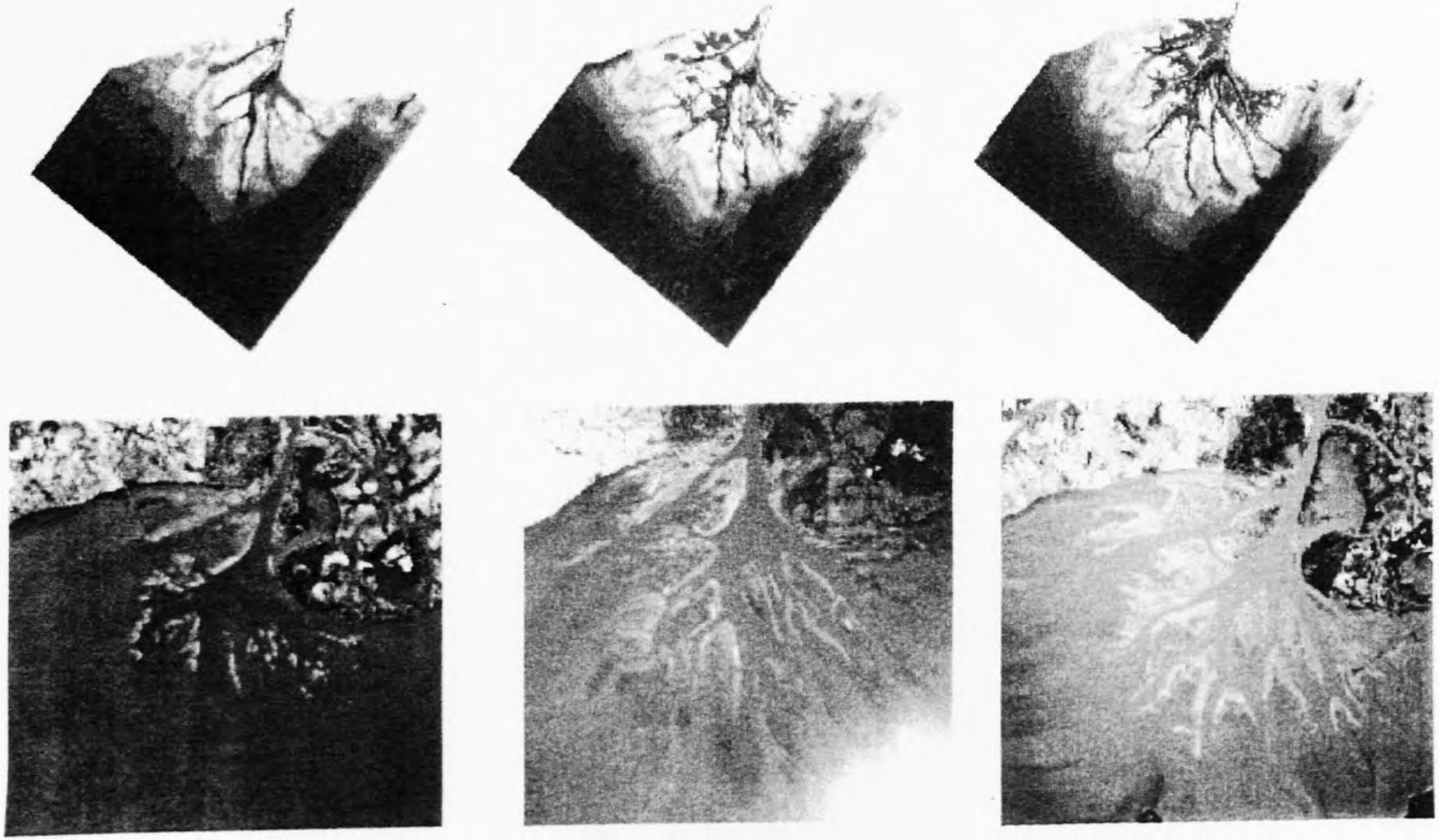

Figure 13. 1981, 1989, and 1994 terrain models and corresponding aerial photos.

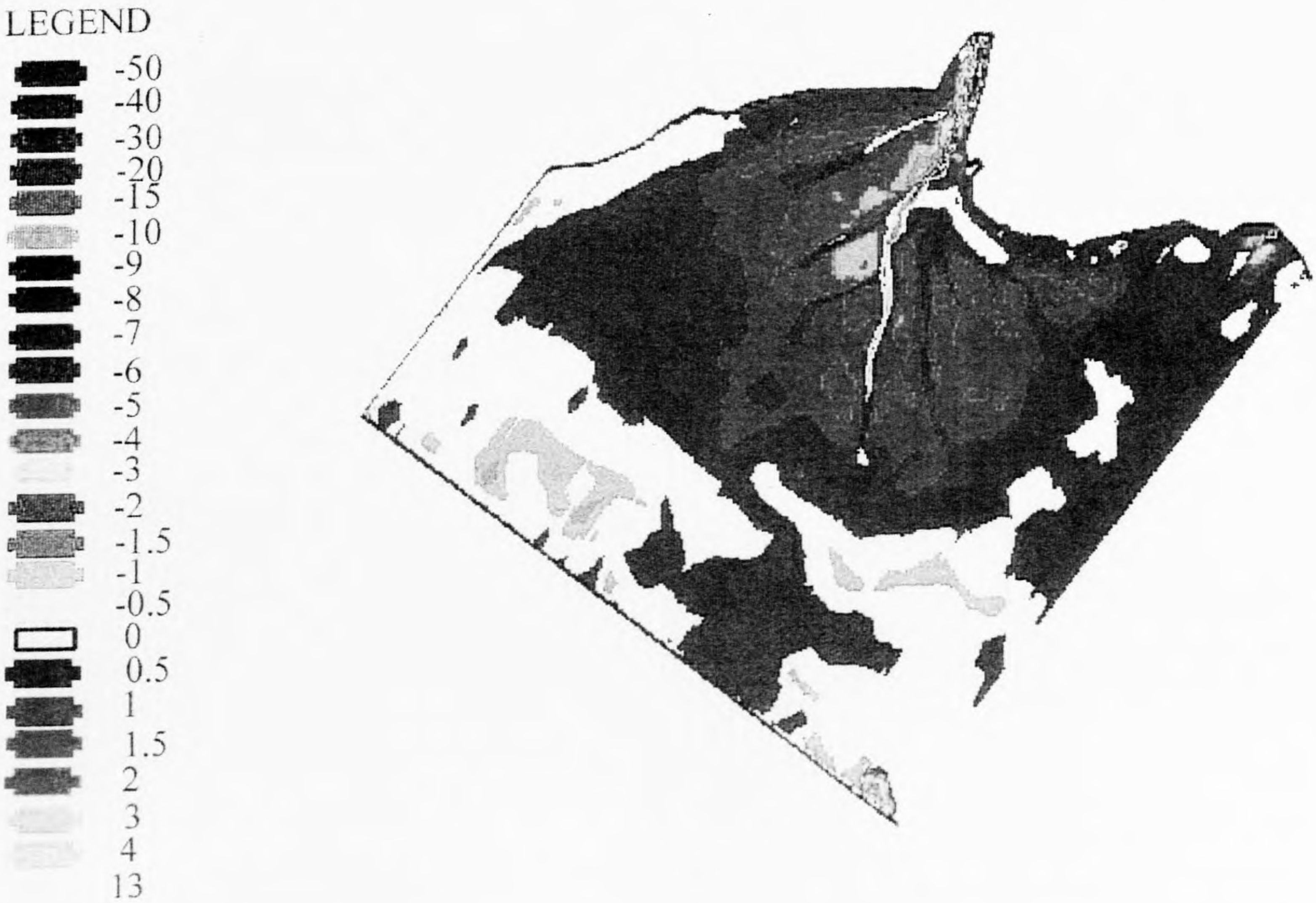

Figure 14. **Navigation chart-1981 difference model.**

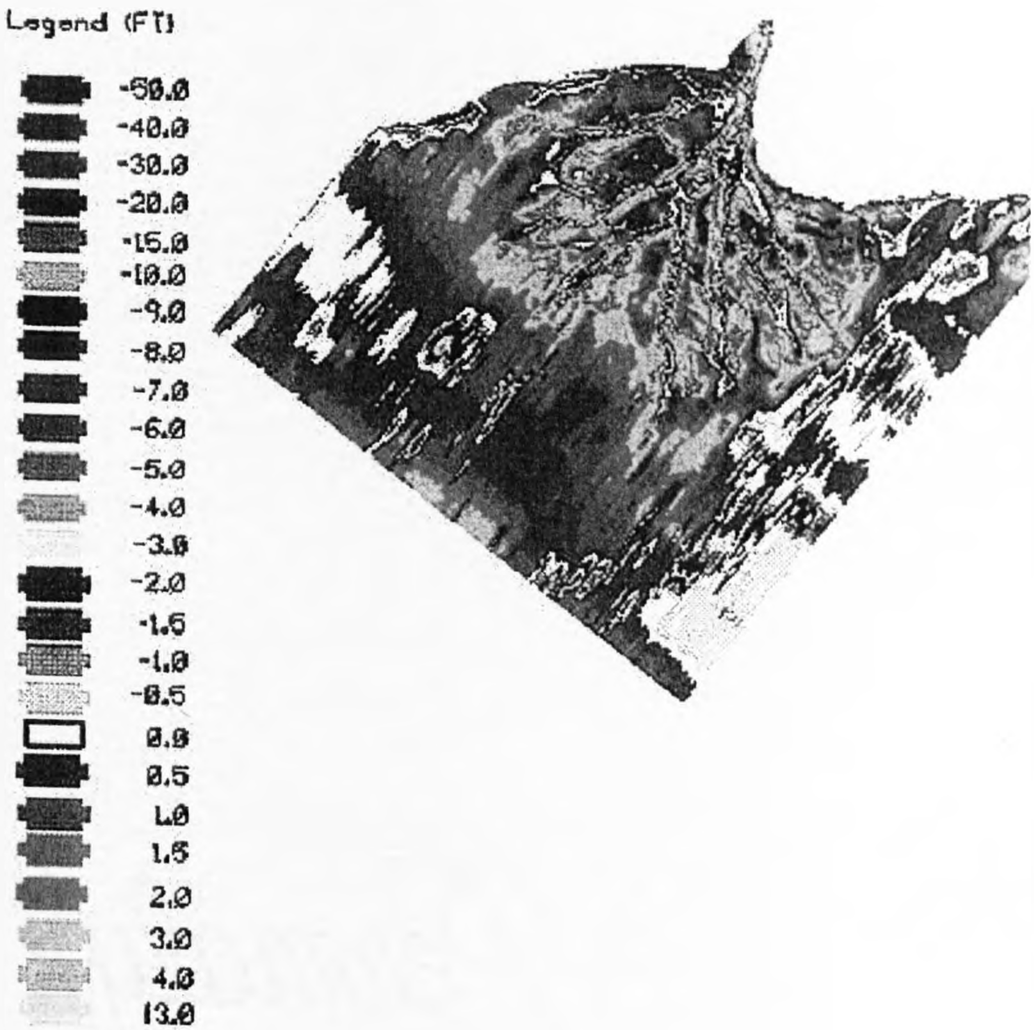

Figure 15. 1981-1989 difference model.

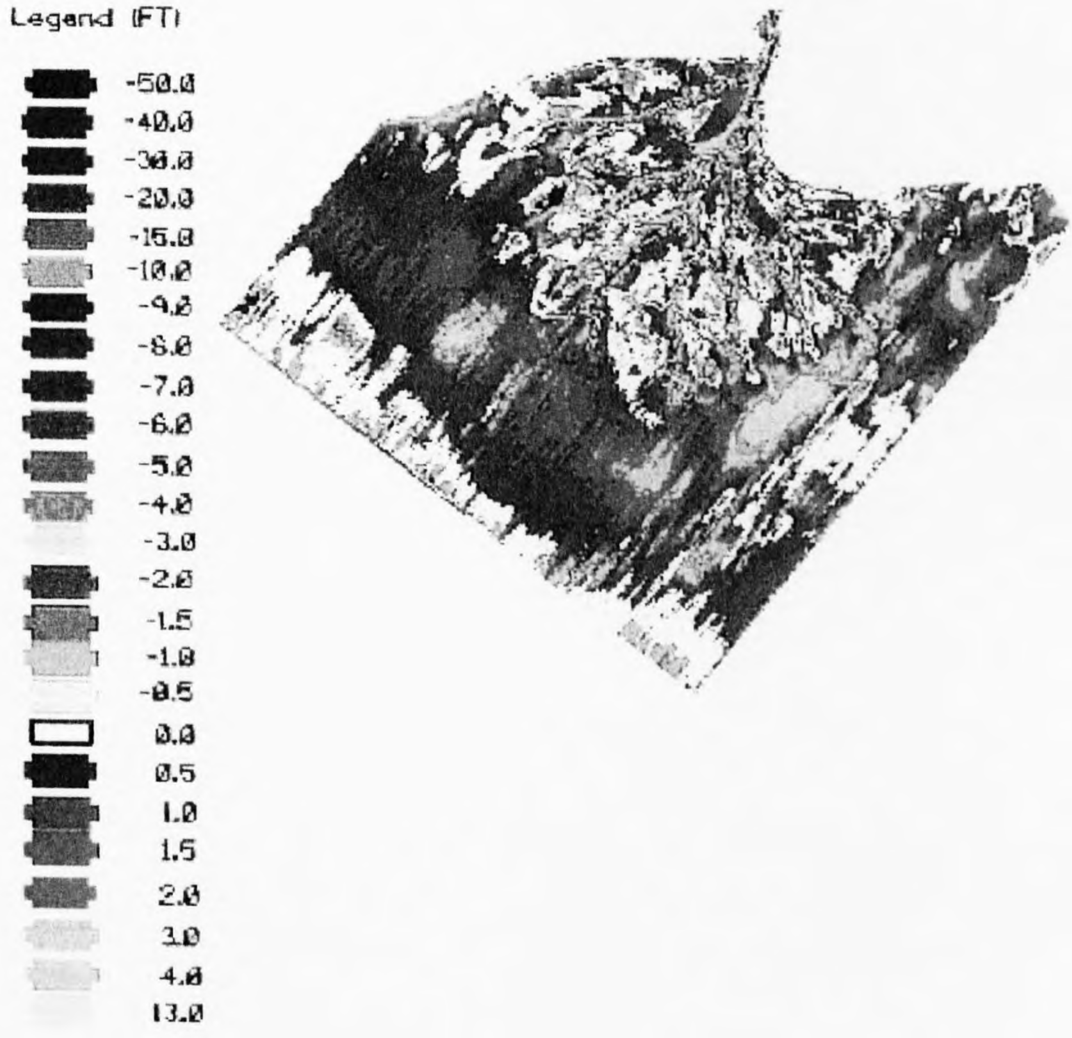

Figure 16. 1989-1994 difference model.

Table 3. **Difference model volumes ($x\ 10^6\ m^3$). "NA" = not available.**

	Wax Lake Outlet			Lower Atchafalaya River			
	Lobe Area	Flank Area	Half- Bay Total	Lobe Area	Flank Area	Half-Bay Total	Atchafalaya Bay Total
NC– 1981							
+	82.5	21.2	103.7	136.1	NA	NA	NA
-	3.1	30.5	**33.6**	28.1	NA	NA	NA
Net	79.5	-9.4	**70.1**	108.0	NA	NA	NA
1981-1989							
+	41.5	24.4	65.9	49.6	26.0	75.6	141.5
-	5.7	10.6	16.3	17.4	5.7	23.2	39.5
Net	35.8	13.8	49.5	32.2	20.3	52.4	102.1
1989-1994							
+	19.5	30.8	50.3	48.5	11.2	59.7	110.0
-	13.5	8.8	22.2	17.1	11.0	28.1	50.4
Net	6.0	22.0	28.1	31.4	0.2	31.6	59.6
1981-1997							
+	52.2	43.6	95.8	77.4	17.4	94.7	190.5
-	6.0	7.3	13.3	14.8	8.1	22.9	36.2
Net	46.2	36.4	82.6	62.5	9.3	71.9	154.4
ANNUAL RATES							
1981-989							
+	5.2	3.0	8.2	6.2	3.2	9.5	17.7
-	0.7	1.3	2.0	2.2	0.7	2.9	4.9
Net	4.5	1.7	6.2	4.0	2.5	6.6	12.8
1989-1994							
+	3.9	6.2	10.1	9.7	2.2	11.9	22.0
-	2.7	1.8	4.4	3.4	2.2	5.6	10.1
Net	1.2	4.4	5.6	6.3	0.0	6.3	11.9
1981-1994							
+	4.0	3.4	7.4	6.0	1.3	7.3	14.7
-	0.5	0.6	1.0	1.1	0.6	1.8	2.8
Net	3.6	2.8	6.4	4.8	0.7	5.5	11.9

they are or are not reflected in the reported changes when interpreting difference values. For instance, Atchafalaya Bay and the surrounding area are known to be subsiding at a rate of about 0.8cm/year (Penland et al., 1994). Therefore even to just maintain elevation values from year to year, 5.5 million cubic meters of material is needed to Atchafalaya Bay annually (3 million cubic

meters in and around the Atchafalaya delta, 2.4 million cubic meters in and around the Wax Lake). Yet because no net elevation changes have occurred, the deposition of this added sediment would go unreported by the difference models. Further, where subsidence rates dominate net accretion rates, negative change values would result regardless of any deposition that occurred. Likewise, once deposited, sediments tend to undergo compaction settling, particularly when they are loaded by additional sediment deposition, or are subject to fluctuating water levels such as in the intertidal zone (Kuecher, 1994). Compaction works in conjunction with subsidence in leading to an underestimation of deposited material. Therefore in a subsiding depositional setting, and where sediments deposited are likely to undergo compaction, positive change values are at best a minimal estimate of the volume of sediment deposited between model years.

Negative change values may result from the loss of elevation by subsidence or from true erosion. When negative change values exceed positive values, transport of material beyond the boundaries of the model may be indicated. Sediments eroded from one area may be deposited in another, contributing both to negative and positive change volumes, yet with no net loss or gain of sediment from the system. For all the reasons listed above, "Net" values given on Table 3 come the closest to an accurate description of dominant processes effecting elevation in the system.

A significant feature to notice on each of the difference models are zones surrounding the area of delta deposition which show change values of zero (white) to -3 feet or more (grays to light blue). Similar zones were found to exist around the Atchafalaya delta (Cunningham et al., 1996). These zones are distinguished from the rest of the bay as areas where net accretion over the model time period is not taking place. Based on their location and consistency over all the difference models, these features are considered to be 'scour' zones resulting from the concentration of discharge around the margins of the developing delta mass. The existence of

this phenomenon was unknown in Atchafalaya Bay prior to the creation of the terrain models. The concentration of discharge energy around the growing delta would develop as the volume of the delta increased. It may manifest itself in the stratigraphic record in the form of an erosion surface and/or lag deposit between finer platform deposits below and the coarser delta package above as delta deposition progressed through the area. Such features may be a characteristic of other deltas which develop within confining bays.

Wax Lake Outlet Delta Development

Figures 17 through 19 present the stratigraphic cross-sections compiled from the core and elevation data. The Wax Lake Outlet delta is composed of the classic prodelta to distributary mouth bar coarsening upward sequence. Its development through 1994 has been broken down into four time periods, based on the terrain models.

Time period 1 (Pre-Navigation Chart model surface)

This area of Atchafalaya Bay is built on Teche-aged submerged marsh deposits, and brackish water deposits described by van Heerden as 'old bay bottom' (Figures 17 and 18; Thompson, 1951; van Heerden, 1983). In the dip section the marsh deposits dip to the south and disappear beneath the old bay, probably due to the gradual transgression of the bay as the marsh subsided. In the northern strike section, the upper boundary of the submerged marsh takes on a concave appearance, possibly due to differing subsidence rates from the margins of the bay seaward. If so, this area of the bay may have formed in a way similar to that proposed by Kuecher (1994) for the formation of Terrebonne Bay to the east, i.e. by the compression of peaty soils. Submerged marsh deposits are not present in cores of the southern strike transect (Figure 19), most likely due to the seaward dip of the unit. Thompson (1951) mentions subsurface marsh deposits in this area, traceable for 5 miles seaward of the Point Au Fer shell reef.

Directly above the submerged marsh deposits lie silty bay fill sediments which match the description of the bay bottom made by Thompson in 1951. This unit thickens seaward

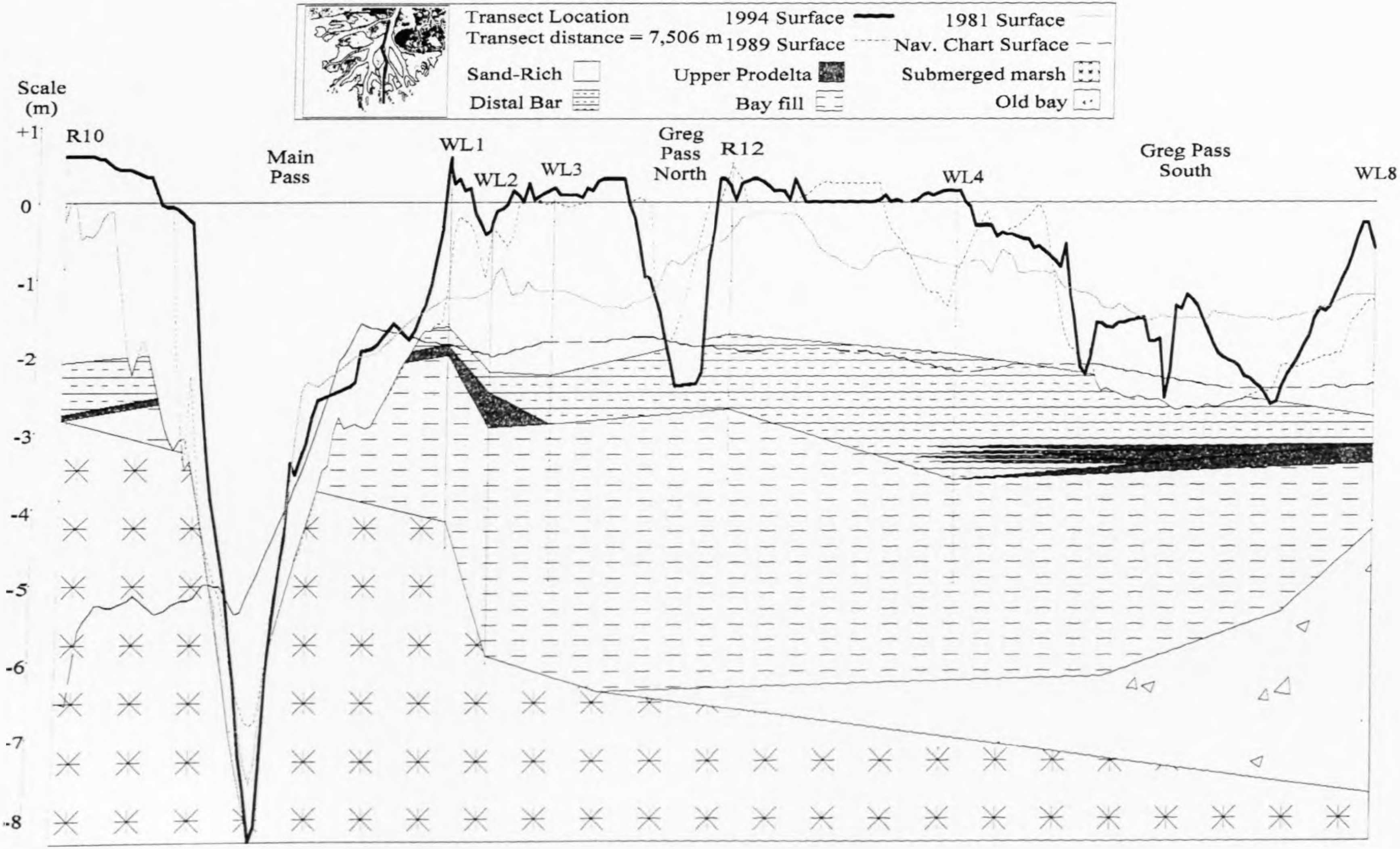

Figure 17. **Wax Lake Outlet delta dip section.**

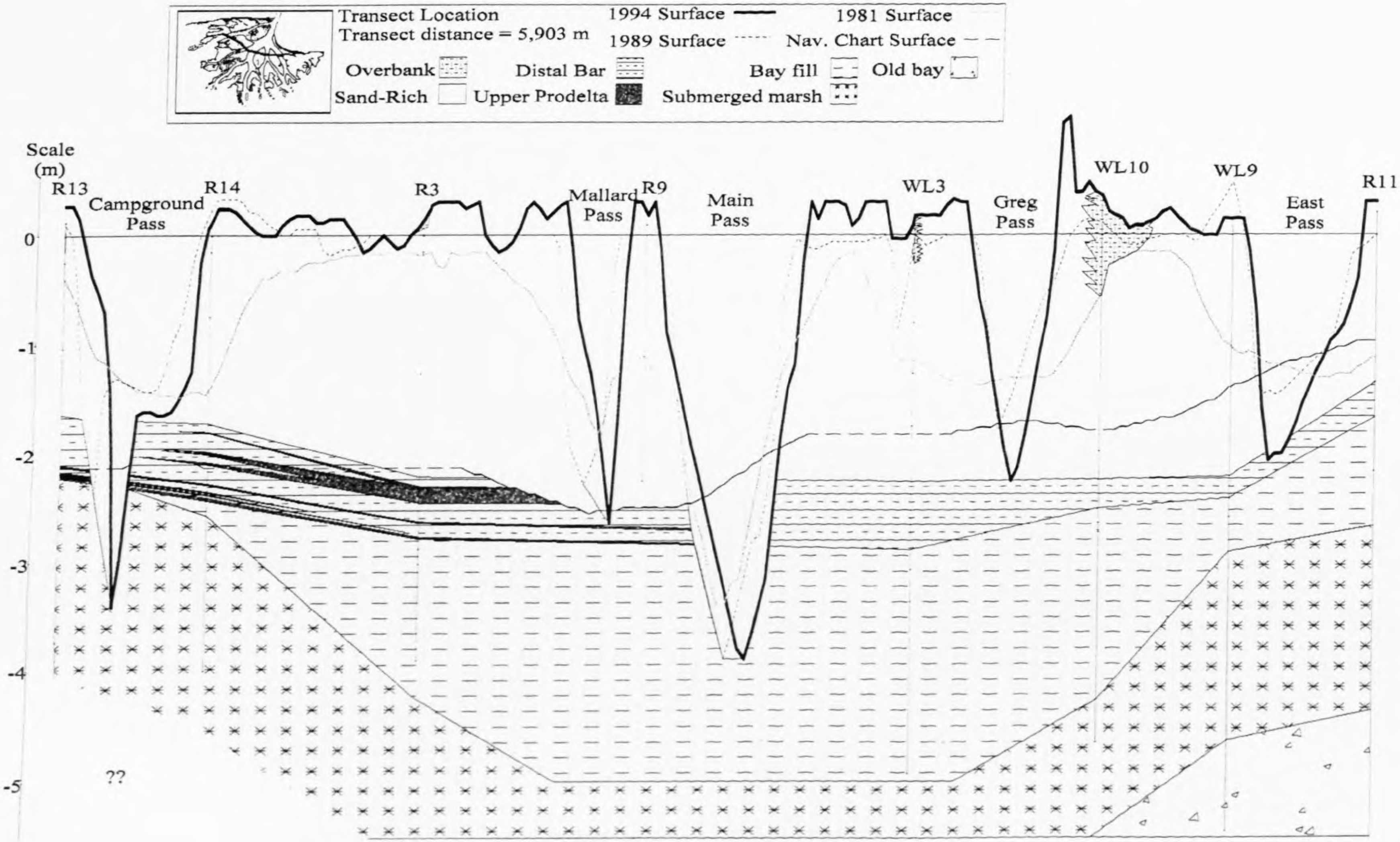

Figure 18. **Wax Lake Outlet delta northern strike section.**

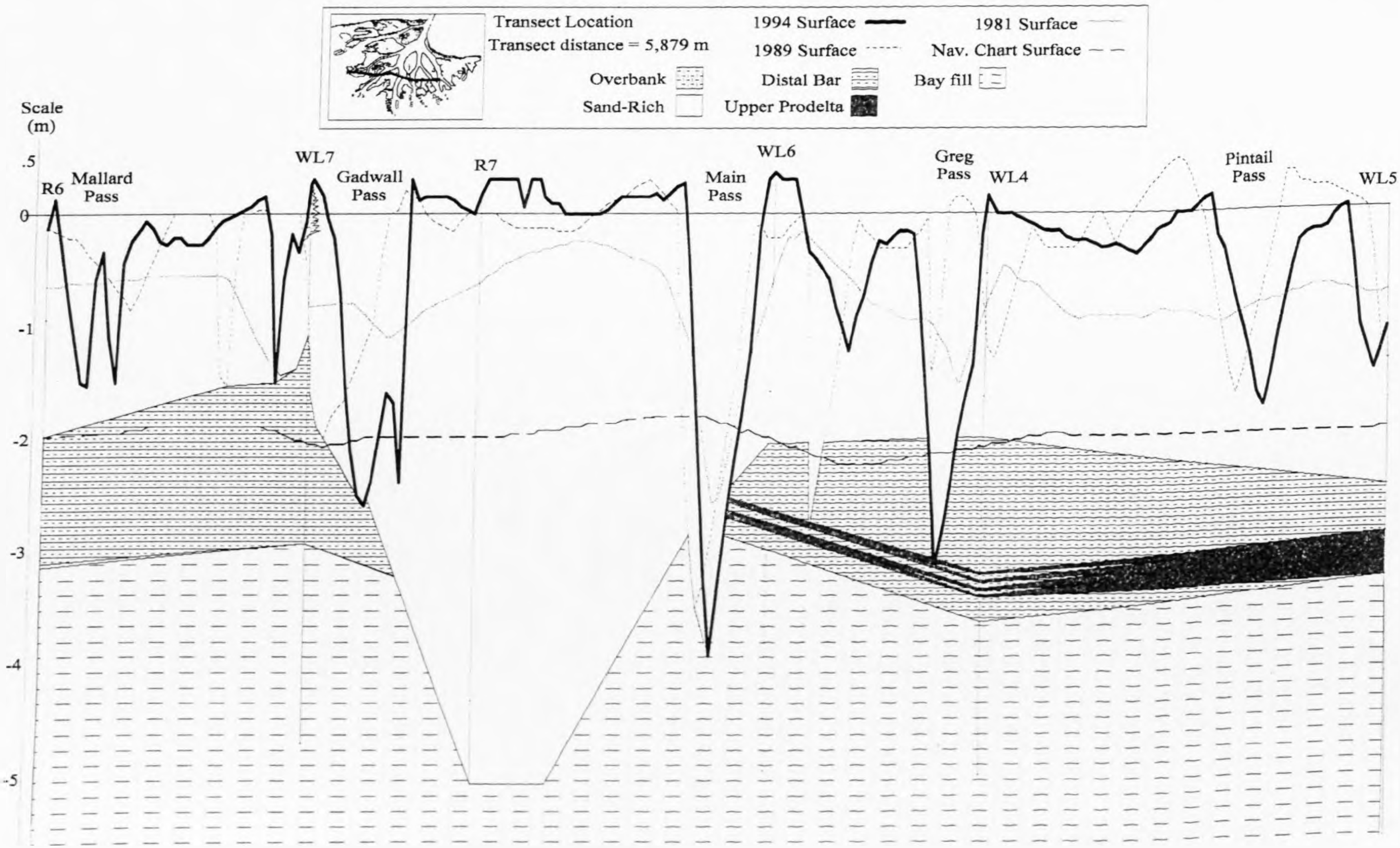

Figure 19. **Wax Lake Outlet delta southern strike section.**

(Figure 17) and to the east in the proximal portions of the delta (Figure 18), achieving a minimum thickness of nearly 3 meters in the region of the southern strike section (Figure 19).

The southern strike section shows what seems to have been a deep channel, midway across the transect. This channel, which cut well below the level of the silty bay fill and filled with sandy deposits, may be related to the former Wax Lake Outlet dredged channel (Shlemon, 1972). If this is so, the channel fill may extend upstream and be found at depth in the vicinity of core R9 (Figure 18), although it is not shown.

Unlike the Atchafalaya delta, the Wax Lake Outlet delta's upper prodelta unit is extremely limited. Thin clay-rich upper prodelta deposits are seen interfingering with distal bar deposits (Figures 18 and 19). Tye (1986) observed similar interfingering of these units in cores from the Lake Fausse Pointe delta, and attributed it to varying flood magnitudes from year to year. In the northern strike section the upper prodelta deposits are found emanating from western bank of Main Pass with no significant thickness found to the east, suggesting that the channel itself supplied these sediments (Figure 18). In the southern strike section, upper prodelta clays extending from the eastern bank of the buried channel thicken to the east, indicating an eastern source (Figure 19). Together, these sections suggest that perhaps both the Wax Lake Outlet and drifting plume of the Lower Atchafalaya River delivered upper prodelta sediments to this area. The dip section (Figure 17) shows both upper prodelta lenses, and also supports this theory.

The navigation chart model surface within the cross-sections roughly coincides with the interface of the distal bar deposits with overlying sand-rich deposits. However, both strike sections (Figures 18 and 19) suggest that deposition of coarse material in the form of distributary mouth bar deposits had begun east of Main Pass (in the vicinity of Northern Greg Pass and Pintail Pass), prior to the date of the Navigation Chart data. But this was not the site of the earliest distributary mouth bar development. Earliest lobe development occurred in the shallow

northwestern corner of the bay. Prior to delta formation, this was the first open water encountered by Wax Lake Outlet effluent upon entering Atchafalaya bay. While the dredged Outlet channel continued south, the effluent began to spread here. As it spread, it decelerated and began depositing coarse-grained material in this area. Its spreading was inhibited when it encountered the western shoreline, and this also encouraged deposition, first of distributary mouth bar deposits, and later of levees. The navigation chart surface does not agree with the core data from core R10 at the head of the delta (Figure17) due to a slight disagreement in horizontal location between the chart model and the other model surfaces. Since the chart surface falls within the submerged marsh unit (seen in the dip cross-section), it logically ought to be disregarded at this one core location.

Time period 2 (Navigation Chart to 1981)

As mentioned, the northwestern portion of the delta was the location of initial deposition of the distributary mouth bar and levees in the area. Once the initial sedimentation took place, continued sedimentation was encouraged in this area through the feedback loop discussed earlier. As deposition continued, the delta appears to have developed in three areas through time (Figure 20), first in the northwestern section, then in the southwestern, and lastly in the east-central section. Growth occurred through this period by the development of parabolic lobes to the west and east, but emerging bars in the central portion of the delta appeared at first thinner, more linear (Figure 20).

Channel patterns differ in the western and eastern sections of the delta, reflecting different processes of progradation (Roberts and van Heerden, 1992). Channels in the western delta extended themselves primarily through channel bifurcation, with the bifurcation most closely aligned with the parent channel assuming dominance and prograding seaward (Roberts and van Heerden, 1992). Van Heerden (1983, 1994) presents evidence that the channel that takes

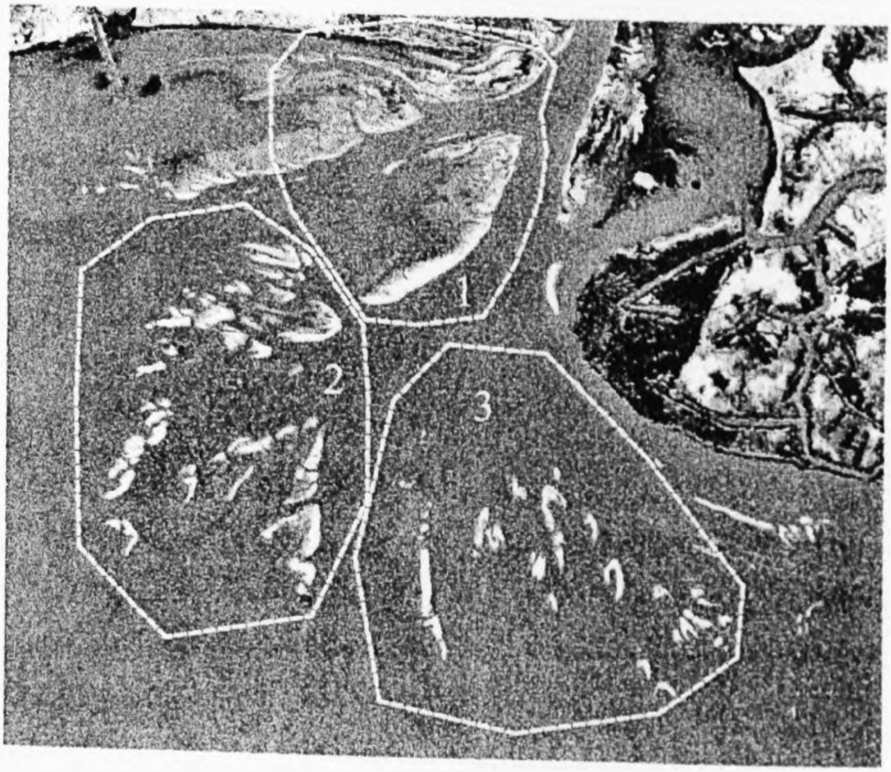

Figure 20. 1983 aerial photo showing sequential areas of delta development.

precedence at a bifurcation is determined by tidal currents and prevailing winds in the bay. In the east-central delta, channels prograded through levee extension, similar to the eastern Atchafalaya (Roberts and van Heerden, 1992). In addition, channel orientations vary from east to west in the Wax Lake delta; western channels have a west-southwestern orientation while eastern channels are oriented to the southeast.

Van Heerden (1983) provided a model for the growth of Atchafalaya delta lobes, which those of the Wax Lake delta appear to follow. During floods, heavily sediment-laden floodwaters flow over subaqueous levees. Zones of greater and lesser turbulence within the water lead to areas of greater and lesser deposition as the water passes over the levee crest. This results in a ridge-and- runnel type drainage system, where ridges form new levee material, and runnels direct flow and develop into overbank channels. Initially, there are numerous small channels, but over time, with continued levee accretion, many are filled in and only the most efficient dominate. Later, new overbank channels may form after a lobe is established. These channels are technically levee crevasses. During the period of the early 1970s to 1981, the processes of bifurcation and channel deepening were occurring along Main Pass. In the northern delta, Main Pass bifurcated several times (forming Campground, Mallard, Greg and East Passes), and these new channels began extending themselves seaward (Figures 14 and 18). Channel extension contributes to increased subaerial growth in two ways: the accretion of subaqueous levees, and the potential formation of mid-channel bars that may weld themselves to nearby levees (Wells et al., 1982).

Scour occurred in the northern portion of Main Pass, reaching through the deltaic deposits and into the underlying bay fill. The low levee represented by the rise in the 1981 model surface near R12 (Figure 17) marks the bifurcation of Northern Greg Pass into Southern Greg and Pintail Passes that occurred during this period. To the south, only Greg Pass to the east and

an unnamed pass to the west appear established alongside Main Pass (Figure 19). At this latitude, Main Pass had not scoured as deeply, only reaching down to the distal bar sequence (Figures 14 and 19). In between the broad major passes, the low initial levees were in place, marking the sites of all major islands (Figures 18 and 19).

A comparison of the 1981 delta surface to that of the navigation chart indicates that a net volume of 7.0 x 10^7 m^3 of material was deposited in the western bay over this time period (Table 3). These sediments formed distributary mouth bar and levee deposits in the delta, and contributed to delta front material seaward (Figure 14). Channel scour, the dredging of the inner shoal reef, and scour along the western shoreline near Point Chevreuil are apparent changes contributing to negative change volumes.

Time period 3 (1981 to 1989)

During this period, all channels (except Campground Pass) continued to extend themselves seaward, and developed past the latitude of the southern strike section (Figure 15 and 19). Welder (1959) explains that in broad, shallow channels, such as had developed by the beginning of this period, zones of maximum current velocity are relatively close to the channel bottom. Turbulent energy is generated by the friction of the current with the bottom, which may be used to scour the channel bed. As the channel deepens, its flow effeciency increases and it is able to transport the same amount of discharge through a smaller cross-sectional area. As a result, relatively slack-water areas develop along channel banks, allowing sedimentation and accretion to occur, brought about by friction between the levee and the sediment laden water. This process is called "lateral levee accretion", and leads to narrowing of the channel cross-section (Welder, 1959; van Heerden, 1983).

Vertical and lateral levee accretion was extremely important during this period, and resulted in well-defined channels and island lobes. In the strike sections, all main passes scoured

their beds and accreted material along the sides of their levees (i.e. Figures 18 and 19). This transformed channel cross-sections from broad, shallow, U-shapes into more narrow, V-shaped channels.

Observed changes suggest that alterations in flow distribution may have been occurring as channels matured. For instance, Campground Pass deepened in the northern strike section, but quickly shoaled to the south (Figures 13 and 15). In its northern section, Main Pass shoaled slightly, by about 0.7 m (Figure 17), and channels migrated within the southwestern delta, between Gadwall and Mallard Passes (Figure 19).

Levees accreted vertically, gaining elevation throughout this period as material was deposited from suspension (Figures 17 through 19). In some areas, levee material was reworked. What was seen in the '81 model as a very small subaqueous levee had aggraded significantly by 1989 to become Leslie Island (Figure 17, cores WL1, 2 and 3). This island also demonstrates upstream levee accretion, which was evident at the heads of other islands in the area.

Levee accretion and channel scour are reflected in the histograms of terrain model elevations (Figure 21). From 1981 to 1989 the histogram broadens as area is gained in the intertidal/subaerial elevations (-2' to +2'), and in the channel depths (-9' to –15').

From 1981 to 1989, Atchafalaya Bay received over 6.08 x 10^8 m^3 of suspended sediment through the Atchafalaya and Wax Lake Outlet each year (Table 4). The Wax Lake Outlet contributed about 40 percent (23.8 x 10^6 m^3) of the suspended load annually, 12 percent (3.0 x10^6 m^3) of which was coarse grained material (Table 5). The remaining portion delivered through the lower Atchafalaya was composed of about 15 percent coarse-grained sediment. Model data over the '81 to '89 period report an average annual net gain of 6.2 x 10^6 m^3 in the Wax Lake Outlet portion of the bay (Table 3). Of the total, 73% of average annual net gain (4.5 x 10^6 m^3 per year) occurred in the delta proper. Ignoring subsidence and bedload supply,

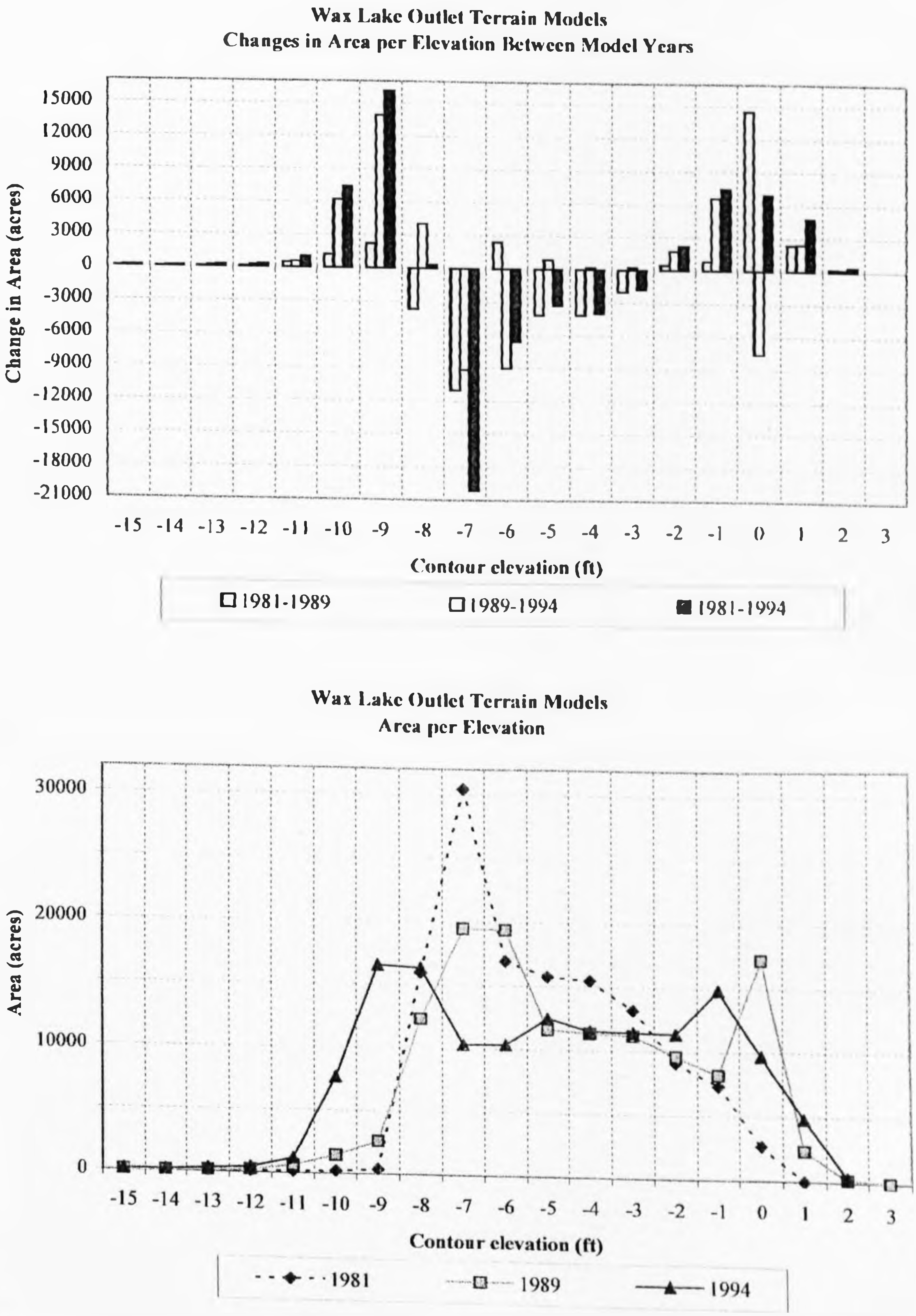

Figure 21. **Wax Lake Outlet terrain model data.**

Table 4. Sediment supply (m^3) through the Wax Lake Outlet (WLO) and Lower Atchafalaya River (LAR) over two study periods.

	Sediment Supply (m^3)					
	Coarse		Fine		Total	
Interval	WLO	LAR	WLO	LAR	WLO	LAR
1981 to 1989	23,864,755	49,409,634	170,344,383	242,537,799	194,209,138	291,947,434
1989 to 1994	18,138,881	55,232,538	68,139,079	136,710,159	86,277,960	191,942,697
Annual Rates						
1981 to 1989	2,983,094	6,176,204	21,293,048	30,317,225	24,276,142	36,493,429
1989 to 1994	3,627,776	11,046,508	13,627,816	27,342,032	17,255,592	38,388,539

Table 5. Average annual percentages of coarse and fine fractions through the Wax Lake Outlet and Lower Atchafalaya River, over two study periods.

tudy Period	981-1989		1990-1994	
	COARSE	FINE	COARSE	FINE
WLO	12%	88%	21%	79%
LAR	17%	83%	29%	71%
Atchafalaya Bay	15%	85%	26%	74%

estimates of sediment retention were calculated by the ratio of the volume of net elevation gain to the volume of suspended sediment supplied In addition, because coarser sediments are more likely to be deposited before finer sediments, estimates of sand retention were calculated by the ratio of the net volume of elevation gained to suspended sand supplied The results are presented in Table 6

During the period from 1981 to 1989, the Wax Lake delta proper retained approximately 18.5 percent of the suspended sediment supplied through the Outlet, while the western portion of the bay as a whole retained 25.5 percent In comparison, the Atchafalaya delta proper retained 10.9 percent of the suspended sediment discharged through the Lower Atchafalaya River,whilethe

Table 6. Sediment and sand retention estimates.

	Sediment Retention: Net Volume Gained / Total Suspended Sediment		Sand Retention: Net Volume Gained / Suspended Sand	
Half-Bay:	1981-1989	1989-1994	1981-1989	1989-1994
WLO	26 %	32%	208%	154%
LAR	18%	16%	107%	57%
Delta Lobe:				
WLO	19%	7%	151%	33%
LAR	11%	16%	65%	57%

The ratio of net volume gained to suspended sand supply indicates that during the 1981 to 1989 period, the WLO delta lobe retained more than enough material (151%) to account for the suspended sand supply. This suggests that fine-grained sediments, as well as the majority of sand supplied, were being deposited within the delta proper. The rate of volume fill for this period was 6.2 x 10^6 m^3 per year (Table 3).

Time period 4 (1989 to 1994)

Channel morphology continued to be dynamic throughout this period. In cross-section, all major channels can be seen to deepen and/or migrate slightly. In the strike sections, Main Pass appears relatively stable over these years, while its distributaries to either side deepen significantly. Thus, these distributaries increased their efficiency. Channel scour may be expected when there is a reduction in bedload (Welder, 1959), such as occurred as a consequence of the WLOCS (Kemp et al., 1995). Northern Greg Pass widened, while mid-channel bars formed in southern Greg Pass (Figure 17). Bar formation may be an indication of reduced discharge through a channel (Kemp et al., 1995). This suggests that northern Greg Pass received more discharge through this period but that a larger portion of its flow was directed down the eastern bifurcation channel, Pintail Pass, rather than the southwestern continuation of Greg Pass

Channel migration and /or lateral levee accretion continued to make minor changes in island morphology (Figure 22).

Lobe fusion joined small lobes in several locations (Figure 22) Conversely, aerial photos suggest there may have been an increase in the number of over bank channels developed on some islands. However, the appearance of these features may be very dependent on water level, making the verification of this development difficult among photos of varying ages and water levels. Figure 23 illustrates the importance of overbank channels in the delivery of sediment to the lobe interior, as evidenced by the formation of sizable splays.

Upstream and downstream levee growth are processes leading to lobe fusion (Wells et al., 1982). Continued upstream accretion was notable at the head of the delta on Leslie and Pintail North Islands (Figure 22) Mallard Pass's mid-channel bar had extended itself downstream toward Skillet Island, although fusion of these island lobes appeared thwarted by a small fourth-order channel, which rejoined the Mallard Pass bifurcation (Rookery Pass) to the parent channel

The plan-view of the change model shows that most of the material deposited over these five years was used for levee accretion and seaward bar formation, particularly to the southeastof the delta (Figure 16) Elevation losses occurred mainly in the interior portions of the islands, although some levee erosion is apparent (Figures 16 - 19). Levee accretion may be responsible in part for the loss of elevation in the interior portion of island lobes As levees gain elevation, the frequency of overtopping by floodwaters diminishes, and one means of delivering sediment to lobe interiors is reduced. Without a sufficient input of new sediment, these areas will subside

The histogram of terrain model data became even broader over this period and takes on a slightly bimodal appearance (Figure 21). Area was gained at all elevations included in the intertidal zone (-2 to +2) except the 0' contour, which lost area The peak of the curve in this

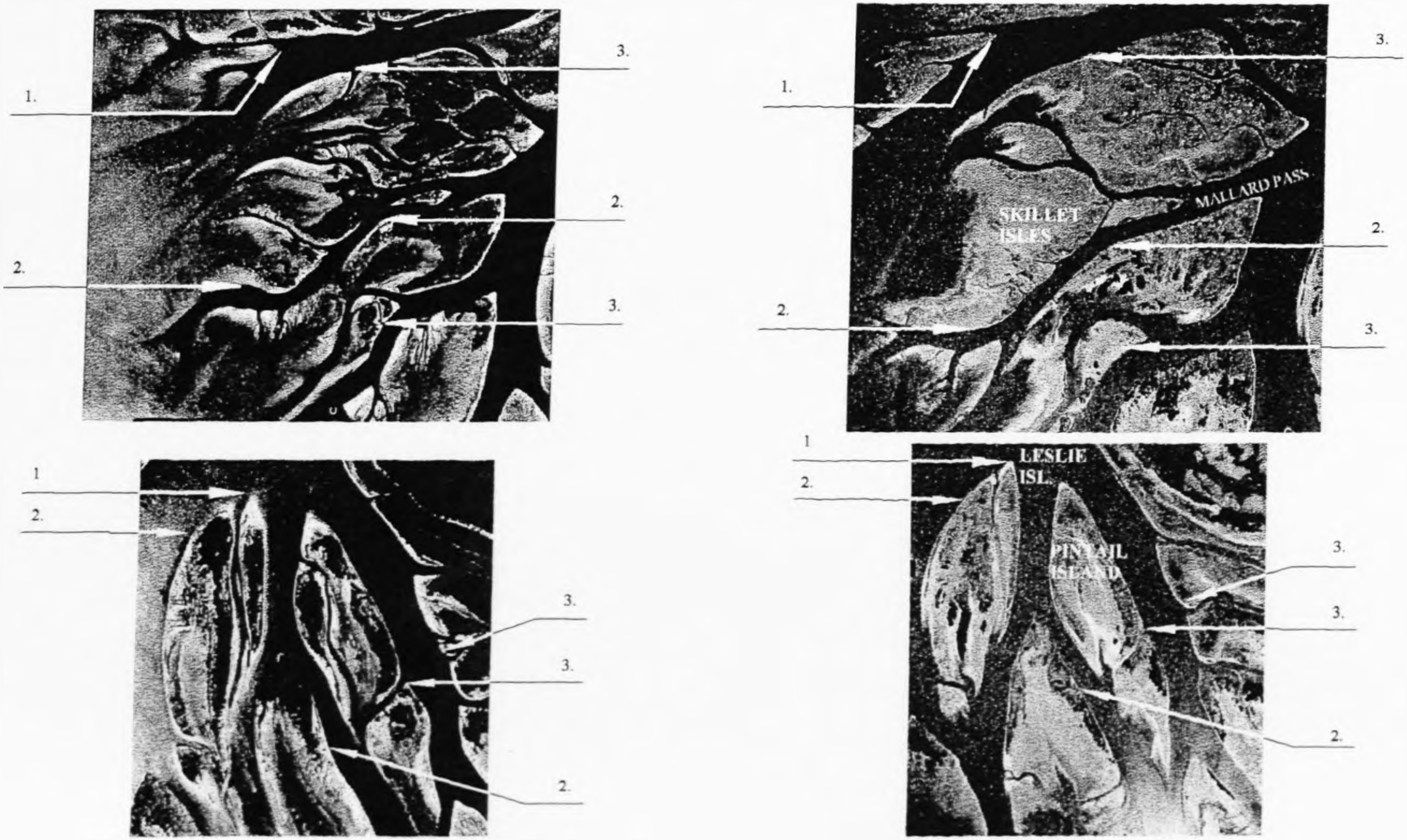

Figure 22. Comparison of 1990 (left) and 1994 aerial photography, showing examples of processes occurring in the Wax Lake delta. 1 = upstream accretion, 2 = channel migration/lateral levee accretion, 3 = lobe fusion.

Figure 23. Aerial photography showing examples of the formation of overbank splays (note arrows) on islands in the Wax Lake delta (October 11, 1990; +0.4' estimated water level.

zone shifted from 0' to –1'. These changes may be due to several processes, including levee accretion, lobe fusion, channel bar formation, the reworking of material from 0' to lower elevations, and subsidence. The redistribution of levee material to lower elevations is documented in the eastern Atchafalaya River delta, a consequence of winter storm erosion and low flood years (van Heerden, 1980). This material forms a shallow platform for further subaerial growth (Wells et al., 1982). Once again, the channel depths from –8' to –15' gained area over this period, reflecting channel extension and deepening (Figure 16). Another possibility contributing in part to the gain at these contour may be minor erosion around the edges of the delta platform, which is seen in the difference models throughout the model years (Figures 14, 15 and 16).

Over the years 1990 to 1994, the average total amount of suspended sediment delivered through the WLO and LAR annually decreased only slightly (by 9 percent) from the earlier period, yet the composition of the load coarsened to 26 percent (Table 4). Wax Lake Outlet's portion of the total supply decreased to 31 percent, yet the sand content of this portion increased to 21 percent. The coarsening of the sediment supply over this period was likely caused by management activities on the Red River which released a 'slug' of material into the Atchafalaya system (G.P. Kemp, pers. Comm.).

Between 1989 and 1994, western Atchafalaya Bay received an average annual net gain of 5.6 x 10^6 m^3 of sediment, only 21% (1.2 x 10^6 m^3) of which is attributed to the delta lobe. The locus of deposition apparently moved out of the boundary of the delta proper and into the outer bay as a result of channel development. Comparing rates from the previous difference model (Table 3), annual elevation loss within the delta proper is seen to increase from the earlier period to 2.7 x 10^6 m^3 per year, a rate increase of nearly 400%.

Sediment retention dropped from 18.5% to 6.9% within the Wax Lake Outlet delta, while the Atchafalaya delta's sediment retention increased from 10.9% to 16.4% due to dredged

material placement (Table 6). The ratios of retention to suspended sand supply within the Wax Lake delta boundary dropped to 33%, suggesting that the distributaries were delivering sands seaward of the –2.0 ft contour of the delta. This is consistent with the development of levees and bars seaward. The rate of volume fill reduced by about ten percent over this period, to 5.6×10^6 m^3 per year (Table 3).

Overall, the Wax Lake Outlet system exhibits better sand conservation from the upstream point of sediment observation (Calumet, Louisiana) to the bay than does the Lower Atchafalaya River. The entire volume of sand observed passing Calumet is accountable for in the western bay, as is evident by sand retention values over 100 percent (Table 6), yet the same is not true of the Lower Atchafalaya River (G.P. Kemp, pers. comm.). Between the upstream measurement of sand volume at Morgan City and eastern Atchafalaya Bay, a volume of sand is unaccounted for in the 1989 to 1994 period.

Wax Lake Outlet Delta Sand Body Volume

Estimation of the volume occupied by the sand-rich facies in the Wax Lake Outlet delta was calculated in two ways. First, a terrain surface was constructed based on the basal elevations of 'sand-rich' units found in the sediment cores. Channel information was borrowed from the 1994 model dataset for this 'base-of-sand' surface, since channels were generally the deepest in that year. Next, the difference volume was calculated between the 'base-of-sand' surface and the 1994 terrain model, giving an estimated sand body volume of 139×10^6 m^3. Because all core data were used in the 'base-of-sand' surface, this volume estimation includes the sandy fill of the buried dredged channel located in the southern strike section (Figure19). However, this channel had filled in prior to the date of the navigation chart and is not technically a deltaic feature; thus it artificially influences the sand body thickness within the southern part of the delta.

The sand body volume was calculated a second time based on the Navigation Chart surface. As the cross-sections showed previously, the Navigation chart surface generally agrees with the base of the sand-rich facies, except for small volumes of distributary mouth bar deposits in the eastern and northern sections. However, using this surface has the advantage of excluding the influence of the buried dredged channel on the volume calculation. The difference volume was calculated between the chart and the 1994 model surfaces within the -2' delta boundary polygon, giving a volume of 129×10^6 m^3.

The first sand volume model shows that the thickest sand deposits are found in the central portion of the delta, associated with the buried dredged channel, and in the northwestern portion, although the reason for this is unknown. On delta lobes, thickest sands are on the upstream ends, but not necessarily at the point of bifurcation. Often they are along the levees parallel to the channel. The second sand model, a plan view representation of which is presented in Figure 24, shows a similar configuration for the delta lobes, although thickest sand volumes are shown along the western flank of Main Pass. This is probably due to rectification error in this area between the two models, which was mentioned earlier in a discussion of the delta's dip cross-section.

Lower Atchafalaya River Delta Study Area

Figure 25 shows the plan-view evolution of the Atchafalaya delta study area. In the mid-1970s, several small lobes and channels were developing. By 1983 the area had evolved through channel migration and levee accretion, to three main islands separated by two small channels. By 1990, levee accretion and lobe fusion are evident, joining the two southern islands into one lobe. Natural processes in the area became dominated by dredged material placement starting in 1990, when deposits were laid on the head of Long Island. Creation of Community and Horseshoe Islands followed soon after, in 1992 and 1993-4, respectively.

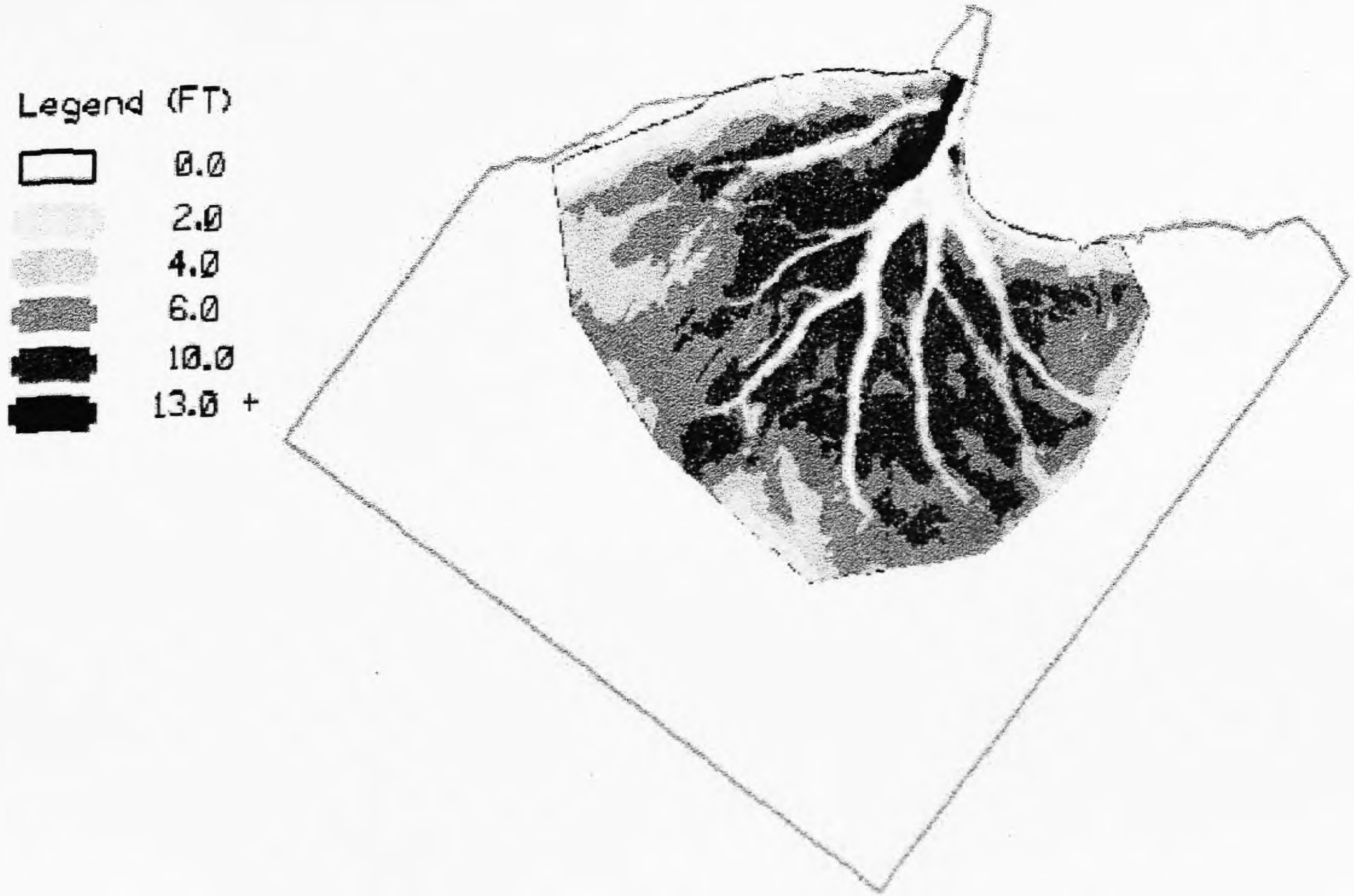

Figure 24. Plan view sand isopach model for the Wax Lake Outlet delta.

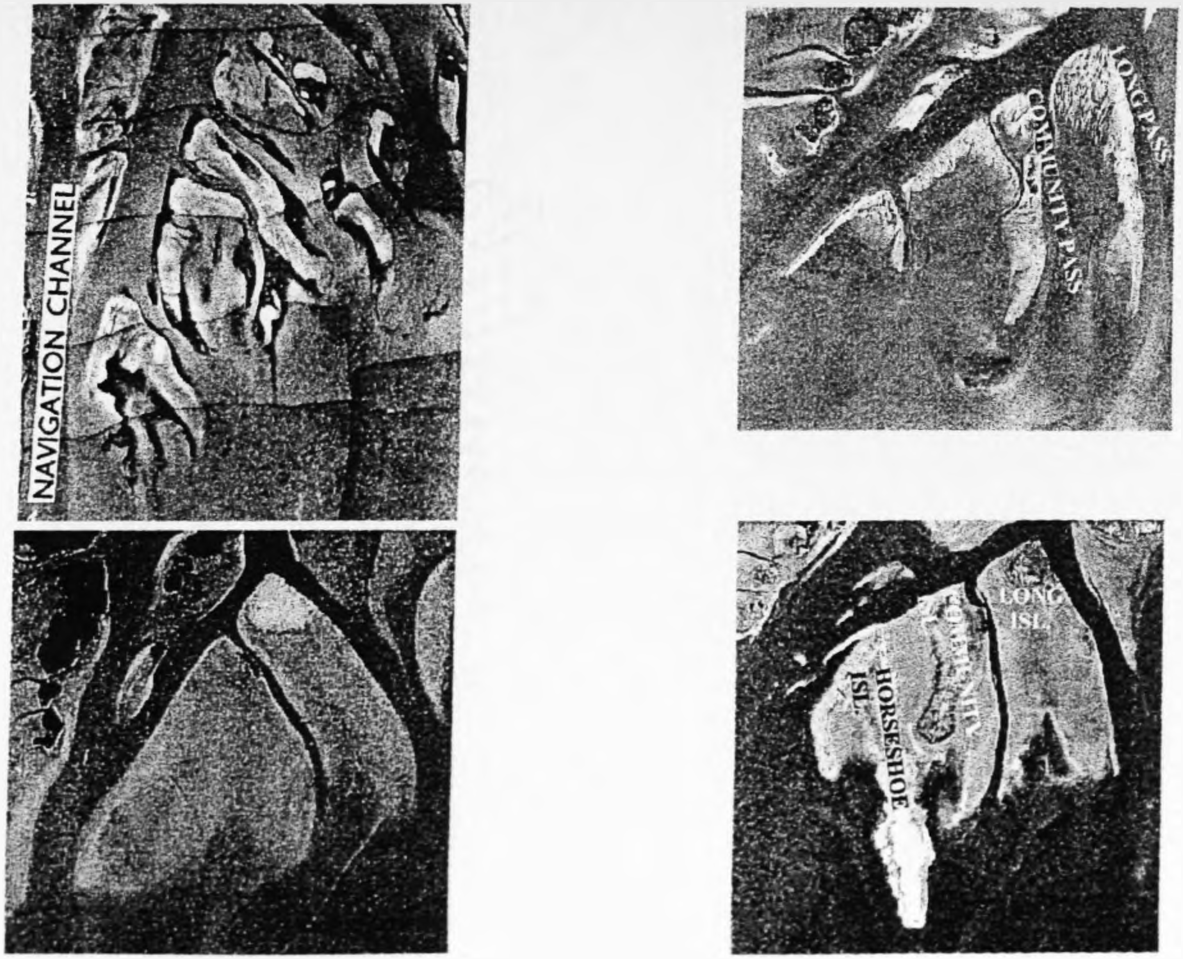

Figure 25. Evolution of the Atchafalaya delta study area, 1976 – 1994. Photomosaic (upper left) from van Heerden, 1980 (October 21, 1976; –0.7' water level). Upper right photo October 28, 1983; +0.3' water level. Lower left photo December 4, 1990; -0.5' water level. Lower right photo November 23, 1994; -0.5' water level.

Cross-sections constructed from Atchafalaya delta cores are presented in Figures (26, 27 and 28). This area contains the same coarsening-upward sequence described by van Heerden in the eastern Atchafalaya, except for the dredged island and 'old channel' deposits, which form coarse upper and lower boundaries to the normal delta sequence (Appendix II) These units are the direct result of human manipulation of the natural system. They, the lower prodelta and interdistributary bay units (Appendix II), are facies that were not found in the Wax Lake delta

Dredged material deposits contain 95 percent sand on average They are more coarse, cleaner deposits than natural levees sampled in the area due to the fact that the sediments come from channel deposits (which are typically better-sorted; Bowles, 1987) and undergo 'winnowing out' of fines during the dredging process Thus, the placement of dredged material which has come to dominate land building in the Atchafalaya delta results in islands which are not only artificial in form, but also in sediment composition

Figure 26 shows a cross section following the eastern bank of God's Pass The 'old channel' unit, a muddy coarse sand in core A11, thins to the south becoming a 0.3 m thick silt and shell deposit in the vicinity of core A13. Evidence of the gradual approach of Atchafalaya River sedimentation is shown in the configuration of the upper prodelta unit in this section At the northern end, thin interfingered beds of upper prodelta and distal bar deposits rest on the 'old channel' unit Eventually distal bar sediments dominate this location, and the deposition of the upper prodelta clays is moved progressively seaward (south) Later at the southern end of the section, the same gradual transition is evident as the front of distal bar sedimentation passed the location of core A13 Model surfaces superimposed on the section show a coarse-grained levee was in place along God's Pass at the time of the navigation chart surface Community Pass had formed by 1981, and deepened through 1989 ('81 model data contained some erroneous data south of Community Pass, and was not

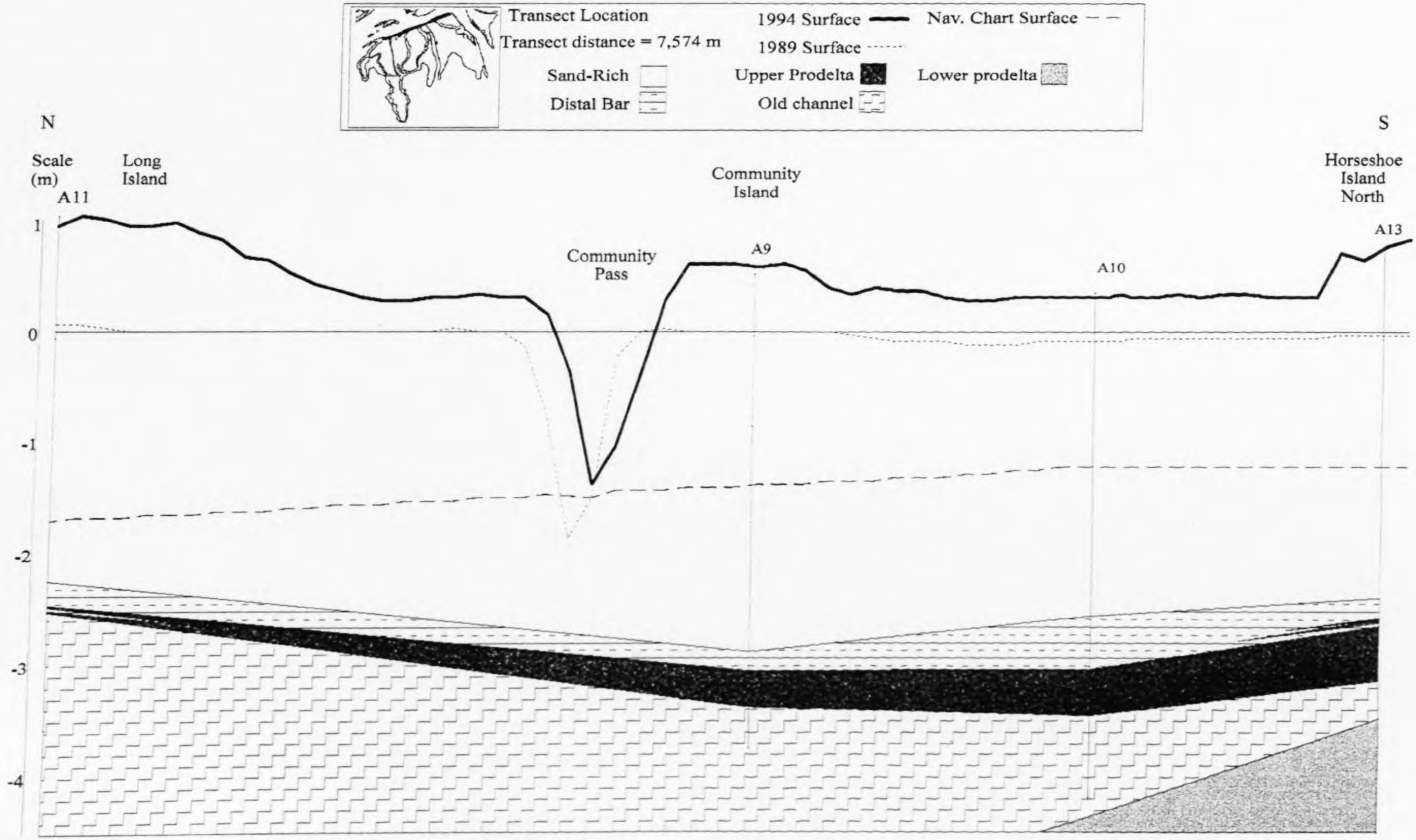

Figure 26. **Atchafalaya delta study area western dip section.**

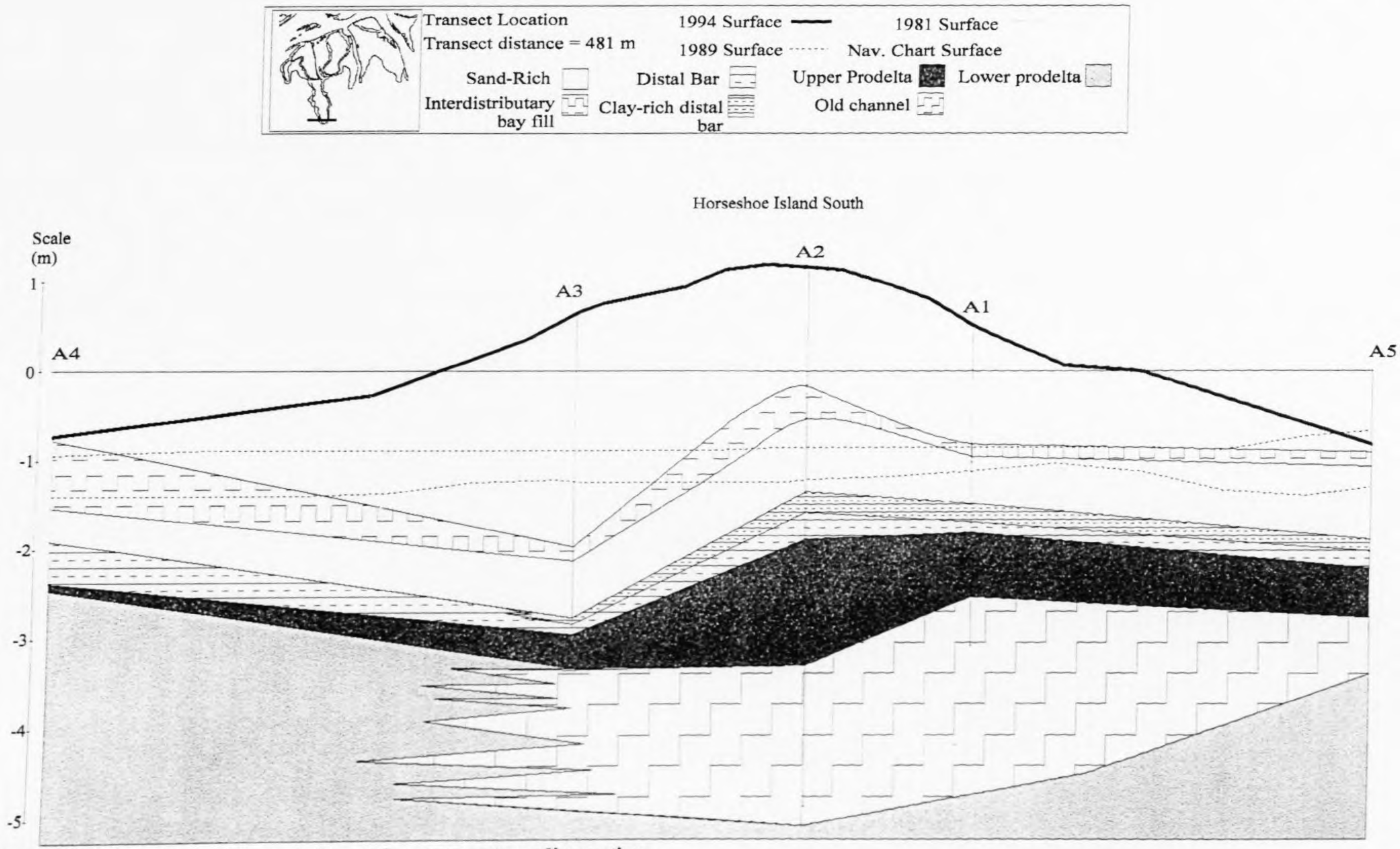

Figure 27. **Atchafalaya delta study area eastern dip section.**

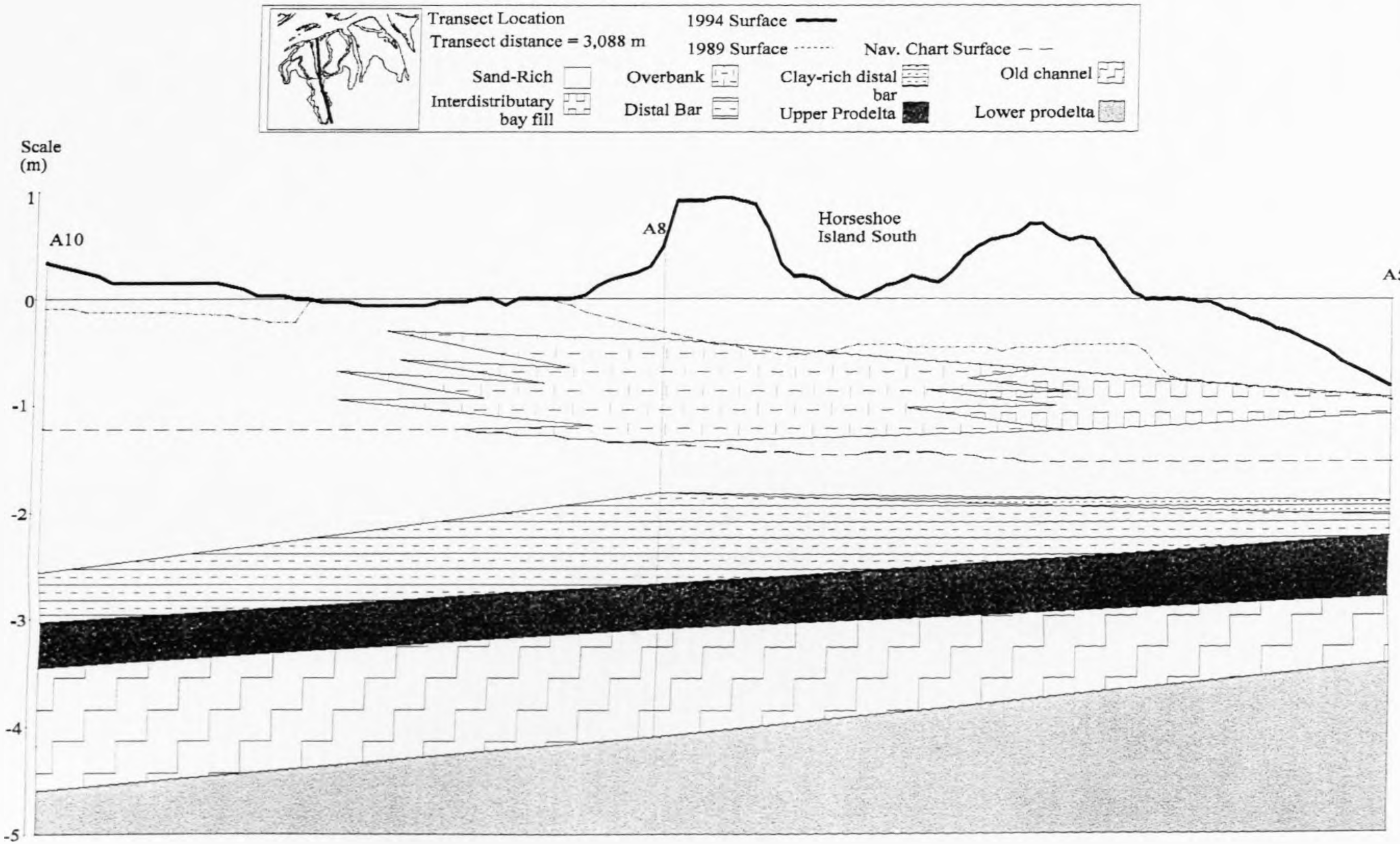

Figure 28. **Atchafalaya delta study area strike section.**

included in this diagram). By 1994 the pass had shoaled, and appears to be in the process of abandonment.

Figure 27 shows a dip section through the southern end of Horseshoe Island, a section of land the farthest from the Navigation channel within the study area. Model surfaces show this to have been an area with a fairly level surface from the time of the navigation chart through 1989, and it most likely remained that way until dredged sediments were placed there in November, 1994 to form this island.

There is some evidence that the weight of dredged deposits caused compression of the sediment units beneath the island, particularly in the vicinity of core A3. This core contained the greatest thickness of dredged material, although it was not located at the highest point of the island. Within the upper prodelta unit, there was a thin bed of brown clay that was found in all five cores in this section. This bed and the distal bar unit was the thinnest in core A3 compared to the other cores across this section, suggesting compression had taken place.

This section also shows that the limit of 'old channel' deposits, which lies somewhere between cores A3 and A4. Clay-rich distal bar deposits were identified in the easternmost cores of this section, which is consistent with transport from van Heerden's study area to the east.

Figure 28 illustrates the near-strike stratigraphy moving away from God's Pass. 'Old channel' deposits thin to the southeast away from the pass, while upper prodelta deposits thicken. Clay-rich distal bar sediments were distinguishable only at the farthest point from the channel to the southeast (core A5). Again, this may indicate that the sediment source for this unit came from the eastern delta. This section also shows the gradual transition, coming away from God's Pass, of levee, to levee flank, to interdistributary bay deposits.

Table 7 lists the average thicknesses of the delta sequence, delta platform (upper prodelta and distal bar units), and sand units in the various cores series used in this project. Also listed

are the percentages of the delta sequence accounted for by the sand unit. For this comparison, base of the upper prodelta facies was used to mark the beginning of the delta sequence. On average, the thickness of the delta sequence is greater in the Atchafalaya study area than in the Wax Lake. Delta front units and sand body thicknesses are also greater in the Atchafalaya cores. However, the sands comprise a slightly greater percentage of the Wax Lake delta than the Atchafalaya study area on average. In comparison, the thickness of the delta package in van Heerden's cores was an average of 2.7 m, platform thickness averaged approximately 1 m, and sand facies averaged 1.4 m. The percentage of the delta sequence accounted for by the sands was an average of 50 percent. Generally, van Heerden's cores contained a thinner delta sequence, a thicker delta platform, and a lesser percentage of sand facies thickness.

Table 7. Average thicknesses of the delta sequence, delta platform, and sands in cores from the WLO and LAR deltas.

Delta	Core Series	Delta Thickness (m)	Platform Thickness (m)	Sand Thickness (m)	Delta Sand (%)
WLO	"WL"	2.9 (s.d. = 0.48)	0.8 (s.d. = 0.64)	1.9 (s.d. = 0.38)	67 (s.d. = 21.92)
	"R"	2.9 (s.d. = 0.48)	0.5 (s.d. = 0.28)	2.2 (s.d. = 0.85)	73 (s.d. = 24.15)
LAR	"A"	3.3 (s.d. = 0.76)	0.9 (s.d. = 0.49)	2.2 (s.d. = 0.90)	62 (s.d. = 21.3)
	"VH"	2.7	1.0	1.4	50

DELTA FORM COMPARISONS

Coleman and Wright (1971) identified the many parameters that determine a delta's form. When comparing deltas built by the same river system, the important factors are narrowed down to those directly related to the site of deposition: river mouth dynamics, near-shore currents, wave energy distribution, tidal energy, and the tectonics and geometry of the receiving basin.

Lake Fausse Point

Tye (1986) investigated the formation and sand body geometry of an Atchafalaya River lacustrine delta that formed in Lake Fausse Point between 1920 and 1932. The conditions of its formation are similar to those of the Wax Lake Outlet delta in that they share a common source (the Atchafalaya River), and built into protected, tideless, river-dominated basins. There were major differences from the Wax Lake Outlet setting that determined the resulting form of the Lake Fausse Point delta, namely, hyperpycnal flow conditions caused by a strong density contrast between the sediment-laden river water and ambient lake water, and pre-existing basin topography.

The strong inertia of the incoming effluent extended the plume several kilometers downstream in the lake (Tye, 1986). Delta formation initially began downdip, then aggraded upstream once levees were established. Upper portions of Lake Fausse point were filled 'in reverse' (Tye, 1986). This is similar to what was seen in the central portions of the Wax Lake Outlet delta, and in the eastern Atchafalaya (van Heerden, 1983). The resulting sand bodies were elongate, although some parabolic lobes were also formed. In some areas,distributary mouth bar sediments were deposited in pods, joined together by later levee deposition (Tye, 1986). Greatest sand body thicknesses were on the upstream portions of the delta lobes at points of bifurcation, parallel to distributary channels, and as individual distributary mouth bar pods.

Mississippi Subdeltas

Wells et al., (1983) ranked the subdeltas of the Mississippi delta according to their similarity to the deltas of Atchafalaya Bay, based on the controlling factors identified by Coleman and Wright (1971) (Table 8). They determined that the Baptiste Collette subdelta was the most similar, varying mainly in the presence of an alongshore current (Wells et al., 1982). The Baptiste Collette and Cubits Gap subdeltas will be discussed here.

Table 8. Subjective evaluation of similarity between Lower Atchafalaya River delta and deltas used in generic analysis (adapted from Wells et al., 1982).

Mississippi Subdeltas:	Baptiste Collette	Cubits Gap	Garden Island Bay	West Bay
Climate	1	1	1	1
River Discharge	1	1	1	1
Sediment Type	1	1	1	1
Wave Power	1	3	3	3
Tide Range	1	1	1	1
Alongshore Current	2	3	3	3
Shelf Slope	1	3	2	2
Tectonics	2	2	2	2
Ave. Similarity	1.25	1.88	1.75	1.75

1= Alike, 2=Similar, 3=Different

Baptiste Collette Subdelta

The Baptiste Collette crevasse was opened in 1874. Discharges carried by the crevasse ranged from 2.6 to 3.9 percent of Mississippi River discharge. The subdelta built into a protected receiving basin less than 2 m deep. Three dominant sand bodies were delineated in this delta: channel sands, distributary mouth bar/transgressive sand sheet, and levee/overbank sands (Bowles, 1987). The highest rate of volume infilling was 13 x 10^6 m^3 per year, which occurred during its period of growth stabilization and deterioration (1946 – 1971, Wells et al., 1982). This

is approximately double the rate of the Wax Lake Outlet to date. On average, from the breaking of the crevasse until 1971, infilling occurred at a rate of 9 x 10^6 m^3 per year (Wells et al., 1982)

Cubits Gap

The Cubits Gap subdelta was ranked as the least similar to the Atchafalaya Bay deltas, primarily because of its open-water environment, and the slope and tectonics of its receiving basin. Yet van Heerden pointed out a few similarities in the form of the Cubits Gap delta to the Atchafalaya delta, which also hold true for the Wax Lake Outlet delta. Welder (1959) reports that early in their development, distributaries in the subdelta were shallow and wide, branching from the single crevasse channel. Over time, as they extended themselves seaward, they deepened and narrowed in their upstream portions. Channel extension and bifurcation lead eventually to rejoining channels, which is also observed in the Wax Lake Outlet delta. These processes are identified as the major growth mechanisms by which the Cubits Gap delta grew, although examination of chart diagrams provided by Welder indicates upstream growth may also have played a role in subaerial growth (Welder, 1959). Van Heerden (1983) noted out that although Welder identified lobe fusion occurring through the process of channel abandonment, it was attributed to lateral bar formation across the mouths of channels through a "reverse eddy" phenomenon, and not through the sealing by subaqueous levee formation that occurred in the Atchafalaya delta. Nevertheless, the resulting delta form bears resemblance to the Wax Lake Outlet delta.

Cubits Gap received about 13 percent of the Mississippi River's discharge compared to an estimated 9 to 13 percent for the Wax Lake Outlet, and 6 percent for the eastern Atchafalaya delta. Rates of volume fill was estimated at 45 x 10^6 m^3 per year during the early phase of rapid growth (1877 – 1905), with an overall average of 26 x 10^6 m^3 per year (1877 – 1971), or four times the rate of the Wax Lake Outlet delta (Wells et al., 1982)

One explanation for the lower rate of volume infilling for the Wax Lake Outlet delta than the Mississippi River subdeltas in spite of similar discharge values is the relative maturity of the sediment delivery system. The subdeltas were separated from the mature Mississippi River by a channel spanning only the width of the natural levee. In contrast, the Wax Lake Outlet is separated from its sediment sources (the Red and Mississippi Rivers) by the approximately 100 miles of intervening Atchafalaya Basin. The Atchafalaya River is a much less mature conduit for transporting sediment to its receiving basin (Atchafalaya Bay) than the Mississippi, and significant sand transport to the bay is sporadic (G.P. Kemp, pers. comm.; van Heerden, 1980).

Another possible factor for this greater rate in spite of lesser discharge is a coarser sediment supply to the Mississippi subdeltas during their growth. Sediment supply on the Mississippi River is known to have become finer over the past several decades as locks and dams upstream have retained the coarser material (Wells et al., 1982).

DELTA GROWTH CURVES AND GROWTH PREDICTIONS

Terrain Models

Data from the three model years 1981, 1989, and 1994 indicate that the Wax Lake Outlet filled the western portion of Atchafalaya Bay from a mean depth of -1.6 m in 1981, to -1.1 m in 1994. This equals a net rate of approximately 4 cm per year

The Wax Lake Outlet and Lower Atchafalaya River models were analyzed for area exposed within the delta polygons, resulting in area values for elevations above -2.0 ft. A plot of these data (Figure 32) reveal that prior to 1990, the Wax Lake delta was steadily increasing in size toward values equaling that of the Atchafalaya delta, at a rate of 3.5 km^2 per year. Following 1989, the growth rate of the Wax Lake delta slows to 3.0 km^2 per year. This decline has been suspected to be related to the presence of the Wax Lake Outlet weir from 1988 to 1994 (Kemp et al., 1995), as is the marked increase in Atchafalaya delta growth. The weir directed increased amounts of sand down the Lower Atchafalaya River, creating the need for more frequent dredging of the navigation channel running through the delta. The material generated by this dredging was used to form relatively low-lying elongate islands within the Atchafalaya delta, resulting in the creation of over 496 hectares (1225 acres) of new land (van Heerden, 1994; Penland et al., 1995).

Kemp et al. (1995) reported decreased bedload in the Wax Lake Outlet caused by the presence of the weir, decreased flow proportion during average flow conditions, and a lower concentration of sediment per unit of discharge. Sediment data compiled by H. Mashriqui shows that the percentage of sand in the suspended sediment load carried by the Wax Lake Outlet increased during the period the weir was in place. Therefore, if the weir was responsible for the decreased growth rate of the Wax Lake Outlet delta, the change was related to its impact on the three above-mentioned parameters.

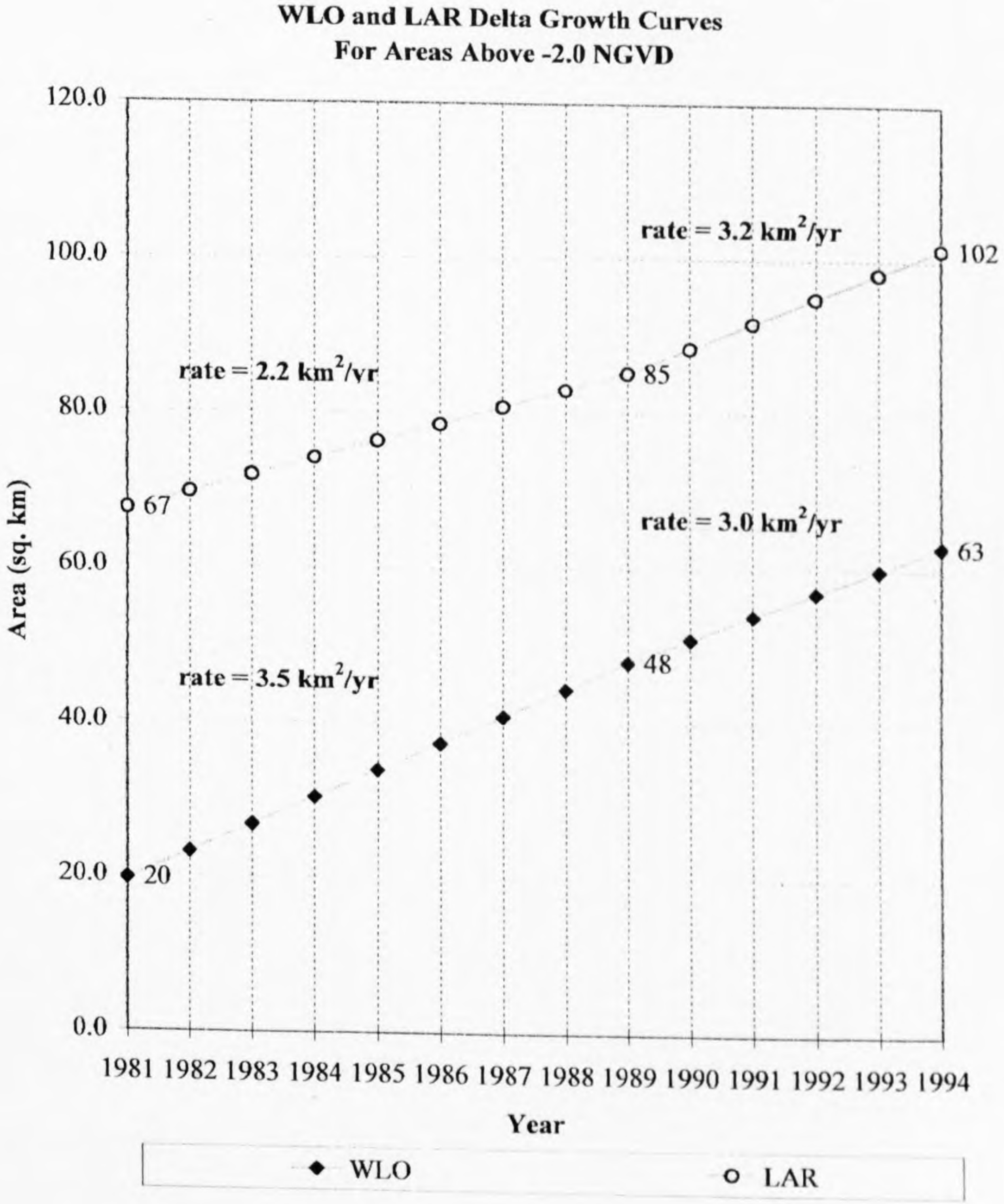

Figure 29. Plot of area above –2' NGVD in the Wax Lake Outlet and Atchafalaya River deltas from 1981 to 1994, based on terrain model data.

The decline in the Wax Lake Outlet delta growth rate may be expected to reverse itself as the system readjusts to the removal of the WLOCS, and bedload transport through the Outlet is restored. On the other hand, the growth of the Atchafalaya River delta may be expected to slow, since the Lower Atchafalaya River has been receiving approximately 50% less sand following removal of the weir (G.P. Kemp, pers. comm.). This will decrease the need for navigation channel dredging, resulting in less prolific dredged island creation. Estimates of future growth for the Wax Lake Outlet delta were calculated by re-establishing the pre-1990 rate of growth following 1994 (Table 9). Growth of the Atchafalaya delta was predicted using a value which is half the '89 to '94 growth rate, reflecting the 50% decrease in sand supply. By this method, land above –2' in the Wax Lake Outlet may be expected to cover 84 km^2 by the year 2000, compared to 111 km^2 in the Atchafalaya delta. The Wax Lake Outlet would then account for 43% of the total in Atchafalaya Bay.

Table 9. **Area (km^2) above –2' in 1981, 1989, 1994, and 2000 (predicted).**

	1981	1989	1994	2000
WLO	20	48	63	84
LAR	67	85	101	111
Atchafalaya Bay	87	133	164	195

Generic Model

Wells et al. (1982) compared life cycle trends of several deltas as a way of developing a generic model to predict the growth of the Atchafalaya deltas. Using normalized growth curves of the Mississippi River crevasse splays they constructed a dimensionless growth curve which could be scaled to the expected life cycle of any delta lobe. Using the values derived for 1980 (at 0.0'), they then could project to any year in the future to arrive at an expected range. A comparative

list of values derived by Wells et al., (1982) and by the terrain models (at 0.0') is presented in Table 10.

The terrain models initially give a value twice that of the generic model for the beginning of the 1980s. By 1989 the terrain model converges on the upper range offered by the

Table 10. Comparison of projections of total subaerial land (km at and above 0.0 MSL) of Wells et al., 1982, and terrain model data.

WELLS ET AL., 1982	TERRAIN MODELS
20.8 to 28.8 (1980)	43.8 (1981)
54.8 to 75.8 (1990)	75.9 (1989)
68.8 to 95.3 (1995)	90.9 (1994)
86.1 to 119.2 (2000)	115.1 (2000, projected)

generic analysis, suggesting a slower actual rate of growth than predicted by the generic model. Values thereafter are generally in agreement.

Rates of volume fill are also quite close. Wells et al. reported a rate of 14 x 10^6 m^3 for the filling of Atchafalaya Bay and the subtraction models yield 11.9 x 10^6 m^3. These in turn are consistent with rates of infilling from the Mississippi River subdeltas (Wells et al., 1982).

Speculation on Future Development

The 1989 to 1994 difference model shows the deposition of a broad platform in advance of the southwestern portion of the delta. This indicates the potential for significant future development in this area. Zones of deposition at the mouths of eastern distributaries appear skewed to the south, presumably by the concentrated flow between the Wax Lake and Atchafalaya deltas. The evolution of the proximal delta area has illustrated a pattern of distributary and island lobe development which is expected to repeat itself as delta growth progresses seaward.

With the locus of deposition now advanced to the outer bay, the loss of elevation in the interior areas of proximal delta lobes may continue. Since levees may be expected to be maintained by flood deposition, the delivery of sediment through levee breaching (i.e., crevassing) will become more important to maintenence of these intertidal areas. Eventually, some of the less efficient distributaries of the Wax Lake system will undergo abandonment, and lobe fusion will play a greater role in land growth.

CONCLUSIONS

The Wax Lake Outlet delta is a beautiful example of a Mississippi River bayhead delta, because unlike its sister, the Atchafalaya delta, its form has been relatively unaltered by human activities. Frequent documentation of this delta over the past fifteen years has provided a unique opportunity to examine in detail the development of what will become a major Mississippi delta lobe.

The form of the Wax Lake Outlet delta, with its branching distributaries separated by complex island lobes, is typical of frictionally dominated deltas building into unstratified, low-energy, shallow water basins (Wells et al., 1982). Primary growth mechanisms of the Wax Lake delta have included channel bifurcation, seaward levee extension, vertical and lateral levee aggradation and upstream accretion, which lead to lobe fusion. Channel progradational processes have varied from east to west across the delta, which may reflect the influences of tidal currents and prevailing winds (Roberts and van Heerden, 1992). Since 1981, delta distributaries have matured from broad, shallow channels to become deeper, narrower, and more efficient. Throughout their development, minor adjustments to the overall system have been evident such as lateral channel migration, and mid-channel bar formation. The Wax Lake delta has filled the proximal Outlet area, and its well-developed channels are now advancing the locus of deposition in the outer bay. The previously unknown occurrence of discharge concentration around the growing delta mass, and the resulting 'zone of scour' lying seaward of the advancing delta, was evident over all time periods examined. This phenomenon may manifest itself in the stratigraphic record as an erosion surface or lag deposit between the delta platform and the coarser distributary mouth bar deposits as progradation advances through these areas, and may be a feature present in other bay-head deltas.

With the exception of a limited prodelta, the Wax Lake Outlet delta has developed through the deposition of a coarsening-upward sequence typical of deltas of the Mississippi River system. Since the early eighties, the Outlet system has behaved conservatively in regard to its sand supply, with the observed volume of suspended sand passing through the Outlet being accounted for by the volume retained in the western bay. Overall, the thickest sands of the delta are located in the central portion of the delta, a consequence of an old dredged channel. Within individual island lobes the thickest sands are parallel to the channels, but not necessarily located at the point of bifurcation. Estimates of sand body volume range from 129×10^6 m^3 to 139×10^6 m^3.

The rate of volume gain from 1981 to 1994 averaged 6.4×10^6 m^3 per year. This is a rate generally less than those exhibited by the subdeltas of the Mississippi Balize delta, and is a consequence of the relative immaturity of the Atchafalaya River channel. The rate at which the Wax Lake delta builds intertidal land area is expected to recover from its recent slowdown as bed material and discharge supplies are re-established following removal of the WLOCS.

Wax Lake delta development and stratigraphy shows evidence of alterations from the natural state brought on by human activities, but neither as extensively nor dramatically as the Atchafalaya delta. Since the early 1990s man has usurped the responsibility for major land gains in the Atchafalaya through dredged material management. The result has been island features which are artificial in form and sediment composition. Alterations are evident in the subsurface primarily by the introduction of coarse grained dredging-related sediment to the delta sequence. This influence generally decreases with distance away from the navigation channel.

The rate at which both deltas are filling Atchafalaya Bay is consistent with the rates of infilling of the Mississippi subdeltas (although proportionally low compared to discharge volume). Land growth curves based on the generic model presented by Wells et al., 1982 are in

agreement with terrain model values, and is proving to be a good method for estimating the first thirty years of subaerial land growth in Atchafalaya Bay.

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APPENDIX I CORE DESCRIPTION LOGS

Core ID: WL1	Location: N 29° 39.08' W 91° 26.24'
Elevation: 0.59 m	Length of Sediment Column: 4.085 m
Depth in Core (m)	**Description**
0 – 0.425	Unit 1: Subaerial levee Dark grayish brown (10YR) silt and very fine sand with parallel to wavy laminations of clayey silt, rootlets, organics and oxidized iron stains. Silty clay at base.
0.425 – 1.925	Unit 2: Levee/Distributary mouth bar Trough cross-bedded, grayish brown (2.5Y) silty fine sand and brown (7.5YR) silty very fine sand, with very thin (<1 mm) lenses of dark gray silty clay, occasional dark grayish brown (10YR) clay, and dark gray (5Y) clayey silt in parallel to wavy, and lenticular laminae. Some burrows and parallel laminae from 1.21 – 1.69 m; parallel laminated silty clay and sand from 1.69 – 1.71 m. Medium sand becomes common in the last 20 cm, in parallel and cross-bedding structures, with occasional thin lenses of clayey sand. A coarse sand with shell fragments overlying an erosional surface at base.
1.925 – 2.10	Unit 2: Distal bar Parallel laminae (1-7 mm) of dark gray (2.5Y) to dark grayish brown (10 YR) silty clay with silty very fine to fine sand.
2.10 – 2.18	Unit 3: Upper prodelta Very dark grayish brown (2.5Y) silty clay with very small silt and shelly silt lenses, shell bits and fragments.
2.18 –3.83	Unit 4: Bay fill deposits 2.18 – 2.21 m Shell hash in silty sand. 2.21 – 2.265 m Silty sand with silty clay and organics in thin. (2 mm) wavy and lenticular laminae. 2.265 – 2.29 m Clayey, silty, very fine sand. 2.29 – 2.41 m Dark gray (2.5Y) silty clay with shell fragments, dark grayish brown (10YR) clay laminae, lenses of silty very fine sand, and occasional organics. Scour and fill structures. 2.41 – 3.46 m Gray clay with root traces and abundant organic inclusions, silt and sand lenses. 3.46 – 3.67 m Gray clay with silt and sand lenses, occasional shell bits. 3.67 – 3.83 m Gray clay with occasional shell bits, organics, and silty lenses. Burrows. Shell bits at base.
3.83 – 4.085	Unit 5: Submerged marsh deposits Gray clay with black organic stains, organics and organic laminae, and occasional thin silty lenses.

Core ID WL2 Location: N 29° 30.98' W 91° 26.359'

Elevation: -0.28 m Length of Sediment Column: 4.97 m

Depth in core (m)	Description
0 – 1.71	Unit 1: Channel 0 – 0.265 m Wavy laminae of very dark grayish brown (2.5Y) sandy silty clay and very dark grayish brown (10 YR and 2.5Y) silty fine to very fine sand. 0.265 – 0.30 m Brown (10YR) silty sand with large lenses of silt and clay. Sharp color change at base. 0.30 – 0.475 m Dark grayish brown (2.5Y) and light olive brown (2.5Y) silty sand with occasional dark gray (5Y) silty clay lenses. Uneven basal contact. 0.475 – 0.81 m Brown (10YR) silty fine sand with trough cross-bedded laminae of silty sand. Distorted bedding in upper 21 cm. Sand-filled burrows in lowest 4 cm. Angular basal contact. 0.81 – 0.84 m Dark grayish brown (2.5Y) silty fine to medium sand. One broken wavy lamina of very dark grayish brown (2.5Y) silty clay at top. Fluid escape structures evident. 0.84 – 0.91 m Brown (10YR) silty very fine sand, showing some planar cross-bedding) with parallel and lenticular laminae of dark grayish brown (10YR and 2.5Y) clay, silty clay and very dark grayish brown (2.5Y) clayey silt and occasional organics. 0.91 – 1.19 m Wavy and lenticular laminae of very dary gray (5Y) silty clay, very dark grayish brown (10YR) very fine sandy silt and dark grayish brown (2.5Y) fine sand. Coarsening-upward cycles, and some trough cross-bedding. Occasional erosion surfaces. 1.19 – 1.425 m Massive olive gray (5Y) fine sand with zones and bands of oxidized iron staining, occasional small organic particles and occasional very small clay-rich lenses. Several erosion surfaces. 1.425 – 1.665 m Dark grayish brown (10YR and 2.5Y) silty fine trough cross-bedded sand with very thin (1mm or less) parallel laminae and lenses of dark gray and dark grayish brown (2.5Y) silty clay. Several erosion surfaces. Occasional fine organics. Rarely, very small shell bits in wavy laminae. 1.665 – 1.71 m Olive gray (5Y) fine to medium sand in parallel to wavy laminations with very small shell bits. Trough cross bedding overlying sharp erosional basal contact.
1.71 – 1.915	Unit 2: Distal bar 1.71 – 1.825 m Interlaminated dark grayish brown (10YR) and dark olive gray (5Y) clay, dark grayish brown (10YR and 2.5Y) silt, and dark olive gray (5Y) sandy clayey silt. Very thin parallel and lenticular laminae, some cross-bedded silts. 1.825 – 1.92 m Parallel laminated beds (1 – 4.5 cm thick) of dark to very dark gray (5Y) silty clay with organics, and olive gray (5Y) very fine sandy clayey silt. Thin interbedded laminae of sandy silty clay with organics. Abrupt basal contact.

1.915 – 4.90	Unit 3: Bay fill deposits 1.915 – 1.97 m Dark gray (5Y) and light olive brown (2.5Y) fine sand. 1.97 – 2.045 m Shell hash (fine) 2.045 – 2.11 m Parallel laminae of dark to very dark gray (5Y) silty clay with organics and clayey silt with very fine sand. 2.11 – 2.265 m Dark and very dark grayish brown (10YR) clay with dark gray clayey silt lenses, occasional shell bits and fragments, and rare organics. 2.265 – 2.375 m Dark to very dark gray (5Y) very silty clay with abundant shell bits and shell fragments, occasional organics. 2.375 – 2.85 m Gray very soupy sandy muck with abundant shell fragments and bits, becoming more firm with depth. Gradual basal contact. 2.85 – 3.00 m Gray silty clay with abundant shell fragments and bits. 3.00 – 4.68 m Gray very silty clay with occasional shell fragments and shell bits, and occasional sandy silt lenses and/or laminae. Thin beds of shell hash at 3.07 – 3.09 m and 3.635 – 365.5 m. Silt content in the clay appears to decrease somewhat with depth to a silty clay. 4.68 – 4.90 m Gray clay with occasional small silt lenses and shell bits. Burrowing evident at top.
4.90 – 4.97	Unit 5: Submerged marsh deposits Very dark brown sapric peat. Burrowing evident at top of unit.

Core ID: WL3 — Location: N 29° 30.794' W 91° 26.375'

Elevation: 0.192 m — Length of Sediment Column: 4.97 m

Depth in core (m)	Description
0 – 0.83	Unit 1: Levee flank 0 – 0.27 m Very dark grayish brown (2.5Y) clayey silty sand with abundant rootlets and organics. 0.27 – 0.83 m Dark grayish brown (10YR) clayey silty sand (some simple and trough cross-bedding) with organics and occasional wavy and lenticular dark grayish brown (10YR) to dark gray (2.5Y) silty clay laminations. Some large burrowing.
0.83 – 1.775	Unit 2: Channel 0.83 – 1.29 m Dark olive gray (5Y) to brown (10YR) silty fine sand with thin small (<5 mm thick) clayey lenses. Distorted bedding in the upper 39 cm, simple and trough cross-bedding in the lower 5 cm 1.29 – 1.57 m Brown (10YR) silty fine sand to very silty very fine sand, simple cross-bedding grading down into trough cross-bedding, with very thin clayey lenses. 1.57 – 1.775 m Dark gray (5Y) to dark grayish brown (2.5Y) silty fine sand in trough cross-beds, with occasional thin dark grayish brown (10YR) clayey lenses. Fines downward
1.775 – 2.28	Unit 3: Distributary mouth bar 1.775 – 1.835 m Interlaminated silty clay and silt in parallel to wavy laminations. Some scour and fill structures. 1.835 – 1.993 m Dark gray (5Y) to dark grayish brown (2.5Y) silty fine sand with occasional thin dark grayish brown (10YR) clayey lenses 1.993 – 2.28 m Interlaminated silty sand (7.5 YR), silt (10YR) and silty clay (2.5Y) with occasional organics and shell bits. Sands fine downward. Upward-fining cycles
2.28 – 2.915	Unit 4: Distal bar Dark gray (2.5Y) to dark grayish brown (10YR) clay and silty clay in parallel wavy laminations with thin parallel to wavy and lenticular sandy laminae. Occasional burrows and occasional shell bits in the sandy laminae. Very thin shell lag (<0.5 cm) at 2.365 m, woody chunks at 2.52 – 2.56 m. Several erosional surfaces.
2.915 – 4.97	Unit 5: Bay fill deposits 2.915 – 3.10 m Very dark gray (5Y) silty clay with fine sand, with abundant shell fragments and occasional organics. One shell, approximately 4 cm long at top of unit. 3.10 – 3.40 m Dark gray silty clay with fine to medium sand, abundant shells and shell fragments. 3.40 – 4.97 m Dark gray silty clay with small silty lenses, abundant burrows, occasional shell bits and thin clay beds and lenses. Silt and shell decrease somewhat with depth. Bioturbated, with remnants showing undisturbed parallel laminae in lower 0.5 m

Core ID:WL4	Location: N 29° 29.605' W 91° 26.244'
Elevation: 0.16 m	Length of Sediment Column: 4.32 m

Depth in core (m)	Description
0 – 0.64	Unit 1: Intertidal levee Dark grayish brown (10YR) silty sand with rootlets, burrows and organics, and parallel laminae of organics and dark gray (5Y) clayey silt and silty sand. Some simple and planar cross-bedding, occasional scour and fill structures. Silt increases with depth, rootlets evident to depth.
0.64 – 1.60	Unit 2: Subaqueous levee 0.64 – 1.39 m Dark grayish brown (2.5Y), to yellowish brown (10YR), to black silty sand with parallel to wavy laminae of dark gray siltier sand. A 2 cm long silty clay inclusion near top of unit. Trough and simple cross-bedding with a minor occurrence of ripple drift. Some burrowing evident. Occasional erosion surfaces. 1.39 – 1.60 m Brown (10YR) silty fine sand in simple and trough cross-bedding with parallel laminae and lenses of dark grayish brown (2.5Y) clayey silt. Minor burrows, occasional erosion surfaces
1.60 – 1.935	Unit 3: Distributary mouth bar 1.60 – 1.74 m Olive brown (2.5Y) to blackish silty medium sand and parallel to wavy and lenticular laminae of dark gray (5Y) and dark grayish brown (10YR) clayey silt. 1.74 – 1.935 m Silty fine sand with silty clay laminae and lenses. Also, large (4 cm) shells and disturbed bedding.
1.935 - 3.225	Unit 4: Distal bar (containing interfingering upper prodelta) 1.935 – 3.02 m Laminae of dark gray (5Y) to dark grayish brown (10YR) silty clay, brown (10YR) silt, and dark grayish brown (2.5Y) silty fine and very fine sand. Distorted parallel to wavy laminae evident to approx. 2.91 m. Sand decreases downward. 3.02 – 3.225 m Dark gray (5Y) to dark grayish brown (10YR) banded silty clay with thin (1 – 10 mm) laminae and lenses of coarse silt or very fine sand.
3.225 – 4.32	Unit 5: Bay fill 3.225 – 3.27 m Very dark grayish brown (2.5Y) clayey silty fine sand with abundant shell fragments. 3.27 – 3.36 m Dark gray (5Y) silty clay with fine sand, organic laminae and shell bits. 3.36 – 3.425 m Shell fragments in dark olive gray (5Y) sandy silty clay. 3.425 – 3.79 m Dark gray (5Y) clay with organics and shell bits 3.79 – 3.91 m Shell hash 3.91 – 4.20 m Dark gray (5Y) clay with organics and shell bits, some large shell pieces. 4.20 – 4.32 m Gray clay, occasional thin silt laminae, organics, and shell bits. Distorted bedding.

Core ID: WL5	Location: N 29° 29.669’ W 91° 25.148’
Elevation: -1.067 m	Length of Sediment Column: 3.99 m
Depth in core (m)	Description
0 – 0.245	Unit 1: Channel Silty sand with clay, shell bits and organics.
0.245 – 1.22	Unit 2: Distributary mouth bar Very dark gray (5Y) to dark grayish brown (10YR) silty sand with parallel to wavy laminae and beds (<7 cm) of dark gray (5Y) and dark grayish brown (10YR) silty clay. One shell (3 cm) present at 0.31 m.
1.22 – 1.58	Unit 3: Distal bar Thin parallel and wavy laminae and beds of dark gray (2.5Y) silty sand , silt, and dark gray (5Y) and very dark grayish brown (10YR) silty clay.
1.58 – 1.86	Unit 4: Upper prodelta Dark grayish brown (10YR) to dark gray (5Y) bands of clay and silty clay with very thin (<3 mm) parallel and lenticular laminae of silty very fine sand and small shell bits.
1.86 – 3.99	Unit 5: Bay fill 1.86 – 2.03 m Very dark gray (5Y) silty clay with shell bits and fragments. 2.03 – 2.09 m Shell hash. Clam shells. 2.09 – 2.11 m Olive gray (5Y) clayey silt. 2.11 – 2.18 m Shell hash with shell (oyster) fragments. 2.18 – 3.14 m Olive gray (5Y) silty clay with shell bits and small sandy inclusions. Gradational basal boundary. 3.14 – 3.52 m Gray silty clay with abundant shell bits and shells (oyster). 3.52 – 3.99 m Shell hash in a gray clay. Oyster shells.

Core ID: WL6 Location: N 29° 29.763' W 91° 26.809'

Elevation: 0.37 m	Length of Sediment Column: 5.32 m
Depth in core (m)	Description
0 – 0.17	Unit 1: Subaerial levee Dark grayish brown (2.5Y) clayey silty very fine sand with laminae of dark grayish brown (2.5Y) silty clay. Abundant rootlets and plant remains.
0.17 – 1.945	Unit 2: Levee 0.17 – 1.0 m Parallel, wavy and lenticular laminae of brown (10YR) silty fine sand and sandy silt, pale brown (10YR) silty fine sand, dark to very dark grayish brown (10YR) silty clay, and dark grayish brown clayey silt. Some organics. Rootlets apparent to 0.35 m. 1.0 – 1.10 m Light yellowish brown (10YR) fine sand with some strong brown (7.5YR) staining, and a distorted bed of dark grayish brown (10YR) very-fine-sandy silt with dark gray (10YR) laminae of clayey silt. 1.10 – 1.112 m A bed of brown (10YR) silty very fine sand with very thin dark gray clayey silt laminae. 1.112 – 1.152 m Brown (7.5YR) sandy silt with dark gray clayey silt very small lenses. Gradual basal contact. 1.152 – 1.22 m Dark gray to dark grayish brown (2.5Y) sandy silt with laminae (1 - 7 mm) of silty clay, very dark gray and dark gray (10YR), with organics. Occasional small lenses of fine sand. Sharp wavy basal contact. 1.22 – 1.945 m Grayish brown (2.5Y) to blackish fine and medium sand. Some distorted bedding and cross-bedding evident. Thin, wavy and lenticular laminae of dark gray (5Y) silty clay. Lenses of siltier dark gray (10YR) material at 0.69 – 0.70 m. Erosional basal contact.
1.945 – 2.41	Unit 3: Distributary mouth bar Brown (7.5YR) sand and silt with abundant parallel to wavy and lenticular laminae of dark gray (5Y) silty clay with organics and dark grayish brown (2.5Y) silt and silty fine sand.
2.41 – 3.35	Unit 4: Distal bar (containing interfingering upper prodelta) Interlaminated dark grayish brown (2.5Y and 10YR) silty very fine and fine sand, sandy silt and silt, and silty clay. Apparent upward-fining cycles. Occasional small organic lenses. Parallel, wavy, and lenticular laminae, and clay beds with thin silt laminae increase in thickness downward, up to 8 cm thick. Cycles are approximately 10 to 12 cm thick.
3.35 – 5.32	Unit 5: Bay fill 3.35 – 3.385 m Gray silt. 3.385 – 3.45 m Shell hash in matrix of very dark gray (5Y) clayey fine sand. 3.45 – 3.555 m Very dark gray (5Y) very fine sandy clay with occasional sandy lenses, with shell bits and occasional large shell fragments and organics.

3.555 – 3.855 m Dark gray very fin sandy clay with organics, with occasional very fine sandy lenses, shell bits and occasional large shell fragments.

3.855 - 3.92 m Shell hash.

3.92 – 5.32 m Dark bluish gray silty clay with occasional small lenses of very fine sand and shell bits. Rarely, small organics

Core ID: WL7 Location: N 29° 29.885' W 91° 27.932'
Elevation: 0.259 m Length of Sediment Column: 4.97 m

Depth in core (m)	Description
0 – 0.44	Unit1: Levee flank 0 - 0.085 m Dark grayish brown clayey silt sand with parallel laminae of dark grayish brown (2.5Y) fine-sandy clay. 0.085 – 0.275 m Dark grayish brown (2.5Y) silty sand with organics and lenses of dark gray (2.5Y) sandy clay. 0.275 – 0.44 m Brown (10YR) to dark grayish brown (2.5Y) sandy silt with parallel to wavy thin laminae of dark grayish brown (10YR) to dark gray (2.5Y) silty clay. Small burrows.
0.44 – 1.08	Unit 2: Levee/Distributary mouth bar Brown (10YR) to dark grayish brown (2.5Y) silty sand with parallel to wavy thin laminae of dark grayish brown (10YR) to dark gray (2.5Y) silty clay. Occasional organic laminae.
1.08 – 3.19	Unit 3: Distal bar 1.08 – 1.735 m Dominantly parallel to wavy laminae of dark gray (2.5Y) clay to dark grayish brown (10YR) clay, dark grayish brown (10YR) silty very fine sand and olive gray (5Y) clayey silty sand. Occasional erosional surfaces. 1.735 – 1.84 m Distorted bedding, dark grayish brown (10YR and 2.5Y) silty clayey very fine sand and clay, occasional organics and shell pieces. 1.84 – 2.355 m Dark gray (2.5Y) and dark grayish brown (10YR) clays, in parallel to wavy laminae and dark grayish brown (10YR and 2.5Y) silty sand with occasional organics and very small shell bits. Organics increase downward. Clay units decrease in thickness downward. 2.355 – 3.19 m Dominantly parallel laminae of dark grayish brown (2.5Y) clayey silty very fine sand, dark grayish brown (10YR) and brown (7.5YR) clayey silt, very dark gray clay, dark grayish brown (10YR) and brown (7.5YR) clay. Occasional thin (2.5 – 4 cm) beds of clay, and organic lenses. Shell pieces at base.
3.19 – 4.97	Unit 4: Bay fill 3.19 – 3.325 m Dark gray (2.5Y) silty clay with abundant sand lenses, organics and shell bits, especially at the top of the unit. 3.325 – 3.38 m Shell hash in dark gray (2.5Y) sandy muck. 3.38 – 3.865 m Gray clay with silty laminae, small silty sand lenses, and occasional shell bits and shelly lenses. 3.865 – 4.275 m Gray very silty clay with abundant sandy lenses and occasional shelly lenses. 4.275 – 4.475 m Shell hash and large shell fragments in gray clay. 4.475 – 4.97 m Gray silty clay with occasional sand and silt lenses and shell bits.

Core ID: WL8	Location: N 29° 28.306' W 91° 26.177'
Elevation: -0.604	Length of Sediment Column: 4.75 m
Depth in core (m)	Description
0 – 1.55	Unit 1: Subaqueous levee 0 – 1.0 m Dark yellowish brown (10YR) silty cross-bedded sand with organics and occasional silt lenses. A thin bed of dark gray clayey silt at 0.615 – 0.635 m. 1.0 – 1.55 m Grayish brown (2.5Y) and brown silty sand with occasional clayey silt lenses, and organics. Dark gray (10YR) and dark grayish brown (10YR) clayey silt laminae between 1.36 – 1.41 m.
1.55 – 2.20	Unit 2: Distributary mouth bar 1.55 – 1.62 m A fine shell hash in medium silty sand. 1.62 – 2.2 m Upward fining cycles of parallel, wavy and lenticular laminae of very dark gray (5Y) and dark grayish brown (10YR) silty sand (also in thin beds), dark gray (2.5Y) and brown (7.5YR) silt, and dark grayish brown (10YR) and dark gray (10YR) clay.
2.20 – 2.572	Unit 3: Distal bar Interlaminated parallel, wavy and lenticular laminae of very dark gray (5Y) and dark grayish brown (10YR) silty sand, dark gray (2.5Y) and brown (7.5YR) silt, and dark grayish brown (10YR) and dark gray (10YR) clay.
2.572 – 2.82	Unit 4: Upper prodelta Brown (7.5YR) and dark gray (10YR) bands of clay separated by very thin sand laminae
2.82 – 3.695	Unit 5: Bay fill 2.82 – 3.09 m Dark gray (5Y) sandy silty clay with abundant shell fragments and shells which increase with depth 3.09 – 3.575 m Dark gray clay with occasional shell fragments, sandy lenses and laminae 3.575 – 3.695 m Shell hash in bluish gray clay matrix
3.695 – 4.75 m	Unit 6: Old Bay Bottom Bluish gray clay with silty inclusions and occasional shelly lenses and shell fragments throughout

Core ID: WL9	Location: N 29° 30.720 W 91° 25.722
Elevation: 0.1524 m	Length of Sediment Column: 5.015 m
Depth in core (m)	Description
0 – 1.57	Unit 1: Levee 0 – 0.21 m Dark grayish brown (10YR) parallel and simply cross-bedded silty very fine sand (with orange staining), with thin laminae of dark grayish brown (2.5Y) silty clay. Top veneer of dark grayish brown (10YR) silty clay. Burrows, parallel laminae, minor scour and fill, and some trough cross bedding. 0.21 – 0.39 m Dark grayish brown (10YR) silty very fine sand and silt with parallel to wavy thin laminae of dark grayish brown (2.5Y) silty clay. 0.39 – 0.54 m Dark gray (2.5Y) clayey silty very fine sand and dark gray (2.5Y) clayey silt with black organic and clay lenses. Burrows and rooting evident. 0.54 – 1.003 m Laminae of dark grayish brown (10YR) silty very fine sand and silt (displaying some cross-bedding), with thin parallel to wavy laminae of dark grayish brown (2.5Y) very silty clay and very dark grayish brown (2.5Y) clay with occasional organic laminae. Some burrows and minor scour and fill structures. 1.003 – 1.15 m Silty very fine sand and sandy silt, in dominantly parallel to wavy laminae, with some simple and trough cross bedding, with thin lenses of silty clay. Some distorted bedding, and some ripple drift. 1.15 – 1.34 m Clayey silt grading into a silty fine sand (some cross-bedding), with thin (<3 mm) parallel to wavy silty clay laminae. 1.34 – 1.49 m Planar and trough cross-bedded silty very fine sand with very thin lenses of silty clay. Distorted bedding at top. 1.49 – 1.57 m Thin, parallel to wavy interlaminae of silty to very silty very fine sand and silty clay. Also, a thin (1 cm) bed of cross-bedded silty to very silty very fine sand.
1.57 – 2.145	Unit 2: Distributary mouth bar Upward-fining cycles of beds of cross-bedded grayish brown to dark grayish brown (2.5Y) fine sand to silty fine sand, and thin parallel, wavy and lenticular laminae of silty clay. Organics, erosion surfaces, burrows and occasional scour and fill structures. A thin bed of fine to medium sand at 1.71 – 1.73 m.
2.145 – 2.30	Unit 3: Distal bar 2.145 – 2.185 m Thin (2 mm) parallel and lenticular laminae of dark gray (5Y) to olive gray (5Y) silty clay, and grayish brown to dark grayish brown (2.5Y) fine to silty fine sand. Some burrow traces. 2.185 – 2.265 m Dark gray (5Y) silty clay with thin silt beds and parallel laminae. 2.265 – 2.30 m Clayey silt.
2.30 – 2.93	Unit 4: Bay fill 2.30 – 2.34 m Clayey silty sand and clayey silt, with silty clay lenses. 2.34 – 2.47 m Shell hash. Matrix changes from dark gray (5Y) clayey silt to a bluer dark gray silty clay.

2.47 – 2.61 m Dark gray very clayey very fine sand with occasional shell bits

2.61 – 2.93 m Dark gray very clayey very fine sand with occasional thin black organic-stained beds and light gray clay laminae. Large and small burrows are present, and rarely, very small brown organics.

2.93 – 4.33 Unit 5: Submerged marsh

2.93 – 3.00 m Gray very fine sandy clay with occasional small brown organic inclusions and lenses, black organic stains, dark gray silty clay laminae and thin (1.5 cm) beds, and occasional brown organic inclusions.

3.00 – 4.33 m Gray clayey very fine sand and gray very silty clay with occasional brown peaty inclusions and black organic stains. Beds (<3.5 cm) of parallel laminated black peaty clay, gray silt and gray clay. Burrows evident.

4.33 – 5.015 Unit 6: Bay fill

4.33 – 4.79 m Gray clay with occasional brown and black small organic inclusions and lenses, and thin wavy beds and lenses of clayey silty very fine sand. Large burrow in upper 20 cm. Thin sand beds appear cyclic.

4.79 – 5.015 m Gray silty clay with occasional thin beds of gray silt. Occasional shell bits, and possible burrows evident.

Core ID: WL10 Location: N 29° 30.458' W 91° 25.953'

Elevation: 0.381 m Length of Sediment Column: 5.05 m

Depth in core (m)	Description
0 – 0.56	Unit 1: Levee flank 0 – 0.31 m Brown and dark grayish brown (10YR) silty fine sand with abundant fibrous organics and root traces. Distorted bedding. 0.31 – 0.56 m Thin interlaminae of brown and dark grayish brown (10YR) silty fine sand, silt, dark gray to dark grayish brown (10YR) silty clay, organics and organic lenses. Some root traces. Parallel laminae and some trough cross-bedding.
0.56 – 2.37	Unit 2: Levee 0.56 – 1.645 m Cross-bedded brown and dark grayish brown (10YR) silty fine sand with parallel, wavy, and lenticular laminae of silt, dark gray to dark grayish brown (10YR) silty clay, organics and organic lenses. 1.645 – 2.205 m Dark grayish brown (10YR) silty fine and very fine sand, with cross-bedding and distorted bedding evident, and occasional small thin lenses of very dark grayish brown (10YR) clayey silt and/or organics. 2.205 – 2.265 m Dark to olive gray (5Y) silty fine sand (trough cross-bedding) with very thin dark gray silty lenses. Gradual basal contact. 2.265 – 2.37 m Dark grayish brown (10YR) silty very fine sand with occasional thin lenses of dark grayish brown (2.5Y) clayey silt and dark gray silty clay. A lens (7 mm) of dark to olive gray (5Y) silty vine sand at base. Sharp, angular basal contact.
2.37 – 2.625	Unit 2: Distributary mouth bar Interlaminated, dark to olive gray (5Y) silty very fine sand, and very dark grayish brown (10YR) clayey silt, with very thin (1 mm) parallel to lenticular laminae of dark gray to dark grayish brown silty clay, and occasional thin beds (1 cm) of dark gray (2.5Y) and dark gray to dark grayish brown (10YR) silty clay. Occasional small shells and burrowing in clay beds. Some trough cross bedding and scour and fill structures, and several erosional surfaces.
2.625 – 2.895	Unit 3: Distal bar Interlaminated parallel laminae and thin beds of dark gray (2.5Y), very dark grayish brown (10YR) and brown (7.5YR) clay, with thin laminae and lenses of dark grayish brown (10YR) silt and silty very fine sand. Burrowing evident, as well as occasional shell bits, small shells and tests. Thin laminae of a fine shell hash at 2.79 m. Sharp basal contact.
2.895 – 4.66	Unit 4: Bay fill 2.895 – 3.025 m Shell hash in a matrix which changes from very dark grayish brown (10YR) to dark gray (5Y) to a slightly more bluish dark gray. 3.025 – 3.10 m Dark gray silty clay with silty lenses and shell bits. 3.10 – 3.12 m Shell hash. 3.12 – 4.66 m Dark to light gray wilt clay with organics and silty lenses. Quasi-rhythmic thin silt beds (1 cm or less) to a depth of 3.61m.

Bands and zones of very dark to medium gray matrix throughout Burrows, and occasional small lenses of shell bits.

4.66 – 5.05	Unit 5: Submerged marsh Thin and medium (~ 3 cm or less) beds of light, medium and dark gray clay with organics, interbedded with peaty beds (3 – 12 cm thick).

Core ID: A1 Location: N 29° 23.793' W 91° 19.627'

Elevation: 0.488 m Length of Sediment Column: 3.58 m

Depth in Core (m)	Description
0 – 1.31	Unit 1: Dredged deposits Light olive brown silty sand with occasional organics.
1.31 – 1.515	Unit 2: Interdistributary bay fill 1.31 – 1.33 m Olive brown silty clay with organics. 1.33 – 1.41 m Small scale trough cross-bedded light reddish brown silty fine sand with lenses of olive brown silty clay, with some organics. Slight burrowing toward base. 1.41 – 1.45 m Upward fining thin (2 cm) beds of dark gray silt to silty clay with organics. 1.45 – 1.515 m Shell hash in a silty sand matrix.
1.515 – 1.98	Unit 3: Distributary mouth bar Beds of cross-bedded and lenticular dark gray to light reddish brown silty sand, with parallel to lenticular laminae of silty clay and organics. Upward-fining cycles. Several erosional surfaces, and an erosional basal contact.
1.98 – 2.19	Unit 4: Clay-rich distal bar Dark gray and brown silty clay with organics, with parallel to lenticular laminations of brown silt. Laminations are thinner and less abundant downward. Occasional erosional surfaces.
2.19 – 2.36	Unit 5: Distal bar Interlaminated light brown silt and dark gray clay in parallel and lenticular laminae. Silt decreases downward.
2.36 – 3.025	Unit 6: Upper prodelta 2.36 – 2.415 m Brown clay. 2.415 – 3.025 m Dark gray to brown clay with organic stains, with occasional thin parallel and lenticular silty and fine sand laminae, 1 – 4 mm thick. Silt content of clay increases downward.
3.025 – 3.58	Unit 7: Old channel deposits (reworked) 3.025 – 3.12 m Silty clay with abundant organics, including wood fragments and roots. 3.12 – 3.145 m Brown clayey silty fine sand. 3.145 – 3.19 m Dark gray silty clay with organics. 3.19 – 3.24 m Clayey silty sand with laminae and lenses of silty clay, and occasional organics. Distorted bedding. 3.24 – 3.275 m Clayey silt with organics. 3.275 – 3.46 m Dark gray sandy silt with organics. 3.46 – 3.58 m Silty and clayey sand with organic lenses. Slightly distorted bedding.

Core ID: A2 Location: N 29° 23.80' W 91° 19.66'

Elevation: 1.582m	Length of Sediment Column: 5.26 m
Depth in Core (m)	Description
0 – 1.32	Unit 1: Dredged deposits Grayish brown sand with occasional organics.
1.32 – 1.52	Unit 2: Interdistributary bay fill 1.32 – 1.33 m Dark gray sandy silt with organics. 1.33 – 1.345 m Dark gray clayey silt with organics 1.345 – 1.355 m Dark gray brown silty clay with sandy laminae, 1 – 3 mm thick. 1.355 – 1.36 m Dark gray clayey silt. 1.36 – 1.52 m Parallel laminated dark grayish brown sand with organics and organic laminae. Shelly lamina at base.
1.52 – 2.18	Unit 3: Distributary mouth bar Cross-bedded laminae of dark grayish brown silty sand with organics, interbedded with parallel and lenticular laminations of very dark gray silty clay. Laminae are 1-9 mm thick, organics lenses up to 1 cm thick. Several erosional surfaces, occasional burrows.
2.18 – 2.355	Unit 4: Clay-rich distal bar Parallel laminated brown and dark gray silty clay with thin dark grayish brown silt lenses.
2.355 – 2.61	Unit 5: Distal bar Wavy interlaminated silt, very fine sand, and clay. Sand increases upward
2.61 – 3.70	Unit 6: Upper prodelta Parallel laminated dark gray and brown clay with occasional very thin (<7 mm) wavy, lenticular, and cross-bedded laminations of very fine sand.
3.70 – 5.26	Unit 7: Old channel deposits (reworked) 3.70 – 3.74 m Shell hash in organic sandy matrix 3.74 – 3.965 m Wavy, interbedded dark gray and brown very fine sand and silty clay. Fine organics are common. 3.965 – 3.98 m Silty clay with abundant shell fragments. 3.98 – 4.055 m Distorted, wavy, interbedded dark gray and brown silty clay and sand, with organics. 4.055 – 4.10 m Wavy laminae of silty clay with fine sand and organics. Some shell material. 4.10 – 4.18 m Wavy and lenticular laminae of silty clay and silty sand with abundant organics. 4.18 – 4.385 m Silty sand with abundant shell bits (<1 cm fragments), parallel laminae and lenses of silty sand with shell bits, clayey silt, clay and organics. 4.385 – 4.755 m Dark gray clayey silty fine sand with organics, with occasional small bits of shell. Distorted bedding. 4.755 – 5.26 m Dominantly parallel to lenticular thin laminae of sand, clayey sand, silty clay, and organics. Some shell fragments.

Core ID: A3	Location. N 29° 23.798' W 91° 19.680'
Elevation: 0.335 m	Length of Sediment Column: 3.265 m
Depth in Core (m)	Description
0 – 2.095	Unit 1: Dredged deposits Grayish brown sand with organics and occasional shell bits. Shell hash at 1.03 – 1.11 m, which includes clastic gravel.
2.095 – 2.26	Unit 2: Interdistributary bay fill 2.095 – 2.155 m Interlaminated dark grayish brown silty sand with organics, with thin (<4 mm) laminae of very dark grayish brown silty clay with organics. 2.155 – 2.18 m Dark gray silty sand with organics, with laminae (<5 mm) of very dark gray silty clay with organics. 2.18 – 2.24 m Very dark gray silty sand with organics. 2.24 – 2.26 m Shell hash.
2.26 – 2.785	Unit 3: Distributary mouth bar Dark grayish brown silty sand with organics, in parallel and small scale trough cross-bedding, interlaminated with thin laminae of dark grayish brown and dark gray silty clay, and silt. Organic lenses common
2.785 – 2.845	Unit 4: Clay-rich distal bar Thinly laminated brown and dark gray silt and silty very fine sand with silty clay and organics.
2.845 – 2.94	Unit 5: Distal bar Interlaminated dark grayish brown silt and silty sand with dark gray silty clay. Thin parallel, wavy and lenticular laminae.
2.94 – 3.19	Unit 6: Upper prodelta Dark gray and brown clay with very thin laminae of silt and/or very fine sand.
3.19 – 3.265	Unit 7: Old channel deposits (reworked) Wavy and lenticular laminae of clayey silt and silty clay. Occasional very fine shell material, organic laminae. Scour and fill structures present. Very thin, interfingering beds of upper prodelta deposits at 3.208 – 3.213 m and 3.23 -3.243 m

Core ID: A4 Location: N 29° 23.808' W 91° 19.732'

Elevation: -0.732 m Length of Sediment Column: 4.04 m

Depth in Core (m)	Description
0 – 0.045	Unit 1: Dredged deposits Dark gray silty sand.
0.045 – 0.80	Unit 2: Interdistributary bay fill 0.045 – 0.11 m Dark gray silty clay with burrows 0.11 – 0.275 m Dark gray silty sand with organics and sandy clay lenses. 0.275 – 0.575 m Interlaminated parallel to wavy and lenticular laminae of silty fine sand, silt and silty clay, with occasional shell material, some erosional surfaces. 0.575 – 0.80 m Brown silty sand, displaying distorted bedding and some cross-bedding, with organic laminations and some silty clay lenses.
0.80 – 1.14	Unit 3: Distributary mouth bar Interlaminated cross-bedded dark gray silty sand with organics, and silty clay in wavy, parallel and lenticular laminae. Several erosional surfaces.
1.14 – 1.645	Unit 4: Distal bar 1.14 – 1.17 m Parallel laminated black clayey silt and silty clay. Erosional basal contact. 1.17 – 1.453 m Parallel laminated brown silty sand, clayey silt, and organics. Sand increases below 1.36 m. 1.453 – 1.645 m Interlaminated silty clay, silt and silty sand. Parallel, wavy and lenticular laminae, some cross-bedded silt, some shell fragments, and thin organics lenses.
1.645 – 1.725	Unit 5: Upper prodelta 1.645 – 1.695 m Dark gray silty clay and silt. Distorted bedding. Small shell bits in parallel and lenticular laminae. 1.695 – 1.725 m Parallel laminated brown silty clay with organics, with thin silt wavy laminae and lenses, and some small shell fragments.
1.725 – 4.04	Unit 6: Lower prodelta 1.725 – 1.97 m Shell hash. 1.97 – 2.26 m Dark gray silty clay with organics, occasional silt and fine sand lenses, shell fragments and bits. Bioturbated, but remnant lenses show parallel silt laminations. 2.26 – 3.00 m Dark brownish gray silty clay with organics, occasional silt and fine sand lenses, shell fragments and bits. Bioturbated. Some parallel silt laminations still evident. 3.00 – 3.38 m Silty clay with sand and silt lenses. Abundant (clam) shell content from 3.12 – 3.32 m. 3.38 – 4.04 m Bioturbated dark gray silty clay, occasional small (<1.5 cm) silt and silty sand lenses, rarely, shell bits.

Core ID: A5	Location: N 29° 23.759' W 91° 19.502'
Elevation: -0.823 m	Length of Sediment Column: 2.98 m
Depth in Core (m)	Description
0 – 0.08	Unit 1: Dredged deposit Dark grayish brown silty sand.
0.08 – 0.20	Unit 2: Interdistributary bay fill 0.08 – 0.13 m Very dark gray silty clay and silt 0.13 – 0.18 m Dark gray silty clay with organics 0.18 – 0.20 m Black organic clayey silt with rootlets.
0.20 – 0.91	Unit 3: Distributary mouth bar Parallel, lenticular and cross-bedded brown and grayish brown silty sand and silt, and parallel to lenticular silty clay with occasional organics and organic lenses. Occasional erosional surfaces.
0.91 – 1.00	Unit 4: Clay-rich distal bar Thin parallel and wavy laminae of dark gray and dark grayish brown silty clay with very thin silt lenses. Some scour and fill structures, and deformed bedding.
1.00 – 1.12	Unit 5: Distal bar Thin wavy and lenticular laminae of very dark grayish brown silt, silty clay, and dark gray clay, with some organics
1.12 – 1.52	Unit 6: Upper prodelta 1.12 – 1.155 m Dark grayish brown clay. 1.155 – 1.52 m Dark grayish brown and dark gray silty clay with organics, with thin (1 – 4 mm) parallel to lenticular silt laminations. Some shell.
1.52 – 2.22	Unit 7: Old channel deposits (reworked) 1.52 – 1.83 m Silt with lenses of silty clay and occasionally silty sand 1.83 – 2.095 m Parallel laminated silt and silty sand. 2.095 – 2.22 m Massive to faintly laminated dark grayish brown silty sand with organics
2.22 – 2.98	Unit 8: Lower prodelta 2.22 – 2.43 m Dark gray silt and clayey silt with shell fragments and organics, and inclusions of dark gray silty clay. Distorted bedding (reworked storm deposits). 2.43 – 2.645 m Dark gray silty clay with organics. Burrowed with large and small burrows. 2.645 – 2.98 m Dark gray clay with thin silty lenses and parallel laminae, and occasional shell fragments. Faint small burrows.

Core ID:A6 — Location: N 29° 24.600' W 91° 19.776'

Elevation: 0.427 m — Length of Sediment Column: 3.755 m

Depth in Core (m)	Description
0 –0.09	Unit 1: Levee flank
	0.0 – 0.06 m Grayish brown sand with organics and roots, occasional wavy laminae of silt.
	0.06 – 0.09 m Very dark gray silty clay with fibrous peat.
0.09 – 0.65	Unit 2: Dredged deposits
	Grayish brown silty sand with occasional parallel silt laminae and organics.
0.65 – 0.93	Unit 3: Interdistributary bay fill
	0.65 – 0.755 m Dark gray silty clay with organics. Distorted bedding.
	0.755 – 0.785 m Bed of silty clay, burrows evident.
	0.785 – 0.84 m Parallel laminated dark olive gray and dark grayish brown silty clay with very thin parallel silty very fine sand laminae.
	0.84 – 0.885 m Dark gray silty clay with some organics, some burrowing evident.
	0.885 – 0.915 m Dark grayish brown sandy silt.
	0.915 – 0.93 m Shell hash.
0.93 – 1.685	Unit 4: Distributary mouth bar
	0.93 – 1.055 m Silty fine to very fine sand with silty clay lenses and laminae.
	1.055 – 1.49 m Silty fine to very fine sand with silty clay lenses and occasional parallel to wavy laminae and organics
	1.49 – 1.685 m Interbedded wavy to lenticular laminae of very fine sandy silt and silty clay.
1.685 – 2.77	Unit 5: Distal bar
	1.685 – 1.76 m Parallel laminated silty clay with organics.
	1.76 – 1.905 m Parallel laminated silty fine sand and silt, with parallel to wavy very thin laminae of clayey silt and silty clay, and occasional organics.
	1.905 – 1.96 m Very thin parallel interlaminae of silt and silty clay, distorted bedding, possible fluid escape structure, evident.
	1.96 – 2.77 m Interlaminated parallel, wavy, and lenticular laminae of silty very fine sand, silt and silty clay. Some thin beds of silty sand are cross-bedded.
2.77 – 3.095	Unit 6: Upper prodelta
	Beds of brown clay and dark gray silty clay with thin silt laminae and lenses.
3.095 – 3.18	Unit 7: Old channel deposits (reworked)
	3.095 – 3.18 m Massive gray very silty very fine sand with silty clay laminae and lenses, one thin fine to medium sand bed, occasional shell bits.
	3.18 – 3.755 m Massive dark gray silty sand with silt inclusions, occasional shell fragments.

Core ID: A7 — Location: N29° 24.588' W 91° 19.730'

Elevation: 1.097 m — Length of Sediment Column: 3.15 m

Depth in Core (m)	Description
0 – 1.21	Unit 1: Dredged deposits Brown silty sand with occasional organics lenses and silty laminae with depth.
1.21 – 1.695	Unit 2: Levee flank 1.21 – 1.22 m Organic lenses and silty sand. 1.22 – 1.24 m Dark gray silty clay with organics. 1.24 – 1.405 m Dark grayish brown silty sand. 1.405 – 1.42 m Dark gray clayey silt, massive to faintly laminated Fine organics. 1.42 – 1.695 m Interlaminated massive and parallel laminated dark gray silty sand with thin (<3 mm) parallel to lenticular laminae of very dark gray silty clay, with occasional organic lenses and one shelly lens near the top, containing shell bits and small tests.
1.695 – 2.73	Unit 3: Levee/Distributary mouth bar 1.695 – 1.875 m Cross-bedded and parallel laminated sand with thin very silty clay and organic lenses. 1.875 – 1.98 m Cross-bedded and parallel laminated sand with thin parallel to lenticular silty clay laminae 1.98 – 2.435 m Tangential cross-bedded and parallel laminated sand with thin parallel and lenticular clayey sand and silty clay laminae, and organic lenses. 2.435 – 2.73 m Interlaminated trough cross-bedded fine to very fine sand with parallel and lenticular laminae of silt and silty clay. Occasional organic laminae and lenses. Several erosion surfaces.
2.73 – 2.955	Unit 4: Distal bar Interlaminated fine to very fine sand, silt, and silty clay. Parallel to wavy and lenticular laminae.
2.955 – 3.125	Unit 5: Upper prodelta Thin beds of very dark gray and brown clay and silty clay, with thin silt and sand lenses.
3.125 – 3.15	Unit 6: Old channel deposits (reworked) Dark gray very fine sandy silt.

Core ID: A8	Location: N 29° 24.578' W 91° 19.640'
Elevation: 0.518 m	Length of Sediment Column: 4.78 m
Depth in Core (m)	Description
0 – 0.78	Unit 1: Dredged deposits Brown silty sand with occasional organic laminae, some parallel silt laminae.
0.78 – 1.57	Unit 2: Levee flank 0.78 – 0.905 m Dark to very dark gray silty clay with organic lenses and laminae. 0.905 – 0.96 m Massive dark grayish brown silty sand with organics. 0.96 – 0.985 m Interlaminated parallel laminae of silty clay and silt, with organics. 0.985 – 1.07 m Massive to faintly parallel laminated sandy silt, with faint very thin organic lenses, a thin shell hash at base. 1.07 - 1.47 m Small-scale cross-bedded and parallel laminated dark gray and brown silty sand and very fine sandy silt, with lenses and wavy laminae of silty clay. 1.47 – 1.57 m Very thin parallel to wavy laminae of silty clay and silt Occasional organic lenses.
1.57 – 2.025	Unit 3: Levee Trough cross-bedded brown silty sand with common organic and clayey silt lenses.
2.025 – 2.79	Unit 4: Distal bar Parallel to wavy and lenticular laminae of silty sand (some of which is trough cross-bedded), silt, brown and dark gray silty clay, with occasional organics, shell bits and erosion surfaces. Silty clay content increases downward
2.79 – 3.12	Unit 5: Upper prodelta Thin beds and parallel laminae of brown and dark gray silty clay and clay with thin (<3 mm) parallel and lenticular silt laminae
3.12 – 4.08	Unit 6: Old channel deposits (reworked) 3.12 – 3.22 m Gray silty very fine sand with silty clay laminae and very thin (1 mm) lenses. 3.22 – 3.80 m Very silty very fine sand with silty clay lenses, grading into very silty clay with silt lenses, with occasional shell fragments and woody detritus. 3.8 – 4.08 m Shell hash in a silty sandy clay matrix.
4.08 – 4.78	Unit 7: Bay Fill/Lower prodelta Gray clay with occasional small shell fragments and thin parallel silt laminae.

Core ID: A9 Location: N 29° 25.566' W 91° 19.382'

Elevation: 0.558 m Length of Sediment Column: 4.255 m

Depth in Core (m)	Description
0 – 0.515	Unit 1: Dredged deposits 0 – 0.195 m Grayish brown (10YR) silty fine sand with yellowish brown (10YR) to strong brown (7.5YR) stains. 0.195 – 0.515 m Dark grayish brown to grayish brown (10YR) silty sand with occasional organics and very thin sandy clay and silt lenses and laminae.
0.515 – 1.36	Unit 2: Levee 0.515 – 0.79 m Dark grayish brown to brown (10YR) silty fine sand, in parallel and occasional small scale cross-laminae, with parallel to wavy laminae of silty clay and clayey silt, and organics. Root traces evident. 0.79 – 1.11 m Brown (10YR) to light brownish gray (2.5Y) silty sand in small scale cross-bedding and parallel laminae. Vertical silt-filled burrows or root traces. Zone of silty clay-rich parallel to wavy laminae from 0.925 – 0.97 m. Organics increase toward base. Several erosion surfaces. 1.11 – 1.27 m Thinly bedded brown (10YR) cross-stratified silty sand with occasional thin organic lenses of clayey silt and organics and parallel laminae. 1.27 – 1.36 m Thin interlaminated parallel to wavy and lenticular laminae of silty sand, clayey silt and organics. Burrows evident.
1.36 – 3.39	Unit 3: Channel 1.36 – 2.245 m Dark grayish brown (2.5Y – 10YR) cross-bedded silty sand with occasional organic laminae and lenses. 2.245 – 2.365 m Parallel laminated dark olive gray (5Y) and dark grayish brown (10YR) clayey silt/very fine sand. 2.365 – 2.415 m Grayish brown (2.5Y) parallel laminated sand. 2.415 – 2.59 m Light olive brown (2.5Y) cross-bedded silty sand. 2.59 – 2.85 m Light olive brown (2.5Y) silty sand with organic lenses. 2.85 – 3.00 m Light olive brown (2.5Y) cross-bedded silty sand. 3.00 – 3.39 m Interlaminated thin beds of cross-bedded and parallel laminae of light olive brown (2.5Y) silty sand, with occasional organic lenses, and parallel lam. dark grayish brown (10YR–2.5Y) silty clay.
3.39 – 3.56	Unit 4: Distal bar Very thinly interlaminated parallel and lenticular laminae of dark grayish brown (10YR) to brown (7.5YR) silt/silty sand and silty clay.
3.56 – 3.89	Unit 5: Upper prodelta Thin beds of dark grayish brown (10YR) and brown (7.5YR) silty clay with thin lenses of silt and/or silty sand. Coarse lenses increase in size to parallel laminae, and coarsen in grainsize below 3.765 m.
3.89 – 4.255	Unit 6: Old channel deposits 3.89 – 4.225 m Dark gray clayey sand with silty clay lenses, shell fragments, and occasional organics. 4.225 – 4.255 m Shell hash

Core ID: A10	Location: N 29° 25.427' W 91° 19.606'
Elevation: 0.351 m	Length of Sediment Column: 4.085 m
Depth in Core (m)	Description
0 – 1.39	Unit 1: Levee 0 – 0.43 m Very dark grayish brown to brown silty fine sand in parallel and small-scale cross-bedding, with clayey silt and silty clay laminae and lenses, occasional lenses. Some burrowing evident. 0.43 – 0.62 m Silty fine sand in simple cross-bedding, with occasional clayey silt lenses; abrupt basal contact. Some burrowing evident. 0.62 – 0.82 m Parallel to wavy and lenticular laminae of silty fine sand, silt and silty clay, and organics. Some scour and fill structures. 0.82 – 0.86 m Black (5Y) massive sand. 0.86 – 1.39 m Interlaminated dark grayish brown (2.5Y) to very dark grayish brown (10YR) silty sand, dark gray (2.5Y) and brown (7.5YR) silt and clayey silt, with occasional organic laminae, in cross-bedded, parallel, wavy, and lenticular laminae. Oxidized iron evident, weak red (10R) to yellowish brown silty clay is present.
1.39 – 2.66	Unit 2: Channel 1.39 – 1.97 m Trough cross-bedded silty fine sand with occasional organics and very thin silty clay lenses and laminae. Some bi-directionality to the bedding is evident. Erosional base. 1.97 – 2.325 m Alternating beds of parallel and trough cross-bedded silty fine sand. 2.325 – 2.36 m Parallel laminae of dark gray (2.5Y) and brown (7.5YR) silty clay with thin silt parallel laminae and lenses. 2.36 – 2.45 m Fine to coarse quartz sand with one distorted bed of silt/silty sand. Very sharp contact at base. 2.45 – 2.48 m Wavy to lenticular laminae of silt and silty clay. 2.48 – 2.66 m Cross-bedded silty fine sand with wavy laminae and lenses of silty clay. Abrupt basal contact.
2.66 – 3.09	Unit 3: Distal bar Parallel and wavy laminae of dark grayish brown (10YR) and brown (7.5YR) silty sand, silt and silty clay. Sand decreases and clay increases with depth. Occasional organics.
3.09 – 3.40	Unit 4: Upper prodelta Thin beds of dark grayish brown (10YR) and brown (7.5YR) silty clay and clay with very thin parallel laminae and lenses of silt. Gradual basal contact.
3.40 – 4.085	Unit 5: Old channel deposits 3.40 – 3.76 m Massive dark gray (2.5Y) clayey silty fine to medium sand with occasional silt lenses and shell bits; increasing shell content with depth. 3.76 – 3.93 m Shell hash. 3.93 – 4.035 m Dark gray (5Y) sandy clay with shell bits. 4.035 – 4.085 m Massive very dark to dark grayish brown (10YR) silty fine sand.

Core ID: A11	Location: N 29° 25.814' W 91° 18.872'
Elevation: 1.03 m	Length of Sediment Column: 4.21 m
Depth in Core (m)	Description
0 – 0.97	Unit 1: Dredged deposits Grayish brown silty sand with occasional parallel silt laminae and organics lenses. Rooted within the topmost 16 cm.
0.97 – 3.00	Unit 2: Levee 0.97 – 1.00 m Black clayey silt with woody fragments. 1.00 – 1.525 m Brown (10YR) and very dark grayish brown (2.5Y) silty fine to very fine sand with occasional very thin silty clay lenses and wavy laminae. Alternating thin to medium beds of massive and cross-bedding structure. 1.525 – 1.775 m Cross-bedded very dark grayish brown (2.5Y) silty sand grading to a parallel laminated brown (10YR) silty sand, with very thin silty clay lenses. 1.775 – 1.85 m Brown (7.5YR) silty sand in tangential cross-beds with dark grayish brown (2.5Y) very thin silty clay lenses. 1.85 – 2.05 m Parallel laminated very dark grayish brown(2.5Y) silty sand with occasional parallel silt laminae. 2.05 – 2.32 m Cross-bedded brown (10YR) silty fine sand with very thin silty clay lenses. Trough cross-beds, grading downward to tangential. 2.32 – 2.88 m Very dark gray fine to medium sand in parallel laminae, with organic lenses, increasing to laminae, and thin beds below 2.58 m. 2.88 – 2.98 m Parallel laminated fine to medium sand with shell bits in parallel laminae. 2.98 – 3.00 m Medium to coarse quartz sand with shell fragments
3.00 – 3.215	Unit 4: Interfingered distal bar, upper prodelta and channel deposits Parallel laminated brown (7.5YR) and dark gray (10YR) silty clay with thin (<5 mm) parallel and lenticular laminae of silt and medium sand. Gradual basal contact.
3.215 – 4.21	Unit 5: Old channel deposits 3.215 – 4.155 m Massive very dark grayish brown poorly sorted fine to medium sand (with an inclusion of coarse sand near the top of the unit), with silt and silty clay lenses and occasional shell bits and organics. 4.155 – 4.21 m Shell fragments and woody organics

Core ID: A12	Location: N 29° 24.807' W 91° 18.468'
Elevation: 0.61 m	Length of Sediment Column: 4.825 m
Depth in Core (m)	Description
0 – 1.20	Unit 1: Levee 0 – 0.145 m Very dark grayish brown (10YR) silty sand with lenses of silty clay. 0.145 – 0.54 m Silty sand and parallel, wavy, and lenticular laminae of silty clay. Occasional cross-bedding in the sand, some burrows evident in the silty clay. 0.54 – 0.85 m Brown (10YR) to dark gray (10YR) silty sand with silty clay lenses occurring rarely. Distorted bedding, some trough cross-bedding in the lower 10 cm. 0.85 – 1.20 m Brown (10YR) to dark gray (10YR) silty sand with occasional silty clay lenses, and organics. Distorted and cross-bedding structures.
1.20 - 2.226	Unit 2: Channel fill 1.20 – 1.25 m Very silty fine sand with organic lenses; organics increase in concentration in the bottom 2.5 cm. 1.25 – 1.49 m Silty fine sand with organic particles common in the uppermost 9 cm. Very thin parallel laminations to massive bedding. 1.49 – 1.60 m Silty fine sand with very thin clayey silt. Parallel to wavy laminations and occasional organics. 1.60 – 1.765 m Faintly parallel laminated to massive silty fine sand, occasional silty clay lenses, and evidence of distorted bedding toward base. 1.765 – 2.03 m Interlaminated brown to dark gray wilt and silty sand (10YR) with parallel to lenticular silty clay laminae 1 – 10 mm thick. Occasional erosion surfaces. 2.03 – 2.226 m Thin beds of fine to medium sand in climbing ripple cross-bedding with occasional thin silty clay lenses, interbedded with thin beds of faintly parallel-laminated silty fine sand.
2.226 – 2.61	Unit 3: Distal bar Interlaminated parallel laminae of brown (7.5YR) to dark gray (2.5Y) silty clay, silt and silty sand.
2.61 – 2.99	Unit 4: Upper prodelta with interfingering distal bar deposits Interlaminated parallel laminae and thin beds of brown (7.5YR) to dark gray (2.5Y) silty clay and clay with very thin (1 mm) parallel and lenticular silt and sand laminae. Burrowing evident in silty clay.
2.99 – 3.48	Unit 5: Old channel deposits (reworked) Massive dark gray (2.5Y) sandy silt with clay lenses (which become more abundant below3.12 m), shell fragments and occasional woody organics inclusions. Gradational basal contact. 3.48 – 3.75 m Massive dark gray very sandy silty clay. 3.75 – 3.98 m Dark gray clayey sand with abundant shell fragments. 3.98 – 4.125 m Dark gray silty clay with abundant shell fragments and silty sand lenses.

3.48 – 4.825	Unit 6: Old bav fill Gray to blue gray clay with occasional shell bits and small sandy lenses Bioturbated, but some parallel laminations evident

Core ID: A13	Location: N 29° 25.334' W 91° 19.820'
Elevation: 0.732 m	Length of Sediment Column: 4.47 m
Depth in Core (m)	**Description**
0 – 0.70	Unit 1: Dredged deposits Brown (10YR) silty sand with occasional rootlets in upper 26 cm, and occasional organics and organic lenses throughout. Distorted bedding.
0.70 – 2.535	Unit 2: Levee 0.70 – 0.90 m Parallel laminated silty sand grading downward into cross bedded silty sand. 0.90 – 0.98 m Interlaminated silty clay and silt in parallel and lenticular laminae. 0.98 – 1.12 m Trough and tangential cross bedded fine silty sand with organics, shell fragment. 1.12 – 1.18 m Cross bedded (trough and climbing ripples) sandy silt, silt, and silty clay. 1.18 – 1.33 m Parallel and wavy laminae of silt and clayey silt, with organics. One thin bed of "coffee grounds" type woody organics at 1.25 – 1.28 m. 1.33 – 1.605 m Distorted trough cross-bedded silty, very fine sand. 1.605 – 1.635 m Interlaminated, parallel and wavy laminae of silt and clayey silt. 1.635 – 1.68 m Distorted trough cross-bedded silty, very fine sand 1.68 – 2.345 m Distorted interlaminae of silty sand, silt, clayey silt. Distorted bedding. 2.345 – 2.535 m Massive silty fine to medium sand grading downward to a silty very fine sand, with organic lenses. Occasional silty clay lenses. Uneven basal contact. One clam shell at 2.50 m.
2.535 – 2.96	Unit 3: Distal bar with interfingering upper prodelta deposits Interlaminated medium reddish gray (5YR) to dark gray (2.5Y) silty clay and silt, in parallel to wavy laminae. Silt laminae decrease in thickness with depth. Possible gas heave structures.
2.96 – 3.32	Unit 4: Upper prodelta Parallel laminated reddish gray (5YR) to dark gray silty clay and clay with occasional very thin (1mm or less) silt/sand lenses or laminae.
3.32 – 3.66	Unit 5: Old channel deposits (reworked) 3.32 – 3.35 m Gray silt and dark gray silty clay in wavy laminae. Some small shell bits. 3.35 – 3.66 m Shell hash in clayey sandy silt muck, dark gray to very dark gray (2.5Y).
3.66 – 4.47	Unit 6: Lower prodelta/Old bay bottom 3.66 – 4.375 m Dark gray clay with shell hash at 3.76 – 3.83 m and occasional shell fragments and small sandy and silty lenses throughout. Occasional burrows and parallel silt laminae evident. 4.375 – 4.47 m Shell hash in sandy silty clay.

APPENDIX II SEDIMENTARY FACIES DEFINITIONS

The facies definitions used to identify core sections are based upon those used by van Heerden (1983), Roberts and van Heerden (1992), Bowles (1987), and Kuecher (1994).

Submerged Marsh

Along the proximal margins of the Wax Lake delta, deposits found at >2 to 4 meters depth contain black organic-stained beds, abundant organics, and in some cases, sapric peat (Figure 33). These represent the remains of marsh deposits belonging to the Bayou Sale lobe of the Teche delta complex (Thompson, 1952) Some time after the splitting of the cores, these units developed yellow and orange coatings on the exposed faces. This is being taken as evidence of the oxidation of sulfur and iron, respectively. The presence of sulfur compounds suggests that the former marsh received some input of seawater from the Gulf. Samples from one of these units were found to contain an average of 2 percent sand by weight

Old Bay Bottom, Lower Prodelta (Atchafalaya), Wax Lake Outlet Bay Fill

Van Heerden (1983) characterized "old bay bottom" sediments underlying the eastern Atchafalaya delta as clays and silty clays with a blue-gray hue, highly bioturbated, with commonly occurring oyster shell fragments (Figure 33). These characteristics result from the minimal fluvial influence and high biological activity of this environment. Weakly graded parallel beds, best seen in X-radiographs, marked possible sediment transport along the bottom following major storm passages (van Heerden, 1983). Median grainsize was reported as 14 mm, but with a slight increase in size and sorting vertically (van Heerden, 1983)

Van Heerden also described a lower prodelta environment in the vicinity of the Atchafalaya River mouth. Deposition of these sediments began following the clearing of the log jams on the Atchafalaya in the early half of the nineteenth century (Roberts and van Heerden, 1992). Lower prodelta deposits are characterized by hightly bioturbated clays and silty clays.

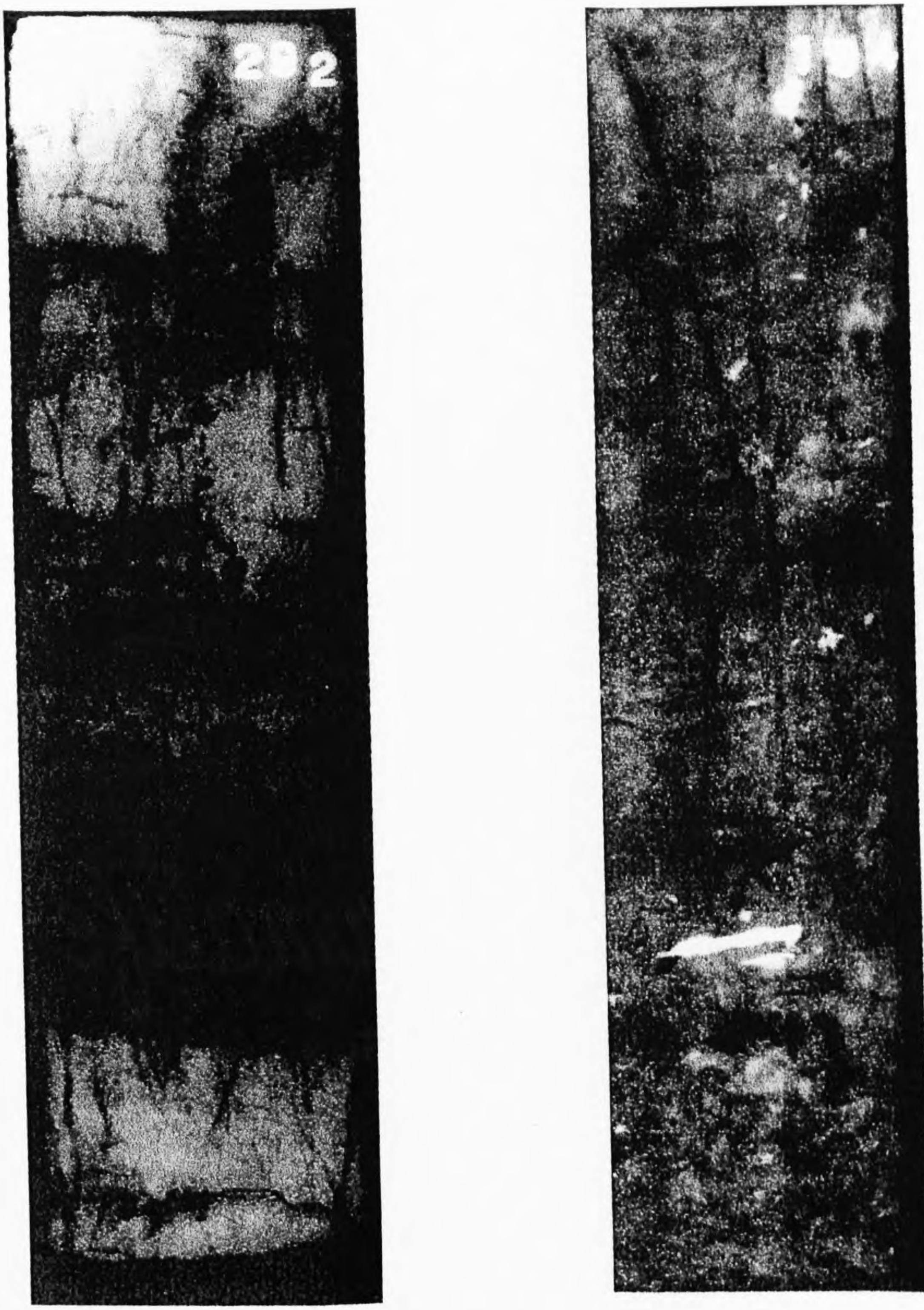

Figure 30. Reproductions of X-radiographs showing examples of submerged marsh deposits (left, core WL9) and old bay fill deposits (right, core WL5).

gray to brown-gray in color, which is indicative of a slightly greater riverine influence (van Heerden, 1983). Besides the color change, van Heerden distinguished these two environments based on microfaunal assemblages; brackish water ostracods dominated old bay bottom sediments, and freshwater ostracods dominated the lower prodelta. Because microfaunal analyses were beyond the scope of this research, for present purposes these two depositional environments are only distinguished when a color difference was noted. They are grouped together here as units indicating a period of minimal riverine sediment input.

Lower prodelta deposits described at the mouth of the Atchafalaya River are not found as such in the area of the Wax Lake delta, most likely because of the relatively recent opening of the Outlet. While some riverine sediment may have been contributed, bay fill deposits directly underlying the Wax Lake delta contain a high silt content, and are composed primarily of reworked sediments derived from shoreline erosion (Thompson, 1952). When the river shifted to its St. Bernard course, marshes in this area (represented by the submerged marsh unit) began eroding; the shelf and bay deposits at the surface were derived from the material eroded from the retreating shoreline (Thompson, 1951). This unit may be assigned a general date of 1951.

Samples of these deposits contained a wide range of sand content, from <1 percent (sample WL1-23) to 43 percent (sample WL1-15) or more if shell content is significant. Several cores displayed a fine, thin shell hash marking the top of the bay fill unit, which Thompson noted at the bay bottom surface of his 1951 cross-sections.

Upper Prodelta

The cyclic occurrence of thin, parallel laminated beds of red-brown clays and silty clays, separated by thin silt lenses, are indicative of an increase in the supply of more oxidized riverborne sediments, and the transition to a later, or upper, prodelta environment (Kemp, pers. comm.; van Heerden, 1983; Figure 34). The silt lenses separating the parallel clay beds occur as

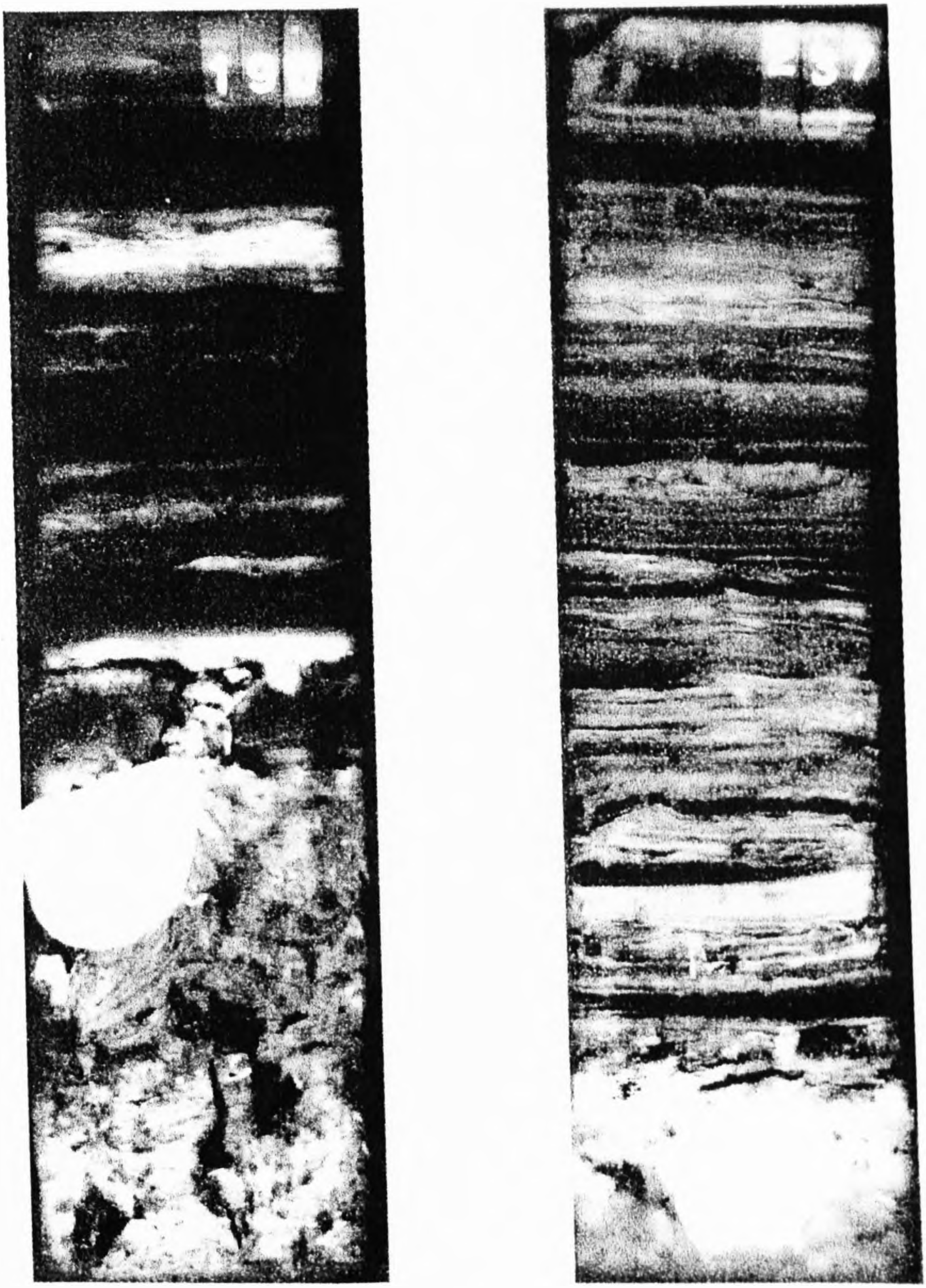

Figure 31. Reproductions of X-radiographs showing examples of upper prodelta (left, core WL8) and distal bar (right, core WL3) deposits overlying bay fill deposits.

a result of periodic sediment reworking in this typically quiescent environment, probably due to storm passages in times of low river discharge (van Heerden, 1983). The conditions that allow for the slow deposition of clays from suspension are also favorable for biological activity, as evident from the small polycheate burrows that are commonly observed extending from the silt lenses into underlying clay beds. In contrast to the Atchafalaya, the Wax Lake lower prodelta unit has very low lateral continuity.

Median grainsize has been reported as smaller (~12 mm) than underlying lower prodelta and bay bottom environments, but sorting is improved (Roberts and van Heerden, 1992). Results from sediment samples collected for this project are in agreement with previous findings. Analyzed for percent of sand content (by weight), samples of upper prodelta deposits contained between <1 percent (sample A1-10) and 6 percent (sample A3-13) sand, with an average of 3 percent. Upper prodelta sample WL1-12 was found to contain 17 percent of its weight attributed to material >4 phi, but this was attributable to a significant amount of shell material.

Distal bar

As the receiving basin receives increasingly coarse-grained sediment, distal bar sequences are developed (Roberts and van Heerden, 1980). The primary indicator of this environment is an increase in silt and sand content, and an associated change in sedimentary structures to include ripple features indicative of the onset of traction deposition (Tye, 1986). Distal bar sequences display parallel and lenticular laminae, and thin beds, of distinctive textural variability ranging from silty clays to coarse silt, and deformation structures are common (van Heerden, 1983). The transition from prodelta to distal bar is generally gradational, and the two may be interfingered as a result of variations in annual discharge (Tye, 1986). Near distributary channels, however, the contact may be more abrupt.

In the Wax Lake Outlet, because of the extremely limited upper prodelta, the distal bar facies directly overlies the bay fill deposits in most cores, as shown in Figure 34 Van Heerden (1983) reports the occurrence of a more 'clay-rich' distal bar environment, which occurs in some cores, above a more coarse-grained sequence. He attributes the coarser facies to deposition prior to the development of bathymetric highs upstream in the delta, and the clay-rich distal bar to deposition after development of these highs, which intercepted the coarser fractions of the sediment supply, leaving the finer fractions to be deposited seaward

Median grainsize for distal bar deposits is reported as 20 mm. although the sequence itself is generally coarsening-upward (van Heerden, 1983) Distal bar deposits were found to contain between <1 percent (sample A1-9) to 23 percent (samples A8-3 and WL7-4) sand by weight, with an average value of 7 percent Clay-rich distal bar sediments that fit van Heerden's description were found in cores from the Atchafalaya study area They generally contained less than 2% sand. Visual inspection of distal bar deposits of the Atchafalaya study area suggested an unexpectedly high sand content. likely due to the proximity of the navigation channel

Distributary mouth bar

With the approach of a distributary, coarser sediments deposited at the river mouth bar gradually overlie the distal bar environment Van Heerden describes upward-fining cycles, 3 to 9 cm thick, of parallel and cross-bedded fine sands, silts and clayey silts, alternating with parallel laminated silty clays. Erosional surfaces are common, caused by reworking of bar material during low river stages, and take on an appearance resembling lenticular bedding (van Heerden, 1983; Figure 35).

Kuecher reports a median grainsize of .147 mm (fine sand) from Mississippi River delta, while van Heerden (1983) median grainsize is between approximately 25 - 77 mm (very coarse silt to very fine sand). Samples from both the Wax Lake and Atchafalaya deltas of units

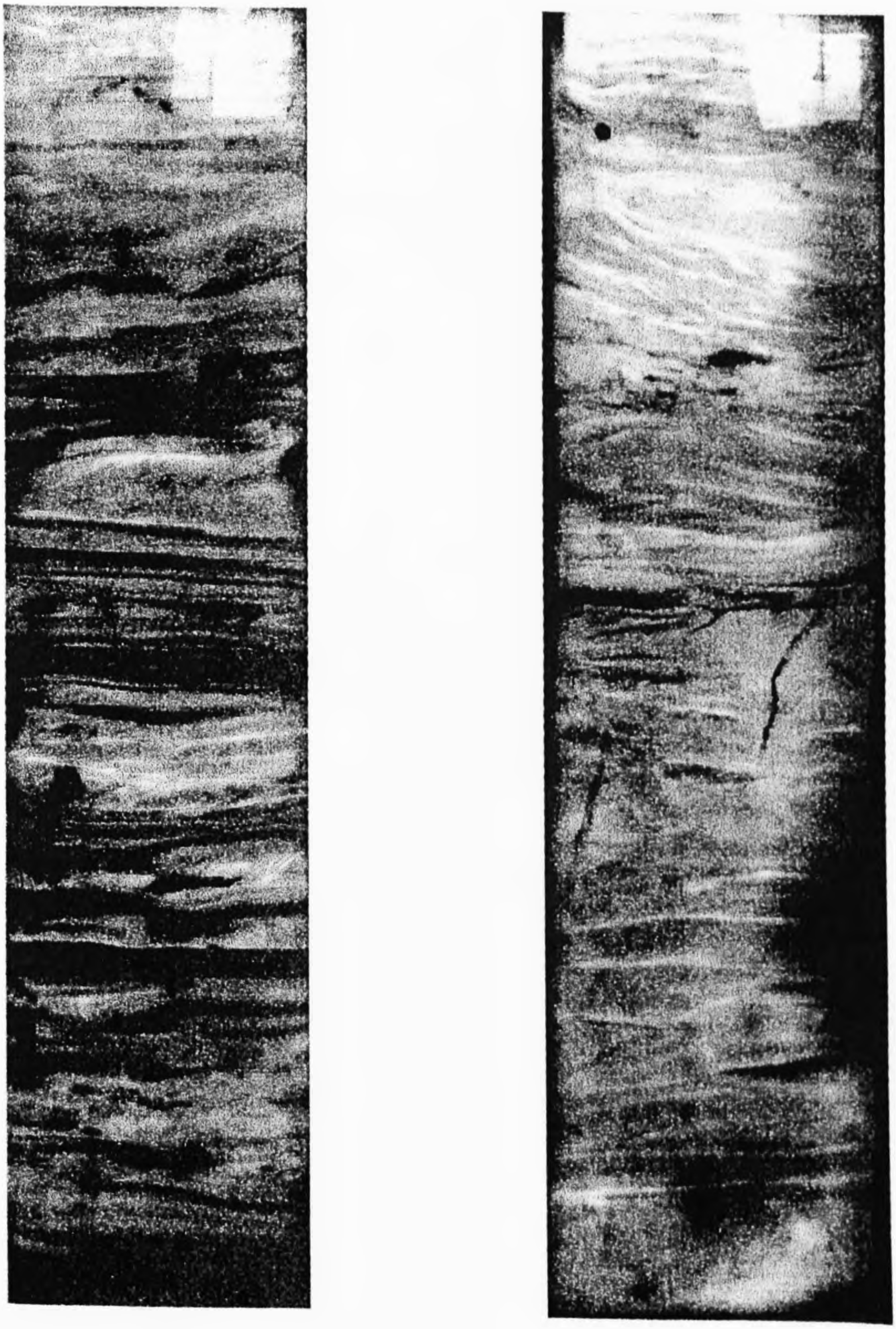

Figure 32. Reproductions of X-radiographs showing examples of distributary mouth bar (left, core WL8), and levee deposits (right, core WL10).

interpreted as being distributary mouth bar deposits were found to contain between 4 percent (sample A3-8) to 55 percent (sample A3-4) sand by weight, with an average of 27.5 percent.

Levee

Sand-rich, well-structured subaqueous levees are often very difficult to distinguish from coarse distributary mouth bar deposits in deltas such as the Wax Lake and Atchafalaya (Roberts and van Heerden, 1992). Stating that subaerial and subaqueous levees are similar and gradational, van Heerden grouped them together into one class. Where possible, the distinction between subaqueous, intertidal, and subaerial levees are noted on the core descriptions. Sedimentary structures include climbing ripple and trough cross-laminations, characteristic of high sedimentation rates during high floods, and simple cross-lamination indicative of lower sedimentation rates during minor floods (Roberts and van Heerden, 1992). Parallel laminae, unidirectional current forms, and wavy laminae are common, as are scour and fill structures, convoluted bedding, clay balls, and silty clay layers showing desiccation cracks (Kuecher, 1994; Figure 35). Ripple drift structures were most common in the levees of Baptiste Collette, although burrowing and rooting on the levees often destroyed all primary structures (Bowles, 1987). Van Heerden describes levees as being composed of silts and fine sands with minor amounts of clay. Median grainsizes range from approximately 25 mm to 95 mm (very coarse silt to very fine sand). Bowles (1987) reports similar findings, an average grainsize of 75 mm in the levees of Baptiste Collette. The levees themselves are composed of 50% to 80% fine sand (88mm), and 10% interlaminated mud (Bowles, 1987). From more recent samples of Atchafalaya delta natural levees, median grainsize is reported as 149 mm (2.75 f), moderately sorted fine sand (Kuecher, 1994). Samples of levee deposits collected for this project ranged from 41 (sample WL1-1) to 97 (WL1-8) percent, with an average of 71 percent.

Levee Flank

Bowles (1987) presents a description of overbank, or floodplain, deposits characterizing low-lying areas located behind subaerial levees. Similar is van Heerden's description of the 'back-bar' environment, although this environment is generally thought of as being located specifically in the lowest portions of the delta lobe. Sediments are delivered to this environment by levee overtopping during river floods, levee erosion (which may contribute thin sand sheets), overbank channels, and by tidal flooding. Sediments here are generally clayey silts and silts, with a small amount of fine-grained sand (Figure 36). Dominant structures characterizing this environment are wavy and small-scale cross-bedding, convoluted bedding, and horizontal laminations. Ripple drift is also noted, and root and animal burrows may be evident.

Core WL3 was collected from this environment, and samples of the uppermost unit had sand content values between 13 percent to 48 percent (probably a sand sheet), with an average of 24 percent.

Interdistributary bay fill

This environment was encountered in cores taken from the Atchafalaya delta study area in a small shallow section of the bay located in the lee of delta island lobes. Channel levees loosely flank this area, but it is open at the seaward end. Water depths in this environment are on the order of 3 to 5 feet. Coarse sediments enter this environment by drift from nearby distributaries, or from erosion of the flanking levees. Samples taken reveal sand contents ranging from 5% (core A5) to 18% (core A6). An example of Interdistributary bay fill deposits is included in Figure 36.

Channel fill and Old channel/reworked old channel (Atchafalaya only)

Van Heerden documents three types of channel fill, sandy, silty and clay plug. In the eastern Atchafalaya River delta, clayey fill was primarily found in abandoned tertiary channels

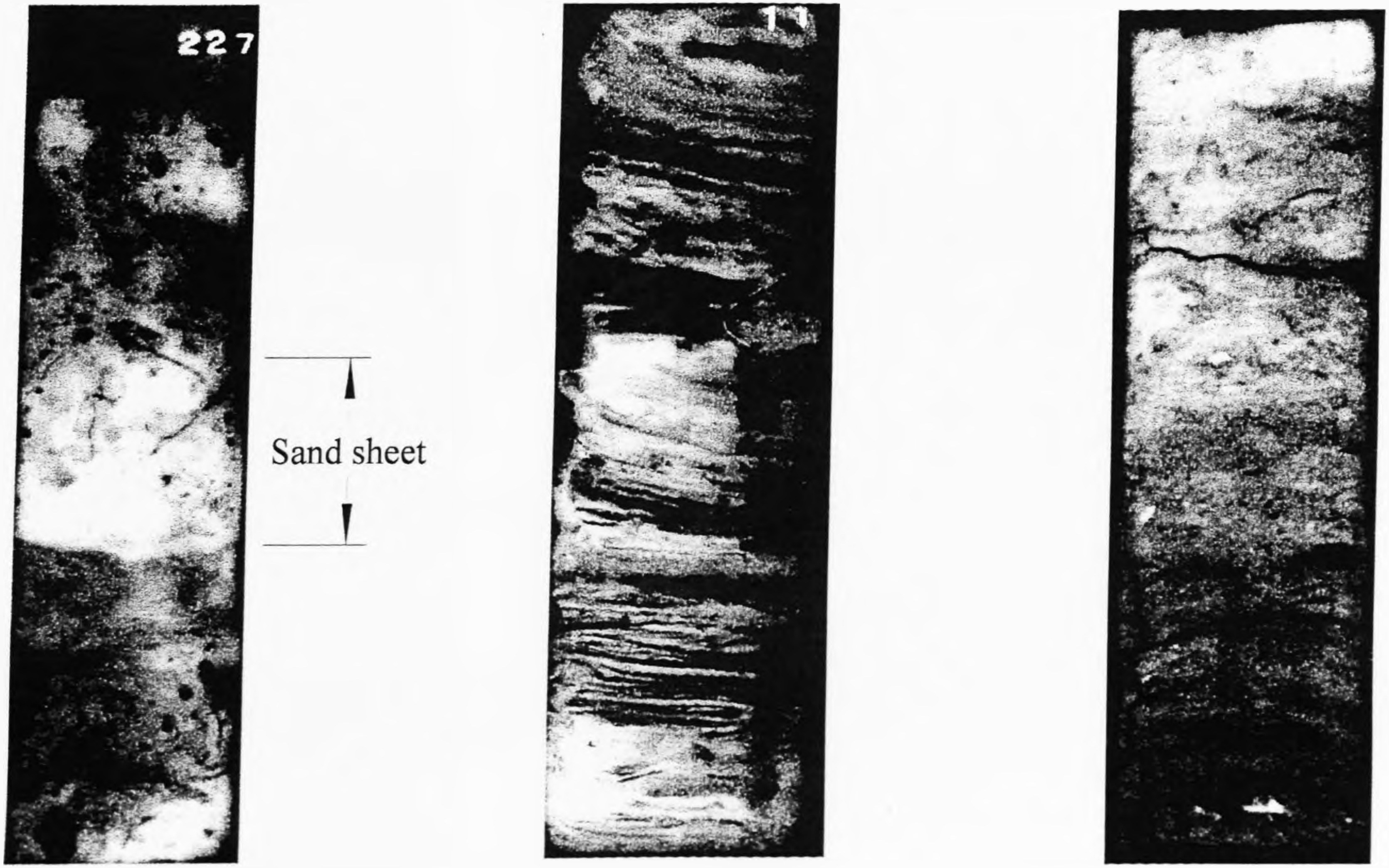

Figure 33. Reproductions of X-radiographs showing examples of levee flank (left, core WL3), interdistributary bay fill (center, core A4) and 'old channel' deposits (right, core A11).

(which result from the bifurcation of second-order channels). Silty fill, the most common van Heerden found, was generally present in shoaling primary and secondary channels as parallel laminated silt and clays, often with worm burrows, and occasional thin, cross-bedded silt lenses which represent starved ripples (Roberts and van Heerden, 1992b, van Heerden, 1983). Sandy channel fill, which appears as parallel and cross-bedded silty sand, was found by van Heerden in areas close to the LAR navigation channel and contributes to the lobe-fusion process (van Heerden, 1983).

Bowles (1987) reports sands found in active channels to be approximately 70% clean well-sorted quartz, with a median grainsize of 88-175 mm, and 30% coarse silt. Trough cross bedding tended to be the dominant bedform (20-75%), with some ripple-drift and cross-bedded silts. Channel sediments sampled from a secondary channel in the Wax Lake Outlet delta (WL5-1) contained 30 percent sand.

Channel sediments sampled in the Atchafalaya delta study area include an overbank channel containing 13 percent sand (A13-18), and what is referred to as 'old channel' deposits underneath the delta which contain an average of 55 percent sand.

'Old channel' deposits are related to other deposits referred to as 'reworked old channel', found in the Atchafalaya study area, and are grouped together as one unit. It is thought that these sediments originated from dredging activity along the Atchafalaya navigation channel. In the northernmost core, from the head of Long Island adjacent to God's Pass, this unit appears as muddy coarse sand. Toward the south and east, it gradually fines into siltier, parallel laminated beds. It is thought that as the coarsest sediments were deposited near the navigation channel, the finer sediments settled out further away, where they were reworked by bay processes. Given, by a general agreement in the literature, that upper prodelta sediments were deposited in the vicinity of the LAR mouth beginning in the early 50's, these channel/dredging deposits date to the first half of this century at the latest. An example of 'old channel' deposits is included in Figure 36.

Dredged Island Deposits

These units are unique to the Atchafalaya delta study area Dredged deposits generally appear massive in radiographs, although thin parallel laminae are occasionally seen Sediment analysis revealed that these deposits may be generalized as well sorted, dominantly very fine-grained sand, containing an average of 95 percent sand by weight In cross sections, dredged deposits were included in the sand-rich group.

APPENDIX III COMPACTION/DECOMPACTION DATA

Core ID	Length (cm)	Compaction (cm)	Total Depth (cm)	Percent Compaction	Decompacted Length (cm)	Top of Core Elevation (cm)	Penetration Depth (cm)	Percent Compaction
A1	358.00	15.70	373.70	4.2	-	48.8	324.93	4.2
A2	543.20					115.8	505.58	
a	405.5	48.9	454.4	10.8	483.70	115.8	367.88	-6.4
b	137.7	unknown		unknown	N/A			
A3	326.5	37.2	363.7	10.2	367.40	33.5	333.87	-1.0
A4	404.0	13.3	417.3	3.2	-	-73.2	490.45	3.2
A5	298.0	86.0	384.0	22.4	363.30	-82.3	445.60	5.4
A6	375.5	51.1	426.6	12.0	431.30	42.7	388.63	-1.1
A7	315.0	121.0	436.0	27.8	338.70	109.7	228.97	21.0
A8	478.0	85.4	563.4	15.2	551.40			2.0
A9	425.5	38.4	463.9	8.3	-	55.8	408.14	8.3
A10	408.5	53.3	461.8	11.6	453.20	35.1	418.15	1.9
A11	421.0	123.8	544.8	22.7	459.70	103.0	356.68	15.6
A12	482.5	91.1	573.6	15.9	506.70	6.1	500.60	2.3
A13	447.0	84.8	531.8	15.9	523.40	73.2	450.25	1.5
WL1	408.5	132.3	540.8	24.5	511.00	59.1	451.87	5.5
WL2	497.0	70.0	567.0	12.4	584.00	0.0	584.00	-1.6
WL3	497.0	28.0	525.0	5.3	-	19.2	505.80	5.3
WL4	432.0	98.1	530.1	18.5	515.30	15.9	499.45	1.6
WL5	379.0	49.0	428.0	11.5	447.00	-106.7	553.68	-7.7
WL6	532.0	46.2	578.2	8.0	-	37.5	540.71	8.0
WL7	497.0	45.7	542.7	8.4	-	25.9	516.79	8.4
WL8	475.0	17.2	492.2	3.5	-	-60.4	552.55	3.5
WL9	501.5	64.5	566.0	11.4	564.70	59.1	505.57	-0.2
WL10	505.0	43.4	548.4	7.9	-	38.1	510.30	7.9

APPENDIX IV SEDIMENT SAMPLE DATA

WLO Samples

Sample ID	Sample Depth (cm)	% Sand	Unit Facies
WL3-1	25-27	48%	Levee flank
WL3-2	43-46	19%	Levee flank
WL3-3	65-67	13%	Levee flank
WL7-1	32-34	17%	Levee flank
WL7-2	65-67	48%	Distributary mouth bar
WL7-3	156-158	23%	Distal bar
WL7-4	229-231	1%	Distal bar
WL5-1	10.000	30%	Channel
WL1-1	20	41%	Levee
WL1-2	38-40	26%	Levee
WL1-3	59-61	70%	Levee
WL1-4	79-81	87%	Levee
WL1-5	98-100	80%	Levee
WL1-6	119-121	90%	Levee
WL1-7	139-141	66%	Levee
WL1-8	159-161	97%	Levee
WL1-9	179-181	90%	Levee
WL1-10	198-200	2%	Distal bar
WL1-11	205.5-208.5	4%	Distal bar
WL1-12	214.5-217	17%	Upper prodelta
WL1-13	218.5-220.5	60%	Bay fill
WL1-14	222.5-225	57%	Bay fill
WL1-15	227-228.5	43%	Bay fill
WL1-16	234.5-237.5	40%	Bay fill
WL1-17	259-261	7%	Bay fill
WL1-18	279-281	11%	Bay fill
WL1-19	298-300	19%	Bay fill
WL1-20	319-321	8%	Bay fill
WL1-21	339-341	3%	Bay fill
WL1-22	359-361	2%	Bay fill
WL1-23	379-381	0%	Bay fill
WL1-24	399-400	2%	Submerged marsh

LAR Samples

Sample ID	Sample Depth (cm)	% Sand	Unit Facies
A1-1	33	97%	Dredged
A1-2	66	98%	Dredged
A1-3	99	98%	Dredged
A1-4	162.5-165	22%	Distributary mouth bar
A1-5	177.5-180	30%	Distributary mouth bar
A1-6	192.5-195	34%	Distributary mouth bar
A1-7	205-207.5	2%	Clay-rich distal bar
A1	212.5-215	1%	Clay-rich distal bar
A1	227.5-230	1%	Distal bar
A1	237.5-240	0%	Upper prodelta
A1	253.5-256	1%	Upper prodelta
A1	268.5-271	4%	Upper prodelta
A1	282.5-285.5	2%	Upper prodelta
A3-1	52.3	99%	Dredged
A3-2	104.6	75%	Dredged
A3-3	157	98%	Dredged
A3-4	249-251	55%	Distributary mouth bar
A3-5	236-239.5	21%	Distributary mouth bar
A3-6	257-259	40%	Distributary mouth bar
A3-7	267-269.5	19%	Distributary mouth bar
A3-8	276-278	4%	Distributary mouth bar
A3-9	279.5-283.5	1%	Clay-rich distal bar
A3-10	286-288	4%	Distal bar
A3-11	291.5-293.5	4%	Distal bar
A3-12	295-296.5	1%	Upper prodelta
A3-13	306-308	6%	Upper prodelta
A3-14	311-313	1%	Upper prodelta
A3-15	315-318	0%	Upper prodelta
A3-16	322-325	3%	Reworked channel
A13-2	39-41	83%	Dredged
A13-3	66-69	83%	Dredged
A13-4	79-81	76%	Levee
A13-5	98-100	83%	Levee
A13-6	119-121	71%	Levee
A13-7	139-141	87%	Levee
A13-8	159-161	43%	Levee
A13-9	179-181	67%	Levee
A13-10	198-200	42%	Levee
A13-11	219-221	54%	Levee
A13-12	238-240	95%	Levee
A13-13	245-247	77%	Levee

LAR Samples

Sample ID	Sample Depth (cm)	% Sand	Unit Facies
A13-14	259-261	9%	Distal bar
A13-15	279-281	3%	Distal bar
A13-16	298-300	1%	Upper prodelta
A13-17	318-320		upd
A13-18	332.5-334.5	13%	Channel
A13-20	359-361	43%	Reworked channel
A13-21	379-381	52%	Lower prodelta
A13-22	398-400		Lower prodelta
A13-23	419-421		Lower prodelta
A5-2	49-51	5%	Sandy bay fill
A6-1	82-84	14%	Sandy bay fill
A6-2	69-71	18%	Sandy bay fill
A6-3	140-142	6%	Distributary mouth bar
A6-4	112-114	22%	Distributary mouth bar
A8-1	200-303	13%	Distal bar
A8-2	232-234	8%	Distal bar
A8-3	265-267	23%	Distal bar
A8-4	246-248	18%	Distal bar
A9-1	390-392.5	68%	Old channel
A11-1	314.5-317	43%	Old channel
A11-2	302.5-304.5	3%	Upper prodelta

APPENDIX V THICKNESSES OF COMPONENTS

Delta	Core	Delta Thickness (m)	Delta Platform(m)	Sand (m)	Sand (%)
WLO	WL1	2.6	0.35	2.2	87
	WL2	2.2	0.27	1.9	88
	WL3	2.9	0.64	1.5	50
	WL4	3.8	1.65	1.5	57
	WL5	2.4	0.81	1.4	57
	WL6	3.4	0.94	2.4	72
	WL7	3.2	2.11	1.7	20
	WL8	2.8	0.62	2.2	78
	WL9	2.6	0.16	2.4	92
	WL10	2.9	0.27	2.1	71
	Ave.	**2.88**	**0.78**	**1.93**	**67.2**
	R1	3.2	0.10	3.1	97
	R2	3.5	0.12	3.4	96
	R3	3.0	0.58	2.4	80
	R4	3.2	0.74	2.4	77
	R5	3.0	0.44	2.0	67
	R6	*	*	1.9	*
	R7	*	*	*	*
	R8	*	*	*	*
	R9	*	*	*	*
	R10	3.5	0.74	2.7	78
	R11	1.9	0.32	1.6	83
	R12	3.2	0.97	2.2	70
	R13	2.4	0.59	1.8	75
	R14	2.6	0.71	1.9	72
	R15	2.8	0.28	0.2	6
	Ave.	**2.92**	**0.51**	**2.12**	**72.8**
WLO	Ave.	**2.9**	**0.65**	**2.03**	**70.0**
LAR	A1	3.0	1.05	1.8	59
	A2	4.5	1.95	2.3	51
	A3	3.6	0.48	2.9	81
	A4	1.7	0.59	0.4	22
	A5	2.0	0.88	0.9	47
	A6	3.7	1.72	1.4	40
	A7	3.4	0.49	2.5	72
	A8	3.6	1.27	1.4	38
	A9	3.9	0.5	3.4	87
	A10	3.4	0.89	2.7	77
	A11	3.2	0.28	3.0	92
	A12	3.4	0.91	2.5	73
	A13	3.9	1.04	2.8	72
LAR	Ave.	**3.33**	**0.93**	**2.15**	**62.4**

VITA

Susan Marie Majersky was born in Erie, Pennsylvania, on April 27, 1967, the seventh child of Kathryn and Joseph Majersky. She graduated from Villa Maria Academy for Girls in 1985, and from Mercyhurst College in 1991, magna cum laude. She worked during her last year of college as an intern at Erie Geological Contractors, Inc., an environmental consulting company in Waterford, Pennsylvania. Following completion of her bachelor's degree she was hired full-time by the company as a staff geologist. In August 1991 she left her job to accept a Board of Regents' Fellowship at Louisiana State University in the Department of Oceanography and Coastal Sciences. Unable to secure research funding, she transferred to the master's program in 1995. She married Ken FitzGerald in September, 1997. Following completion of the master's degree requirements, she and her husband will be relocating to Seattle, Washington.

MASTER'S EXAMINATION AND THESIS REPORT

Candidate: Susan Majersky FitzGerald

Major Field: Oceanography and Coastal Sciences

Title of Thesis: Sand Body Geometry of the Wax Lake Outlet Delta Atchafalaya Bay, Louisiana

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

3/10/98