Deltaic Sedimentation in Eastern Atchafalaya Bay, Louisiana.

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DELTACIC SEDIMENTATION IN EASTERN ATCHAFALAYA BAY, LOUISIANA

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A DISSERTATION

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The Department of Marine Sciences

by

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ABSTRACT

A new Mississippi delta—now in the subaerial growth phase—is building in Atchafalaya Bay, south-central Louisiana, as the result of a natural upstream diversion. Early studies of this event documented gross accretion in Atchafalaya Bay. The present study focuses on subaerial delta lobe responses, stratigraphic development, and sedimentation processes that are incorporated into a model for delta growth.

A sedimentological research program undertaken in the eastern half of the Atchafalaya delta has shown that two distinct stages of subaerial delta response are recognizable. The first (younger) response consists of channel extension, bifurcation, and development of sinuous overbank channels. A latter, more mature response of upstream lobe growth and consolidation becomes dominant once progradation through bifurcation ceases.

Stratigraphic relationships as interpreted from vibracores show that deltaic sedimentation in Atchafalaya Bay began in the early 1950s. By the early 1960s upper prodelta sediments covered large portions of the bay. The next decade was characterized by coarser grained distal bar development, resulting from an increase in the grain size of suspended sediments transported by the Atchafalaya River. By 1972 distributary-mouth bars were present at the heads of major bifurcations. The major floods of the early 1970s beginning in 1973 resulted in rapid subaerial growth as natural levees were formed. From this period through the early 1980s subaerial delta growth continued, although modulated by erosive storm effects.
The model for growth of the eastern Atchafalaya delta incorporates both the plan view and stratigraphic development. Details of the model include a discussion of channel bifurcation patterns, which are principally related to the orientation of the channel as compared with that of flood tide currents. In addition, the selective partitioning and deposition of the sediment load is shown to be an important factor in determining grain size distributions of each sedimentary environment.

The model of delta growth should prove useful in understanding other "bay head" deltas that commonly form in protected environments.
INTRODUCTION

The development of two deltas in Atchafalaya Bay, Louisiana (Fig. 1), the result of an upstream diversion of the Mississippi River (Fisk 1952), has created an exciting problem for geologists. For the first time in recorded history, a major shift in the locus of Mississippi River deposition is underway, thus providing a unique opportunity to study the evolution of a new Mississippi delta. In its present stage of development, the Atchafalaya setting is similar to many "bay head" deltas, comparable with those that are building into bays behind barrier islands along the Texas coast. Like back barrier lagoons, Atchafalaya Bay is shallow (less than 2 m), with a barrier forming the seaward margin. In this case, the barrier between the bay and open marine shelf is a submerged oyster reef complex. A detailed study of the Atchafalaya delta could well answer many of the questions posed from studies of other Mississippi subdeltas and the Texas deltas, questions such as: How is delta growth initiated? What processes are active in prograding and shaping the delta? How is delta abandonment initiated? Study from the very beginning of deposition (1950s to 1980s), very good stratigraphic control, and current knowledge of the processes of deposition make it possible to link processes and responses more efficiently in this delta than in the other delta locations mentioned.

A research program in the eastern Atchafalaya delta was initiated in 1977 by the Center for Wetland Resources, Louisiana State University. This area was chosen for study because it is an integral part of the delta, having formed bayward of the major

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Figure 1. Location of the Atchafalaya delta, Louisiana.
east fork, East Pass (Fig. 2), and is the area least modified by man's activities. Initial research concentrated on changes in delta lobe and channel morphology (van Heerden 1980, van Heerden and Roberts 1980a, b).

The present study is a detailed sedimentological investigation in the eastern delta designed to complement the earlier morphological studies. Major objectives were to:

1. Determine morphological changes in the delta during its subaerial evolution.
2. Assess the relative roles of individual deltaic processes.
3. Document stratigraphy of the eastern delta.
4. Formulate a model for the temporal evolution of the eastern Atchafalaya delta.

In order to fulfill these objectives, several research methods were employed. These study methods will be discussed in the main text in the order that they are now mentioned. Since 1973, when the subaerial phase of the delta began, growth patterns and plan view morphology have been examined through the use of aerial photographs and LANDSAT imagery. Channel cross sections were monitored from May 1977 to March 1982 to aid in morphological interpretations. A coring program, combined with historical and more recent bathymetric data, as well as published reports on subsidence, was used to construct the stratigraphy of the delta. In this way, detailed knowledge of delta morphology and development could be inferred for the historical development of the delta up to the subaerial phase in 1973. A combination of
Figure 2. Photo mosaic of Atchafalaya delta, 21 October 1976. Water Level M.S.L. - 0.22 m.
concepts and information, interpreted from the data collection, led to the creation of a four-stage model for the temporal evolution of this delta.
Deltaic sedimentation

The Atchafalaya delta can be classified as a highly constructive delta (Fisher et al. 1969), a type 1 delta (Coleman and Wright 1975), or as a fluvially dominated delta (Galloway 1975). Receiving basin conditions include low wave energy, low tidal range, and littoral drift. The offshore slope is low and the sediment load is fine grained. Deltas with a similar classification include the various modern Mississippi subdeltas and the back barrier lagoon deltas of the Texas coast.

1. Mississippi subdeltas

The Atchafalaya delta is inherently different from the modern Mississippi-Balize delta, which has resulted from sediment deposition directly on the continental shelf, because of a confined, shallow receiving basin. The essentially fresh Atchafalaya Bay waters are mixed and unstratified (U.S. Fish and Wildlife Service 1976). In contrast, the modern birdfoot distributaries are discharging their sediments in stratified waters, resulting in buoyant spreading of sediment-laden freshwater plumes over saline Gulf water, an important sediment dispersal process (Wright and Coleman 1974). However, subdeltas of the Mississippi delta built or are building into shallow bays where waters are generally mixed and unstratified.

Four Mississippi River subdeltas have been active since the first accurate survey of the Mississippi River delta in 1838 (Coleman and Gagliano 1964). Subdeltas typically carry between 3% and 13% of the discharge that reaches the lower Mississippi delta.
Each subdelta forms initially from a break in the natural levee formed by the major distributary during flood stage, gradually increases in flow through successive floods, reaches a peak of maximum deposition, wanes, and becomes inactive (Coleman 1976). Details of individual subdelta development can be traced through comparative map studies. Wells et al. (1982) recently summarized these data. Other than subaerial mapping, the Cubits Gap and West Bay subdeltas have been the most thoroughly studied.

Welder (1959) produced one of the most often cited reports concerning Mississippi delta growth. He mapped the growth of the Cubits Gap subdelta and suggested mechanisms responsible for delta progradation, channel extension, bifurcation, and rejoining. Unfortunately, he did not observe these processes in action, but documented the active processes of channel sealing and abandonment, features consistent with the subdelta's deterioration phase, which started in 1946 (Wells et al. 1982).

Coleman (1976) illustrated the development (1839-1961) of the West Bay subdelta using historical maps. In addition, he reported on the subsurface characteristics of the West Bay subdelta bay fill. These stratigraphic lithofacies data record the history of seaward progradation and abandonment of three complete cycles of deposition in the West Bay subdelta area. However, he did not present much process data, principally because his studies were undertaken during the abandonment phase of the delta cycle.

Coleman and Gagliano (1965) and Coleman et al. (1964) recognized that, in actively prograding deltas, the delta's front is the focus of most active deposition. They concluded that this
region can be differentiated into the following environments: distributary channels, subaqueous levee, distributary-mouth bar and distal bar. Each of these environments is dominated by a different sedimentation process; thus, the spectrum of sedimentary structures in each of these sedimentation units is distinct. Data from the present study agree with these interpretations although, in the Atchafalaya delta, additional subenvironments were recognized within major environments.

Most of the studies of Mississippi subdeltas were undertaken during the abandonment phase. Nevertheless, Coleman et al. (1969) concluded that Mississippi subdeltas could be used as natural models of delta sedimentation.

2. Texas Deltas

As mentioned earlier, the Atchafalaya setting is similar to those of the Trinity, Colorado, and Guadalupe deltas of east Texas. The sediment load of these deltas, which varies from $8.8 \times 10^5$ to $11.6 \times 10^6$ metric tons/yr, is one to two orders of magnitude less than that of the Atchafalaya delta (Wells et al. 1982). As with Mississippi subdeltas, the details of each delta’s growth have been traced through comparative map studies. The Guadalupe and Colorado deltas have been subjected to the greatest sedimentological study. The principal work on the Guadalupe was that of Donaldson et al. (1970), and Kanes (1970) studied the Colorado delta. These studies were comparable since, in each case, numerous closely spaced borings made possible an accurate delineation of the deltaic facies. In addition, each of the
authors describes in detail the lithologic and biologic properties of each depositional environment.

Donaldson et al. (1970) conclude that the Guadalupe delta can be considered as a distinct model because the delta is fluvially dominated; waves rework bay sediments; distributary channels are deeper than the immediate bay floor; the bay becomes progressively shallower as the delta progrades; tectonic subsidence is less than that in the Mississippi delta; and delta growth is through the development of successive subdeltas. Many of these characteristics are shared by the Atchafalaya; however, subsidence is greater and the bay less protected than the back barrier lagoon into which the Guadalupe is building.

The Colorado delta, according to Kanes (1970), may also serve as a model for those deltas forming under protected conditions. Unlike the Guadalupe, which is growing through successive subdeltas, the Colorado delta has evolved through two distinct phases. Initially, a sheet sand formed at the front of the delta through the coalescence of distributary-mouth bars. A second phase of delta construction is suggested by progradation that tended to encircle the eastern half of the initial lobe. Such phases have not been recognized in the eastern Atchafalaya delta, although distributary-mouth bars, at the seaward ends of distributary channels, are presently starting to fuse.

Unfortunately, as this literature review reveals, no Mississippi subdelta or Texas delta has been subject to an intensive process-response sedimentary study incorporating all of the following data bases: bathymetric and plan view development,
delta lobe and channel morphology, stratigraphy, sedimentary facies relationships, grain size distribution (lateral and vertical), and sedimentation processes. In addition, all the deltaic bodies mentioned were studied just prior to, or during, the deterioration phase. The present study was designed to investigate the evolution of the Atchafalaya delta since its inception and includes all the data sources listed as necessary for a process-response study.

Atchafalaya delta

1. Initiation of sedimentation

The modern Balize delta lobe has been the locus of Mississippi River deposition for the past 600-800 years and has produced a sequence of sediments 150 m thick, which have prograded onto the continental shelf (Coleman 1976). Because of this extensive progradation, the course of the modern Mississippi River has undergone a reduction in gradient and general flow efficiency to the point that a new major channel, the Atchafalaya River, is now favored. The course of the Atchafalaya River to the sea is 307 km shorter than that of the modern Mississippi and, therefore, it possesses a steeper gradient (Shlemon 1972).

Fisk (1952) pointed out that the Atchafalaya River was a definite distributary of the Mississippi River by 1542, but discharges were small and sporadic until 1839 (Morgan et al. 1953). At this time, major log jams in the Atchafalaya were cleared and the Atchafalaya River started to capture more of the Mississippi's flow. After 1839, Atchafalaya River discharges were aided by dredging, and by 1900 the Atchafalaya carried 13% of the...
Mississippi's flow (Morgan et al. 1953). Although discharges continued to increase, so that by 1952 almost 30% of the Mississippi's flow was diverted to the Atchafalaya, only minor amounts of sediment were reaching the bay (Shlemon 1972). Between the early 1500s and mid-1900s, most of the sediment carried by the Atchafalaya was deposited in the Atchafalaya basin (Roberts et al. 1980).

Although only minor amounts of fluvial sediments were reaching Atchafalaya Bay, bottom configuration changed very little between 1858 and 1952 (Shlemon 1975). Because water depth was maintained during continual subsidence, it is obvious that sedimentation was occurring in the bay. Morgan and Larimore (1957) show that shoreline erosion rates were high before delta formation. Bay bottom sediments were therefore primarily derived from eroded shore material.

2. Subaqueous delta growth

By the early 1950s the Atchafalaya River basin was approaching a sediment-filled state and, as a result, prodelta clays began accumulating in Atchafalaya Bay. Morgan et al. (1953) and Shlemon (1975) suggest that the present phase of deltaic sedimentation in Atchafalaya Bay was initiated in 1952. In 1963 the increased capture of Mississippi waters by the Atchafalaya River was terminated by the construction of a control structure at the point of diversion. Since then, discharge has been held to 30% of the combined Mississippi River and Red River 1950 flow regime (Roberts et al. 1980).
Thirty-four years of hydrographic data collected on Atchafalaya River flow at Simmesport, Louisiana, have shown that the average annual discharge over the sample period (1938-1972) was 5,126 m$^3$/s (U. S. Army Corps of Engineers 1974). Within this period, it was also determined that the average annual peak discharge that occurred during the spring months was approximately 12,100 m$^3$/s (Fig. 3). About 70% of this discharge arrived at the coast through the lower Atchafalaya River outlet, while the remainder was transported through the manmade Wax Lake Outlet (Fig. 1). Van Heerden et al. (in press) showed that an average of 27% of lower Atchafalaya River discharge entered East Pass (Fig. 2) from May 1979 to May 1981. Thus, approximately 6.0% of the total Mississippi River discharge was passing through the eastern Atchafalaya delta.

Since deltaic sedimentation began, the grain size of transported sediments has changed. Since 1960, sediment reaching Atchafalaya Bay has changed from a dominance of silt and clay to silt and fine sand (Roberts et al. 1980). Between 1965 and 1972, the average annual flood discharge was 7,500 m$^3$/s, which carried an average annual sediment load of 42.6 x 10$^6$ metric tons (Roberts et al. 1980).

Deposition of large portions of this sediment load (Wells et al. 1982) in the bay led to rapid expansion of the subaqueous delta. Sedimentation in the bay between 1952 and 1972 has led to the recognition of a number of distinct subaqueous depositional facies. Bathymetric surveys and shallow cores in the bay (Shlemon 1972, Cratsley 1975, and Roberts et al. 1980) revealed that by
Figure 3. Mean monthly discharge for the Atchafalaya River at Simmesport, Louisiana for 1956-1981. The dotted line represents average annual peak flow.
1960 upper prodelta deposits covered most of the bay floor in the vicinity of the lower Atchafalaya River mouth (Fig. 4a). Coarser distal bar sediments were present on the flanks of major subaqueous channels. By 1967 distributary-mouth bars were present but localized on channel flanks and at subaqueous channel bifurcations (Fig. 4b). By this time, upper prodelta sediments had spread throughout the bay and the distal bar material covered three times its 1960 area. Subaqueous progradation continued through the late 1960s and into the 1970s (Fig. 4c). By the late 1970s, distal and distributary-mouth-bar sediments had spread to cover most of Atchafalaya Bay (Fig. 4d) (Roberts et al. 1980).

3. **Subaerial delta growth**

Under the impetus of continued deposition, portions of the subaqueous delta eventually evolved into subaerial features. Although the subaerial phase was initiated during the 1973 flood, subaqueous delta growth continues. During the major flood in 1973, an abnormally increased quantity of sediment was transported to Atchafalaya Bay, resulting in a number of well-developed subaerial lobes.

In the 1973 flood, average annual peak discharge was exceeded for six months. Major floods were repeated during the following two years, 1974 and 1975 (Fig. 3). During these years of high water, the average annual sediment load was nearly double (88.9 x 10^6 metric tons) that of the years in which there was no subaerial growth. Abnormal sediment transport to Atchafalaya Bay reflected both scour in the lower reaches of the Atchafalaya River system.
Figure 4. Evolution of deltaic sedimentary environments in Atchafalaya Bay between 1960 and 1978 (from van Heerden et al. 1981).
and above-average sediment supply from the Mississippi River (Roberts et al. 1980).

Although subaerial expression has increased since 1973 (Fig. 5a), the growth of total subaerial land has been episodic (Fig. 5b) (Rouse et al. 1978, van Heerden 1980, and Wells et al. 1982). The subaerial expression of new land increased steadily during the major flood years from 1973 to 1976, but during 1977 and 1978 there was a reduction in surface expression. This reduction reflects the balance between accretional and erosional processes acting in the bay. Deposition during these years, in which floods were of average size (Fig. 3), did not exceed erosion induced by winds and waves during the passage of cold fronts in the winter months (van Heerden 1980). Whereas winter land loss may not be completely replenished by minor floods, the land surface aggrades significantly during major floods, thus off-setting land loss that results from cold-front related erosion. A large increase in subaerial expression occurred during the 1979 flood. By the end of 1981, a reduction of subaerial land was already evident because of winter erosional effects (Fig. 5b).

4. Distributary channels

Van Heerden (1980) recognized a hierarchy of three channel sizes in the Atchafalaya delta. Primary channels, the highest order, are wider than 900 m and approximately 3 m deep at their upstream ends. Secondary channels are formed upon bifurcation of a primary channel and are less than 300 m wide and generally about 2 m deep. Tertiary channels are the lowest order of distributary channels thus far developed in the eastern
Figure 5a. Extent of subaerial exposure obtained from LANDSAT images and aerial photographs depicting progressive evolution of the Atchafalaya delta.

5b. Subaerial growth curve for Atchafalaya delta (modified from Wells et al. 1982).
Atchafalaya delta. Van Heerden (1980) suggests that tertiary channels result from the bifurcation of secondary channels which leads to the formation of two channels, one much smaller than the other. All distributary channels in the eastern delta shoal in a downstream direction.

Distributary channels are responsible for transporting and distributing sediments supplied to the delta by the lower Atchafalaya River. Suspended sediment measurements made in distributary channels reflect the amount of sediment each carries and the relative importance of each hierarchial size. Van Heerden et al. (in press) showed that suspended sediment loads in tertiary channels were approximately 10% of those of their parent secondary channels, irrespective of discharge rate. Secondly, suspended loads in both channels during the spring flood discharge in 1980 were about 10 times the loads present in the same channels during low discharge periods of the same year.

This literature review reveals that a detailed sedimentological study of the Atchafalaya delta could greatly add to our understanding of deltas building into protected bays ("bay head" deltas). In addition, past studies have created a solid foundation on which to base the present study.
METHODS

**Delta lobe responses**

LANDSAT (Band 7) images and aerial photographs acquired from the U.S. Corps of Engineers, New Orleans District (Appendix A), were examined to determine subaerial growth patterns of the eastern Atchafalaya delta. Band 7 imagery was used because of the sharp contrast between land and water in this spectral region (0.8 to 1.1 microns). Cloud-free images were enlarged through photographic processing to a scale of approximately 1:80,000. Original aerial photographs obtained from the Corps of Engineers were at a scale of 1:10,000. Areas of subaerial lobes were mapped for 1973, 1976, and 1982.

In order to determine the third dimension of delta morphology, channel profiles were sequentially monitored at 20 locations in the delta (Fig. 6). These data were then combined with the subaerial mapping to determine lobe and channel responses to major physical forcing processes such as floods and storms.

**Stratigraphy and grain size**

Two hundred-fifty bottom samples were collected between June and September 1980 in a grid pattern with roughly equidistant spacing. Grain size was determined by sieve and hydrometer analysis following the standard techniques of Folk (1968). A grain-size map was compiled and compared with an earlier one created by Cratsley (1975) in order to help determine facies migration in Atchafalaya Bay.

Detailed stratigraphic information about the study area was derived from sediment cores (Fig. 7). Thirty vibracores up to 7 m
Figure 6. Names of subaerial lobes and channels of the eastern Atchafalaya delta and locations of channel cross sections and cores used in grain-size study.
Figure 7. Location of short and long cores in Atchafalaya Bay.
in length were retrieved during field work between February 1981 and July 1982. Additional subsurface control was provided by 44 shallow hand held cores.

Vibracoring has proved to be a useful method of obtaining shallow undisturbed cores in unconsolidated sediment. Coring with a portable vibracorer was described by Lanesky et al. (1979) and by Moslow (1980). Similar methods were used in this study; a brief description of the procedure is presented here. The vibracoring technique utilizes a Dreyer concrete vibrator, the head of which is attached to an aluminum irrigation pipe 10 m long and 75 mm in diameter. The pipe is driven vertically into the sediment by vibrations. When the desired depth is achieved, the top of the pipe is sealed and extraction is accomplished with a tripod and winch. Shallow cores were obtained by sinking plastic tubing, 1 m in length and 60 mm in diameter, into the sediment. In order to ensure minimal disturbance, cores were dug out of the ground. Each core was split parallel to the inferred predominant direction of flow, logged, and then examined by X-ray radiography, using the techniques described by Roberts et al. (1976). All X-ray radiographs presented in this paper are duplications of the radiograph negative. Dense material allows less X-ray penetration and results in lighter tones in X-ray radiographs. For this reason, dense sandy material is light grey in color and organic-rich layers are dark.

Primary sedimentary structures are easily recognized in radiographs. Combinations of primary structures in any particular environment are a signature of the sedimentary processes.
responsible for their development. The vertical and lateral variability of sedimentary structures in a sequence provide clues to understanding depositional history and the relative importance of forcing mechanisms, such as sedimentation rate and current shear.

Three of the long cores, each situated in or close to a lobe that became a subaerial feature in 1973 (Fig. 6) and encompassing most of the environments of deposition, were subjected to determinations of grain size (using a sieve and Coulter Counter) and clay mineral composition (using X-ray diffraction). Of interest to the present study were median grain size, sorting coefficient (graphic standard deviation—Folk 1968), and clay mineral composition. Oriented crystal mounts were used in the diffraction process. Because montmorillonite, kaolinite, and illite have similar mass absorption rates and oriented mounts were used, the semiquantitative abundance of each mineral in a sample could be determined by measurement and comparison of peak areas on the X-ray diffractograms (Carroll 1970).
DELTA LOBE RESPONSES

Systematic monitoring of delta growth by the mapping of subaerial lobes revealed two entirely different responses in the study area.

Channel elongation and bifurcation

Subaqueous delta growth started in the early 1950s as a major bifurcation between East Pass and the navigation channel, in the area now known as the Poule d'Eaux Islands (Fig. 2) (Shlemon 1972). By 1972 East Pass was a well defined primary channel (Fig. 4c). The presence of distributary-mouth bars, which were exposed at mean low water (Fig. 8a), revealed that after the 1973 flood a number of broad secondary channels branched out from East Pass.

During the next three years, these secondary channels extended seaward and also underwent a series of major bifurcations that generally produced channels of unequal size. The larger channels formed in bifurcations were essentially straight continuations of parent channels, and are called secondary channels in the nomenclature. Other channels formed in the bifurcations were much smaller, branching at acute angles to the parent channels. Smaller channels did not undergo further bifurcations, and are henceforth referred to as tertiary channels. These classifications are refinements of the terminology originally introduced by van Heerden (1980). As secondary channels extended seaward, through bifurcation, they underwent a stepwise reduction in width (Fig. 8b).

Concurrent with secondary channel bifurcation was the establishment of a network of small channels on delta lobes.
Figure 8. Comparison of delta lobes and channel patterns in 1973 and 1976. Secondary channels are named.
between secondary channels (Fig. 8b). So that these small channels will not be confused with teritary channels, they will be called "overbank channels". Overbank channels originated as breaks in the subaqueous levees bounding secondary channels, and were responsible for delivering sediment to the interior of delta lobes (Fig. 9b). Although these channels were short-lived they played an important role in building lobe interiors (back bar algal flats) during the high discharges of 1973, 1974, and 1975.

Channel abandonment and lobe fusion.

Aerial photography and LANDSAT interpretation did not reveal the seaward extension or bifurcation of secondary channels between 1977 and 1982 (Fig. 9). Neither was there any extension of the overbank channel network, even though a major flood occurred in 1979. Delta growth occurred through the fusing of lobes by channel abandonment and by subaqueous upstream accretion of lobes.

Tertiary channels, because of their size, do not offer efficient pathways for sediment transport. These channels shoal downstream, as width and levee height decrease, forming excellent sediment traps. Channel cross-section data reveal that between 1977 and 1982 tertiary channels became steadily narrower. The rate of reduction increased slightly because of the 1979 flood (Fig. 10). It is probable that tertiary channel narrowing eventually reaches a point at which discharges are so small that the channel mouth starts to close because of subaqueous levee construction associated with the parent channel (Fig. 11). Sealed channels slowly fill with extremely fine sediment introduced from the downstream end by tidal pumping and from levee overtopping.

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Figure 9  Comparison of delta lobes in 1976 and 1982. Note the upstream migration of lobes during this period.
Figure 10. Profiles of channel cross section 1, a tertiary channel. See Figure 9 for location.
Figure 11. Oblique aerial photograph at low water of subaqueous levee sealing a former tertiary channel.
during floods. The overall effect is the fusion of adjacent lobes, creating larger lobes.

Overbank channels present after the 1976 flood suffered the same fate as tertiary channels. That is, they became filled with sediment which in turn contributed to subaerial delta growth.

Since 1977, upstream subaqueous growth of lobes has occurred at all locations in East Pass (Fig. 9). Successive analyses of channel cross sections over the period 1977-1981 show that, once initiated, upstream accretion can be a rapid phenomenon (Fig. 12). At channel cross-section 2, between May 1977 and May 1979, the midchannel bar (Fig. 9) accreted and the smaller western channel sealed. Unfortunately, a shell dredger was active in this area in the latter half of 1979; otherwise, the cross sectional area in March 1982 would have been smaller. Nevertheless, accretion continued in the center of the channel where the effects of shell dredging were minimal (Fig. 12).

During the period from 1977 to 1982 secondary channels narrowed through the aggradation of channel flanks. However, these channels maintained their depth or deepened slightly (Fig. 13).

In the eastern Atchafalaya delta, two distinct delta lobe responses are discernible. The first (younger) response consists of channel extension and bifurcation, and the development of a sinuous overbank channel system. The latter, more mature, response of upstream lobe growth and consolidation becomes dominant once delta progradation through bifurcation reaches its peak.
Figure 12. Profiles of channel cross section 2, a former primary channel. See Figure 9 for location.
Figure 13. Profiles of channel cross section 3, a secondary channel. See Figure 9 for location.
STRATIGRAPHIC RELATIONSHIPS

In the previous section, the subaerial growth patterns of the eastern Atchafalaya delta were determined. Repeated surveys of cross-channel profiles revealed aspects of the morphology of delta lobes during subaerial growth. In order to develop a set of concepts dealing with delta growth and sedimentation, the third dimension and stratigraphic relationships of the delta were determined. This approach was achieved through a coring program.

Locations of vibracores used to build stratigraphic sections are shown in Fig. 14. Description and discussion of environments of deposition as interpreted from the cores appear in Appendix B. Published reports on subsidence, combined with excellent historical and more recent bathymetric surveys, permitted the establishment of date lines in stratigraphic sections (Appendix C). In addition, accurate ground control through an extensive survey benchmark system facilitated the exact determination of locations and heights of cores (Appendix C). The following discussion is based on data interpreted from all core lines (Figs. 15 through 19).

Initiation of delta growth

The lowest stratigraphic unit pierced by the cores (Fig. 15) was old bay bottom sediment (Fig. Bla). These sediments, derived from shoreline erosion, were apparently deposited at a rate that balanced subsidence. Old charts (i.e., 1859) of Atchafalaya Bay showed that the bay floor sloped to the south, away from the shoreline. Depths ranged from 1.2 m near the shore to 3.3 m at the shell reef. Conceivably, rapid bay water setdown and wave
Figure 14. Lines of deep vibracores in the eastern Atchafalaya delta. These lines of cores are used in sedimentary facies relationship determinations shown in Fig. 15 through 19.
Figure 15. Core line 1. See Figure 14 for location.
action associated with winter cold air outbreaks (Appendix E) could have been responsible for moving sediment from shallow near-shore locations to deeper parts of the bay. Sedimentological evidence of this process (Nelson 1982) was the graded bedding (Fig. Bla) sometimes discernible in the bioturbated old bay bottom sediments.

Faunal remains in the blue-grey old bay bottom clays indicate a marine-to-brackish water environment (Appendix B). Brown-grey lower prodelta clays, which overlie the old bay bottom sediments, contain freshwater fauna, specifically ostracods (Appendix B). Lower prodelta sediments, which are coarser grained than the old bay bottom material, also display structures coincident with a low sedimentation rate and high biological activity. These changes in fauna, color, and lithology suggest that fresh water input into the bay started to increase with the onset of lower prodelta sedimentation.

Using subsidence rates interpreted from Hicks (1972) and Frazier (1967) (Appendix C) and water depths as known in 1858, a date of approximately 1839 was assigned to this facies change. In 1839 major log jams were cleared in the Atchafalaya River and discharges started to increase (Shlemon 1972). Although most of the sediment was being trapped in the Atchafalaya River basin, the increased amount of fresh water entering the bay in 1839 forced an environmental change.

Although the freshwater supply was increasing, evidence existed that brackish-water oyster reefs were present during the deposition of lower prodelta sediments. The presence beneath
Figure 16. Core line 2. See Figure 14 for location.
Rodney's Island (Fig. 18) of shell-dredged spoil, consisting of closely packed shell fragments, revealed that an oyster reef occurred within the immediate vicinity during the early history of the eastern delta. In all other core lines (Figs. 15, 16, 17, and 19), two distinct shell layers were found in the lower prodelta material. These layers occurred throughout the study area (Figs. 15 and 19) and appeared to have been deposited in the middle to late 1800s. The shell layers are interpreted as lag deposits of oyster reef material, which were eroded and spread as a veneer over the bay during the passage of a hurricane. The complete lack of these deposits in the deeper locations of core lines suggests that Atchafalaya Bay was formerly a more protected environment.

It is important to note that lag layers are not of even thickness. In the vicinity of Natal Channel (Core 14, Fig. 17), layers are much thicker than under the lobes adjoining the channel (Core 13, Fig. 17), suggesting the presence of a former bathymetric low, possibly a tidal channel. If a tidal channel system was present, it could have influenced the location of future deltaic distributary channels.

By the early 1950s, the bay, which originally deepened seaward, had attained a generally uniform depth (compare Figs. 16 and 19). Thompson (1951) suggested that normal wave action maintained an "equilibrium depth" in the bay of 2 m. Waves reworked and redistributed bottom sediments, material in suspension being flushed out of the bay by tidal currents. This mechanism, coupled with the seaward transport of sediment during
Figure 17. Core line 3. See Figure 14 for location.
rapid bay water-level set down after a frontal passage (Appendix E), appears to have been responsible for the bay attaining an even depth by the early 1950s.

**Subaqueous delta growth**

In the early 1950s sediment started to pass through the Atchafalaya River basin and enter Atchafalaya Bay. The first significant sedimentation, which initiated the subaqueous growth phase of the Atchafalaya delta, was the appearance of upper prodelta deposits (Fig. 16). Upper prodelta material commonly consists of parallel-laminated clays in contrast to the highly bioturbated lower prodelta clays. This structural change in the fine-grained sediments reflects the dramatic increase in fluvial sediment supply that occurred in the early 1950s (Fig. B2).

Shlemon (1972) presented bathymetric evidence that subaqueous delta growth and channel formation started as a major bifurcation between East Pass and the navigation channel. Stratigraphic evidence supported this observation in that more coarsely grained distal-bar sediments were being laid down in the midchannel area (Core 3, Fig. 15) at the same time that finer-grained upper prodelta deposition was occurring farther to the east (Core 1, Fig. 15).

Concurrent with the formation of the major midchannel bar was the establishment of a subaqueous distributary channel system. Evidence for the age of these channels was interpreted from the core data. On the west side of Core Line 2 (Fig. 16), the 1952 surface described a slight depression associated with the formation of a "proto" East Pass. Apparently, the proto channel
Figure 18. Core line 4. See Figure 14 for location.
had been active since the initiation of delta growth as upper prodelta sediments were being deposited on the channel flanks. Further evidence for the age of distributary channels was the lack of upper prodelta sediments at the location of the core in Natal Channel (Fig. 16), which suggested that this channel had functioned as such since the early 1950s, or the channel scoured out prodelta sediments as it was formed. This last contention was considered the least likely, for two reasons. Firstly, evidence was presented earlier that Natal Channel may have occupied the site of a former tidal channel (Fig. 17), and secondly, high flow velocities would not have occurred in the subaqueous proto channel because of the lack of confinement of discharge. Thus, scour of the very cohesive fine-grained upper prodelta sediments, if they occurred at the location of the channel, would not have been very likely.

Further evidence of the age of the subaqueous channel system was obtained from the core in East Pass (Core 11, Fig. 16). By June 1982, East Pass contained almost 1 m of silty-channel fill. From its base the channel fill consisted of 18 layers of thin silty clays (many containing starved ripples), which grade into clays; a major 10-cm silt unit topped by three layers of clay-rich parallel-laminated silts, which each graded into thin clays. As interpreted from previous work (van Heerden 1980), the thick silt layer was deposited during the 1979 flood. Material above the silt equated to one layer per year up to and including the 1982 flood. If each silt and clay layer beneath 1979 material was deposited in one year, then channel fill started in 1961.
Figure 19. Core line 5. See Figure 14 for location.
Although upper prodelta sedimentation began in 1952, close to East Pass, it was a few years before these sediments appeared at more seaward locations of the core lines (Fig. 16 and 18). This condition reflected the normal regressive sedimentation associated with deltaic progradation.

Roberts et al. (1980) stated that sediment reaching Atchafalaya Bay changed after 1960 from a dominance of silt and clay to silt and fine sand. Stratigraphic relationships established by coring showed that the shift in depositional environment from prodelta to distal bar (Figs. 16, 18, 19), and the coincident change in median grain size from clays and silts to silts and fine sands (Fig. B10), was initiated in the early 1960s.

Inhomogeneities in both grain size and shell content occurred in both the prodelta and distal bar deposits in the form of laterally continuous major storm deposits. Storm evidence consisted of erosional surfaces overlain by either a thick graded silt, or overturned bedding (Fig. B3b). The presence of these layers is attributed to hurricanes in the period from the late 1950s to late 1960s (Appendix E).

As subaqueous delta growth continued, distal bar material was overlaid by distributary-mouth bars (Figs. 16 and 18). Stratigraphic relationships showed that this change in the depositional environment occurred in the early 1970s. Distributary-mouth bars consisted of repeated upward-fining cycles of parallel- and cross-laminated silts and fine sands that passed into parallel-laminated clays (Fig. B4). Cycles varied between 3 and 9 cm in thickness. These structures were in contrast to the
parallel-laminated distal bar sediments (Fig. B3). In addition, during the phase of subaqueous growth, distributary-mouth bars were restricted in their area of occurrence, being present most commonly at the sites of channel bifurcations. It is interesting to note that since distributary-mouth-bar deposition began concurrent distal-bar deposits have become more fine-grained (Figs. 16 and 18).

These facies—upper prodelta, distal bar, and distributary-mouth bar—aggraded the bay bottom over a period of 20 years (1952-1972) and prepared the setting for the progradation of coarser facies that became subaerial. Pinching and swelling of these facies as determined from correlations between cores, show that the trends of the distributary channel system were established early in delta growth.

Subaerial delta growth

Transport of large quantities of coarse sediment to Atchafalaya Bay was enhanced during the period between 1973 and 1976 by abnormally high discharges in the Mississippi (Fig. 3). The input of large amounts of coarse sediments during the 1973 flood was responsible for a major lithologic change in nearly every core as subaqueous levees were formed (Fig. B4). By the end of the 1973 flood, many of these features had evolved into subaerial forms (Figs. 8a and 16).

Deposition of large amounts of coarse material was so rapid in the 1973-1976 period that, in the seaward portion of the eastern delta, levees overlie distal bar deposits (Fig. 19). Few sedimentary units were found with the upward-fining,
parallel-laminated characteristics typical of distributary-mouth bars. Instead, parallel-laminated distal bars were overlaid by coarse, cross-laminated levee deposits. This lack of distributary-mouth-bar deposits in seaward locations is an indication of the rapid progradation and subaerial growth under the impetus of these large floods (Fig. 8).

Generally, levee material deposited in the 1973 flood displayed structure associations formed under high sedimentation rates (greater than 0.3m/flood) (Fig. B6a). Levees formed in the lesser 1974 and 1975 floods displayed structure associations indicative of sedimentation rates between 0.15 and 0.5 m/flood (Fig. B6a and b). During the low-flow months following the 1973 flood, levees were covered with parallel-laminated silts and clays. The 1974 flood was initiated by scour of the upper portions of pre-existing material, followed by the deposition of cross-laminated silts and fine sands. This sequence of events was repeated in the 1975 flood. As a result, individual flood units could be recognized in cores (Appendix C). Because individual flood deposits could be traced laterally, the year of lobe emergence along each core line could be determined from core logging. Subaerial mapping of emergence (van Heerden 1980) was in agreement with the stratigraphic data generated from the core logs.

From 1973 to 1976, subaqueous growth continued as distributary-mouth-bar environments spread rapidly over the prodelta/distal bar platform. In more bayward locations, clay-rich distal bar material was laid down (Figs. 16 and 18).
addition, algal flats formed in the central and back bar parts of emerging lobes. Sediments from these depositional environments of low elevation directly overlie distributary-mouth-bar deposits and are surrounded by higher relief natural levees, except at their seaward ends where they are open to the bay. Sediments are introduced into these areas by overbank channels and levee overtopping during floods (Fig. B7), and through redistribution of levee material during winter storms (Fig. B8).

As noted earlier, deltaic processes underwent major changes following the 1976 flood since an important part of subaerial delta growth now involved upstream accretion of lobes. Channel cross-section data revealed this process (Fig. 12), in which most midchannel bar growth occurred after 1976 as the result of upstream accretion and aggradation of a delta lobe. Stratigraphic evidence of this process is displayed in Core Line 5 (Fig. 19), which incorporated the location of the channel cross section in East Pass (Fig. 14). Core data indicate that depositional history up to the late 1960s was identical to that of areas on the channel flanks (Fig. 19). However, after 1973, most bar growth occurred as the midchannel bar evolved through a distributary-month-bar phase into a subaqueous levee (Fig. 19). These data illustrate an important growth phenomenon of the eastern Atchafalaya delta. Deposits with the characteristics of distributary-mouth bars formed in upstream locations of the delta, and also formed middle ground deposits in channel bifurcations.

The coalescence of minor lobes into larger subaerial features caused by the abandonment and filling of small channels also
occurred in the later period of growth. Evidence for two former overbank channels occurred in the levee of the eastern half of Rodney's Island (Fig. 17). Since 1976 these features have been covered by levee deposits. Core 1 (Fig. 17) was located in the area of a former tertiary channel created in a bifurcation that was abandoned early in the life of the delta as revealed by 1.5 m of silty-channel fill (Fig. B5). Since December 1978, this area has been dominated by levee deposition and no surface expression of a channel is now evident.

Even though midchannel bars formed in downstream locations of East Pass, no evidence of channel fill existed at the head of East Pass (Fig. 15). The channel base had 3 cm of coarse channel lag material indicating that velocities at the head of the channel had been strong enough to inhibit suspended sediment deposition. Lower flow velocities, resulting from the spreading of East Pass discharge through a number of distributaries, were responsible for sediment accumulation in more seaward locations of the channel.

The 1973 flood saw the onset of subaerial delta growth with the appearance of natural levees. "Layer cake" stratigraphy was now no longer applicable. Back bar algal flats built up at the same time as levee formation during the 1973-1976 period. After 1976, subaqueous upstream accretion and coalescence of lobes were the dominant mechanism of subaerial delta growth.
SEDIMENTATION MODEL: DEVELOPMENT OF THE EASTERN
ATCHAFALAYA DELTA

In this chapter a temporal model for the evolution of the eastern Atchafalaya delta is developed. The model utilizes the plan view and the morphological and stratigraphic data presented in the previous chapters, and is divided into three sections. The first section discusses the overall plan view and stratigraphic development of the delta. The second section recognizes the dominant subaerial growth mechanisms and discusses these in detail. Lastly, the dynamics of sedimentation are inferred from the lateral and vertical distribution of sediments and sedimentary structures. In order to test the applicability of the model, comparisons are made with other "bay head" deltas.

Plan view and stratigraphy

From the initial capture of the Mississippi River flow up to the middle 1900s most of the sediment carried by the Atchafalaya River was deposited in the Atchafalaya basin. Stratigraphic relationships revealed that fluvially dominated sedimentation began in Atchafalaya Bay in the early 1950s, as upper prodelta deposits started to accumulate.

The upper prodelta facies is characteristically a blanket of clays deposited from suspension, having high lateral continuity and low lithologic variation, as opposed to lower prodelta sediments which are defined as highly bioturbated brown-grey clays. Subsurface core data (Figs. 17, 18, and 19) show that by 1962 upper prodelta sediments covered a large area of the Atchafalaya Bay and bifurcations close to the mouth of lower Atchafalaya River

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had been initiated resulting in broad subaqueous primary channels (Fig. 20a).

Deposition from 1963 to 1972 resulted in a continuous buildup of the subaqueous delta platform (Fig. 21a). Stratigraphically above the prodelta deposits occur sediments of the distal bar (see Figs. 16, 18, and 19). This depositional environment is the seaward sloping margin of the advancing delta sequence (Fig. 21a). Increase in sedimentation rates and coarseness of the sediments distinguish these deposits from the underlying prodelta clays.

By 1972 primary channels were more clearly defined and a secondary distributary channel network had formed through bifurcation processes. At this time, distributary-mouth-bar sediments were being deposited on prodelta/distal bar platforms between subaqueous secondary channels. Subaqueous levees that existed at the heads of subaqueous delta lobes were cut by sinuous overbank channels (Figs. 20b and 21b). The major floods of 1973 and the next two years heralded the subaerial phase of delta growth, forcing rapid subaerial development and seaward delta expansion.

Extensive development of the levees occurred under the impetus of these large floods (Figs. 20c and 21c). Unlike many other small deltas (Donaldson et al. 1970, Kanes 1970, and Coleman 1976), levee deposits in the Atchafalaya delta form the most significant stratigraphic unit, approximately 40% of the total sequence. Individual flood deposits can be recognized in levee material, each having its own suite of sedimentary structure associations that reflect deposition rate (Appendix B). High rate structure associations characterized by trough and climbing-ripple
Figure 20. Four stage plan view model for development of the eastern Atchafalaya delta.

Subaqueous Phase
  a) Prodelta/distal bar platform
  b) distributary-mouth bar and subaqueous levee

Subaerial Phase
  c) channel bifurcation and elongation
  d) lobe consolidation

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Figure 21. Stratigraphic relationships of section x-x of four-stage Atchafalaya development model (Fig. 20).
cross laminations (Fig. B6a) are most common in the 1973 flood deposits. Medium-rate associations dominate in the 1974 and 1975 flood deposits and simple cross laminations are the most common structures preserved (Fig. B6b). Low-rate, parallel laminations are most common in the 1976 flood material (Fig. B6c). If the years 1973 through 1975 had been marked by average floods, it is possible that levee deposits might not have been so thick. Instead, distributary-mouth-bar deposits, which can be distinguished by cyclic deposits of upward-fining material, might have been more substantial.

The major floods of 1973 and of the following two years resulted in rapid extension of the secondary channel network through a series of bifurcations (Fig. 8). Seaward extension of secondary channels terminated after the 1976 flood. If the floods of these years had been average in size, the bifurcation process would still have occurred, but channel elongation in the delta growth process would have continued well past 1976.

During the high discharges of the period 1973-1976, sedimentation was so rapid that a network of sinuous overbank distributary channels was established on lobes between secondary channels. These distributary channels, which cut through levee deposits, were no more than 1 m deep (Figs. 20c and 21c). Although overbank channels were short-lived, they were responsible for rapid deposition and accretion of delta lobe interiors. The surface expression of abandoned overbank channels led earlier workers (van Heerden 1980) to believe that overbank channels were formed during bifurcation processes. However, as is now known
from aerial photo mapping and coring, they formed concurrently with levee buildup, the trend of the major distributary channel system having been established during the subaqueous phase of delta growth.

Distinct changes in delta morphology and consequent sedimentary structures occur during periods of below-average discharges. Below-average discharges were most common during the period 1977-1982, although a major flood occurred in 1979 (Fig. 3). Low or negative subaerial growth rates (Fig. 5b) during low-flow years reflect both the minimal supply of sediments and the erosive mechanisms generated by winds associated with winter storms (Appendix E). Depositional responses to the 1979 flood were quite different from those of the early 1970s. A blanket of silts and clays was deposited on delta lobes without the formation of overbank channels. These sediments buried many former overbank delivery channels, so that their locations can only be inferred from earlier aerial photographs or from cores. No secondary channel bifurcations were produced in the period 1977 to 1982.

Although bifurcation and channel extension were not occurring, the delta continued to grow after 1976 by lobe fusion associated with tertiary channel abandonment, and upstream accretion and aggradation of lobes (Figs. 20d and 21d). Abandoned tertiary channels filled with fine sediments fusing adjacent lobes creating larger lobes (Fig. 20d). Between 1977 and 1982, subaqueous accretion and aggradation of lobes occurred at the upstream ends of all lobes in the primary channel, East Pass (Fig. 9 and 12). Initially, the deposits at the heads of secondary
channels consisted of parallel-laminated upward-fining cycles of silts and fine sands that graded into clays. Cycles were generally less than 9 cm thick. Such cycles are coincident with those described as being characteristic of distributary-mouth bars in Appendix B. Thereafter deposits at the heads of lobes aggraded into levees, which display cross laminations indicative of sedimentation rates of less than 0.3 m/flood. This rate corresponds with that interpreted from sequential channel profiles (Fig. 12).

Fundamental input data for the model indicate that within a period of 30 years (1952-1982), the eastern delta has evolved into a large subaerial feature. However, lobe coalescence in the period from 1977 to 1982 suggests that the eastern Atchafalaya delta has perhaps reached its peak in growth rate. Eventually, this delta will be abandoned as a subaqueous levee forms across the entrance to East Pass. A new delta cycle may, however, form in this area after the present surface has subsided to such a level that an open body of water is created.

**Subaerial growth patterns**

1. **Channel elongation and bifurcation**

   Subaerial growth in the Atchafalaya delta is related to elongation and bifurcation of the delivery channel network. Three basic channel patterns are discernible (Fig. 22). The first group, located on the eastern side of the eastern delta, has long axis orientations towards the southeast quadrant. Southeast Pass is the best example from this group. Channels in the eastern Atchafalaya delta that flow with orientations in the southwest
Figure 22. Groups of channel types in the Atchafalaya delta and the location of selected sediment samples.
quadrant make up the second group. The third group (Fig. 22) includes those channels on the western side of the delta, of which Log Channel is the best example.

a. Controlling processes

The configuration of bifurcations and the mechanisms of channel extension are determined by river mouth processes. The most important river mouth processes relate to: (1) the inertia of issuing river water and associated turbulent diffusion; (2) friction between the effluent and the bed immediately seaward of the mouth; and (3) buoyancy resulting from density contrasts between issuing and ambient fluids (Coleman 1976). In Atchafalaya Bay, inertial and frictional factors are important. Buoyant forces are not a factor, since the bay waters are essentially fresh.

Fluctuations in the inertia of the water passing from distributary mouths, related to tides and prevailing wind direction, strongly influence bifurcation configurations in the Atchafalaya delta. Studies of turbidity patterns using LANDSAT imagery and a mathematical model (Cunningham 1978) show that flood tide currents in Atchafalaya Bay are directed toward the east and southeast in the delta area, whereas ebb tide currents flow toward the west. These tidal current directions suggest that in the eastern delta, rising tide has the effect of increasing distributary channel discharge velocities while in the western delta, velocities are decreased. Falling tide would cause a decrease in discharge velocities in distributary channels of the eastern delta. Van
Heerden et al. (in press) documented these tidal constraints on outflow velocities in the eastern delta (Natal Channel) during both the spring and fall of 1980.

Prevailing winds also influence outflow inertia. During the spring months, winds are out of the south and southeast 53% of the time (Cunningham 1978). Such wind patterns tend to reduce discharge velocities in the eastern delta by blowing almost parallel into the long axis of most secondary channels (Fig. 2).

In addition to outflow inertia, friction between the outflow and bed immediately seaward of the mouth influences the form of any deposition. Water depths in Atchafalaya Bay seaward of distributary mouths are much shallower than in the distributary channels themselves. Thus, in this situation, it has been suggested that turbulent diffusion becomes restricted to the horizontal and bottom friction plays a major role in causing effluent deceleration and expansion (Coleman 1976).

Geomorphologic and sedimentological components of the Atchafalaya delta suggest that, during floods, the rapid expansion of effluent seaward of a confined distributary mouth, initially produces a broad, arcuate bar with the central portions of this bar shoaling most rapidly. This phenomenon appears to be related to the suspended sediment-carrying capacity of the stream during floods.

Maximum current velocity and, thus, maximum suspended load apparently occur in the central portion of the distributary channels during floods. As the sediment load passes from the deep, confined channel to the unconfined shallow bay, there is a
dramatic reduction in current velocities. Under these conditions, the deep central portions of the stream apparently can no longer support their original high suspended load and the coarser fraction is deposited. Most deposition thus occurs at the central part of the radial bar, forming a midchannel bar.

As deposition on the bar continues, natural subaqueous levees develop beneath the lateral boundaries of the expanding effluent where velocity gradients are apparently steepest (Coleman 1976). The development of levees tends to inhibit further increases in effluent expansion, so that with continuing bar accretion continuity can no longer be maintained simply by increasing effluent width. As the central portion of the bar grows upward, channelization develops along the threads of maximum turbulence; Coleman (1976) suggests that this dynamic zone follows the subaqueous levees. The overall effect of this differential sedimentation under the impetus of floods is a branching of the channel into two distributaries.

b. Group 1 channels

Group 1 channels (Fig. 22) created bifurcations of unequal size in the major floods of 1973 through 1975. The largest channel formed was an in-line continuation of the parent secondary channel and was also the most easterly or northerly of the newly created channels. This orientation was nearly in line with increased flood outflow energy, which apparently occurred during flood tide conditions (van Heerden et al. in press). Higher velocities during rising tide appear to have caused channel scour
as the new secondary channel extended seaward. In addition, the prevailing southerly winds would have forced the strongest flows to take a more northerly route.

Although current data were unavailable, dye experiments (van Heerden 1978) showed that discharge at points of bifurcation took a more westerly route during ebb tide conditions. In addition, outflow velocities were generally lower. Because of lower velocities during ebbing tide, bar scour was apparently less in the westerly oriented channel and a smaller, tertiary channel was created during flood discharges. Selective tidal discharge routes apparently explain why most tertiary channels formed in bifurcations of group 1 channels had a southerly or westerly orientation. This orientation was also more into the prevailing winds, further reducing discharge velocities. In this manner, group 1 secondary channels extended seaward but underwent a stepwise reduction in width at each bifurcation produced.

c. Group 2 channels

Group 2 distributary channels were confined between the deposits being formed by Southeast Pass and those being formed by channels branching east from the navigation channel (Fig. 22). For this reason the channels were not well defined and did not undergo extensive bifurcation. Lack of bifurcation might reflect the fact that maximum discharges during floods in this part of the delta occur under low velocity ebb tide conditions (van Heerden 1978).


d. Group 3 channels

Channel patterns in the western delta (Fig. 22) are distinctly different from those on the east side. Here, channels produced in bifurcations are more uniform in size, although a single more sinuous parent channel still dominates (see Log Channel, Fig. 22). These features can be explained by local tide conditions.

Unlike the eastern delta, maximum discharge velocities occur under ebb tide conditions, ebb current being oriented almost parallel to the outflow direction of the parent channel. For this reason, outflow inertia during floods in the newly created channels is almost equal and channels are initially similar in size (Fig. 22). However, field observations reveal that channels with orientations closest to the parent channel will eventually dominate.

Geomorphic and sedimentological data reveal that local tidal currents apparently have a strong influence on the channel patterns displayed in the Atchafalaya delta. However, rapid subaerial progradation and channel elongation occur only under the impetus of major floods.

2. Upstream lobe accretion, channel abandonment, and lobe fusion.

Upstream lobe accretion, channel abandonment, and lobe fusion resulted in increased subaerial expression of the eastern delta after progradation through bifurcation had ceased. These non-progradational processes were, however, not as important in terms of land growth as extension and bifurcation of the sediment delivery network.
From 1977 to the present, eastern delta growth has been dominated by upstream accretion and aggradation of lobes. It appears that the eastern Atchafalaya channel network had incorporated so many small distributaries that sediment transport efficiency dropped significantly. Supportive evidence for this contention is the lack of coarse suspended load in the secondary channel monitored for discharge and suspended load in the 1980 flood (van Heerden et al. in press). Mean grain size at this time was less than 9.0 microns. Apparently, the coarsest fraction of the sediment load was deposited at the heads of major bifurcations, rather than being transported through the system to open water locations. Channel cross section data showed that upstream accretion and aggradation were rapid.

Additional subaerial growth, after 1977, was initiated through channel abandonment. In the previous section it was shown that channel bifurcations in the eastern delta area usually create channels of unequal size. Smaller tertiary channels experience the lowest outflow velocities (van Heerden et al. in press) and reductions in cross sectional areas occur rapidly after initial channel formation (Fig. 10). Eventually, tertiary channels seal and are filled with fine sediments through levee overtopping and tidal pumping. The coalescence of smaller lobes is thus accomplished by channel abandonment.

The most important nonprogradational growth mechanism in the eastern Atchafalaya delta involves the upstream growth of lobes. A less significant increase in subaerial expression occurs through channel abandonment.
Sediment distribution

Distributary channels are conduits for transport of sediments that form the delta. Therefore, in order to complete the model, sediment-grain size and the primary sedimentary structures present in levees, distributary-mouth bars, channel fill, and distal bars will be discussed.

Coleman and Gagliano (1965) state that the coarsest deposits in the Mississippi delta are distributary-mouth bars. However, in the eastern Atchafalaya delta, grain size data revealed that the coarsest sediments were generally found in levees. Data from the levee forming the southern flank of Natal Channel (Fig. 22) are presented in Fig. 23a. However, grain size analyses show that all levees in the eastern delta are similar in character. Histograms of sediment distribution show that median grain size generally decreases seaward from upstream locations of levees.

Although grain size decreases seaward along any particular levee, the opposite is true in distributary channels. Histograms of sediment grain size in Natal Channel (Fig. 22) reveal that the amount of coarse silt increases from the head of the channel (Sample 4) to the distributary-mouth bar, at the seaward end (Sample 6) (Fig. 23b). Similar trends were observed in other eastern delta channels.

These grain-size relationships indicate that a marked differentiation (selective size deposition) of the sediment occurred prior to 1977, as flood waters passed through the delta. It is suggested that because of high turbulence during major floods, little sedimentation occurred in the channels at their
Figure 23. Grain size histograms for selected sediment samples. (For location see Fig. 22).
confined upstream ends. Instead, coarse fractions of the sediment load were deposited on the levees flanking the channel because of: (1) reductions in current velocity along the subaqueous flank of channels; and (2) levee overtopping by elevated flood waters. During major floods, sediments were continuously available to the levee environments as the water column surrounding the levees was never really impoverished in sediments during continuous levee overflow. Waters depleted in coarse sediments, moved into the back bar algal flat, where fine fractions of the load were deposited. Due to sediment loss through levee overtopping the entire water column became progressively depleted in coarse suspended sediment as it moved through the distributary channel network. The seaward decrease in grain size of levee deposits supports this observation.

Concurrent with a seaward decrease in levee grain size was an increase in the amount of coarse silt in channel fill material (Fig. 22b). This observation suggests that in addition to a seaward decrease in the size of transported sediments, discharge velocities also decreased. Flow velocity in a particular channel decreased downstream because of discharge lost to other distributary channels. As the velocity decreased seaward, so coarser fractions of the load could be deposited in the channel. Once the effluent left the confines of the distributary channel, it underwent a dramatic reduction in velocity. At this point, coarse fractions of the remaining load were rapidly deposited as distributary-mouth bars. However, the sediments were finer than those deposited on levees.
Distributary-mouth bars are made up of upward-fining cycles (less than 9 cm thick) that apparently reflect pulses in spring flood discharges. The maximum grain size of transported sediments in the Atchafalaya delta decreases as flood waters fall (van Heerden et al. in press). During peak flow, areas bayward of confined distributary channels are the sites of coarse sediment deposition because of frictional reduction in flow velocity. As flood levels fall, the grain size of available sediment decreases, and the net accumulation after a flood pulse is a single upward-fining cycle. Portions of the remaining fine-grained suspended load bypass the distributary-mouth-bar environment and are deposited as clay-rich distal bar deposits. Farther seaward, fractions of the residual suspended load settle out as prodelta deposits. In a distance of about 5 km, from the lowest Atchafalaya River mouth to open bay, almost total size segregation of the suspended load occurs in the eastern half of the Atchafalaya delta.

Coarseness of levee deposits suggest that these features are the most rapidly created, during major floods. Primary sedimentary structures reflect this phenomenon. Levees display a wide variety of structures, from climbing-ripple cross laminations to parallel laminations. Cross laminations display tangential-to-concave forest laminae, and cross bed sets are commonly festoon-shaped. Such features, combined with the marked difference in grain size between levees and back bar algal flats, (approximately 70 microns versus 30 microns), suggest that deposition on levees
is very rapid from predominantly suspended loads. Flow strengths vary from high to low, as do bed shear stress.

Although levees are principally formed during floods, infill of active channels is negligible at these times. Sequential cross section data for secondary channels reveal that most sedimentation in these channels occurs during low discharge periods, as fluid muds deposited on channel bottoms. These muds dewater rapidly, which dramatically increases their cohesive strength. By the onset of the next flood, channel muds may attain enough cohesive strength to resist erosion. In this way, active channels become filled with parallel-laminated fine-grained muds (median of 20 microns; Fig. B12).

The previous discussions related principally to major flood conditions; however, segregation of the sediment load was still important after 1977. Most of the coarse fraction was being deposited at the heads of bifurcations while portions of the fine material passing down distributary channels were incorporated in the clay-rich distal bars.

Evidence exists that segregation of the sediment load was not always the dominant mechanism controlling sediment distribution in the eastern Atchafalaya delta. Distal bar sediments deposited before 1970 (Core 8, Fig. 16) have a greater amount of coarser material (Sample 7) than that present in the clay-rich distal bars presently forming (Sample 8) (Fig. 23c). Upward decrease in grain size of distal bar sediments suggests that prior to the formation of bathymetric highs in the bay, blanket deposition of the suspended load occurred. However, once distributary-mouth bars and
levées had become established, segregation of the load became important and only fine-grained material was being deposited in distal bar locations.

Comparison with other Mississippi subdeltas

The Atchafalaya delta is evolving in such a way that the environments of deposition are similar to those described for subdeltas of the modern Mississippi River and other shallow water deltas. Presently, the mass and areal extent of the Atchafalaya delta are comparable with those of the Mississippi River's Baptiste Collette subdelta and somewhat smaller than the Cubits Gap subdelta. Eastern Atchafalaya delta carries approximately 6.0% of Mississippi River flow, as compared with the 3.9% and 13% carried by the Baptiste Collette subdelta and Cubits Gap subdelta, respectively (Wells et al. 1982).

Close scrutiny of Welder's (1959) Cubits Gap data reveals that patterns of early delta growth were similar to those of the Atchafalaya (Fig. 20). Between the time of the break in the Mississippi levee (1862) and about 1870, a platform of sediments developed in Bay Rondo (Welder 1959). Patterson (1875) remarked that, during this time, the distance from the deep, confined crevasse channel downstream to the widespread shoal was about 100 m (Fig. 24b). Welder (1959) stated that by 1870 several channels were cut through the platform, but that all were shallow and broad. By 1877, the Cubits Gap subdelta had morphological characteristics similar to those of the Atchafalaya delta in 1976 (Fig. 24c). Similarities included a secondary channel network branching out from the main crevasse channel; and evidence of tertiary and
overbank channels. Thereafter, channel patterns in the Cubits Gap subdelta were dissimilar to the Atchafalaya as flow volume was much greater than in the present eastern Atchafalaya delta, and the Cubits Gap subdelta was building into a seaward-deepening bay. As a result, distributary channels in the Cubits Gap area were more commonly of secondary channel size and the pattern was dominated by the branching and reconnecting of channels (Fig. 24d).

As is now known from the work of Wells et al. (1982), the Cubits Gap subdelta, during the time of Welder's (1959) study, had reached the stage of maximum progradation and had entered the abandonment phase. Welder (1959) observed and commented on the mechanisms of lobe fusion caused by channel abandonment. As was the case in the Atchafalaya, Cubits Gap subdelta channels sealed at their upstream ends at the time of abandonment. However, Welder (1959) documented that channels sealed because of a reverse eddy effect, which was responsible for progressive lateral bar growth across the entrance of the channel. Lateral bar growth is in contrast to the subaqueous levee sealing that occurred in the Atchafalaya delta.

Comparison with Texas deltas

Comparison is made with the Guadalupe delta, which has been the subject of numerous studies (Donaldson et al. 1970, Morton and Donaldson 1978). The Guadalupe delta is building into a protected lagoon that is less than 2 m deep. Growth was initiated about 2000 years ago. Growth patterns, in terms of lobate delta forms, are somewhat similar to those of the Atchafalaya delta, although the sediment load of the Guadalupe is 100 times less than
that of the Atchafalaya. In addition, the area is tectonically more stable than Atchafalaya Bay (Donaldson et al. 1970). Four subdeltas of the Guadalupe have been recognized, but all are different ages (Donaldson et al. 1970). Within the Atchafalaya delta, four distinct deposition centers or lobes can also be recognized, but all developed contemporaneously.

The most striking difference between the Atchafalaya and Guadalupe deltas is the dominance of birdfoot distributary channel patterns in the latter. These features form where subdeltas, prograde into deeper parts of the lagoon. Lobate subdeltas do occur, however, where progradation is into shallower water. Besides depth constraints, the birdfoot pattern of the Guadalupe delta might also be explained by its small sediment load, very protected environment and small tide range (only 10 cm). Unfortunately, data are insufficient on which to make process comparisons with the Guadalupe.

Other similarities between the two deltas include a decrease in levee grain size in a seaward direction; channels deeper than the bay; and levees forming an important part of the stratigraphic record (Donaldson et al. 1970).

The presence of numerous small deltas along the microtidal Gulf Coast suggests that perhaps a new term "bay head deltas" should be introduced to the literature. The Atchafalaya delta would fall midway between the extremes of such a classification. At one end of the spectrum would be the relatively unprotected settings of the Mississippi subdeltas, and at the other end would be the very protected environments of the Texas deltas.
CONCLUSIONS

Delta switching is the major mechanism responsible for building the Louisiana deltaic plain. Upstream diversions occur approximately every 1000 years, resulting in a change in loci of sedimentation and growth of new delta lobes. The Atchafalaya delta is forming as a result of such an upstream diversion.

The field study described in this paper was designed to investigate the processes of sedimentation and evolution of this important new phase of delta building in the Mississippi River delta complex.

Analysis and interpretation of aerial photography, LANDSAT imagery, channel cross sections, bathymetric data, limited physical data, and sedimentological data derived from cores and surface samples have led to the following conclusions.

(1) In the eastern Atchafalaya delta, two distinct subaerial delta lobe responses were discernible. The younger response (1973-1976) consisted of channel extension and bifurcation and the development of a network of short overbank channels. The latter, more mature, response of upstream lobe accretion and consolidation became dominant once delta progradation through bifurcation had reached its peak.

Three distinct progradational channel pattern types were recognized in the Atchafalaya delta. Each group had a distinctive type of bifurcation that reflected the local tidal current pattern, channel orientation, and direction of prevailing winds.
Under the impetus of the major floods from 1973 to 1976, sinuous overbank channels built up on lobes between larger channels. These small channels were responsible for the building of lobe interiors.

From 1977 onwards, channel elongation ceased as the coarsest fractions of the sediment load were deposited at the heads of major bifurcations. Upstream lobe accretion was now the dominant mechanism of delta growth. Additional growth occurred through the coalescence of delta lobes as tertiary channels were abandoned.

(2) An earlier model of Atchafalaya delta growth (van Heerden 1980) has proved to be too simplistic as additional stages of delta development have been recognized. Fluvially dominated sedimentation began in 1952 and by 1982 the following sedimentary facies had evolved: upper prodelta, distal bar, distributary-mouth bar, natural levee, back bar algal flat and channel fill. Concurrent with facies progradation was the establishment of a distributary channel network. Trends of a subaqueous channel system were initiated early in delta growth and by the onset of the subaerial phase of delta growth, channels had become well established.

Major floods in 1973 and the next two years heralded the subaerial phase of delta growth, forcing rapid subaerial development and seaward delta expansion. However, progradation terminated after the 1976 flood as a major change in deltaic processes occurred. Thereafter, fusion and upstream accretion of lobes were the dominant mechanisms of delta growth. Sedimentary
deposits formed at upstream locations of lobes had the characteristics of distributary-mouth bars, prior to formation of subaqueous levees.

(3) Excellent stratigraphic control and current knowledge of the processes of deposition in Atchafalaya Bay make it possible to more efficiently link process and response in this delta than in other deltas of the Mississippi River system. Primary sedimentary structures in depositional environments range from high-energy climbing-ripple cross laminations to low-energy parallel laminations. Median grain size varies from 90 microns to 14 microns. Grain size and structures associated with a particular environment reflect proximity to distributary channels, severity of floods, and exposure to erosive mechanism during winter months.

Penecontemporaneous deformation structures are occasionally encountered in the subaqueous environment. They primarily reflect the effects of storms.

During the early development of the prodelta/distal bar/platform bathymetry was uniform resulting in blanket deposition of silts and clays. Once sediment load grain size increased after 1960, bathymetric highs such as distributary-mouth bars were initiated in the bay and segregation of the sediment load started to become important. Because of frictional effects and the resultant reduction in velocities, the coarse fraction of the sediment load was deposited on levees and newly created distributary-mouth bars. As a result, the suspended load bypassing the delta was impoverished in coarse fractions and clay-rich distal bars formed immediately seaward of the delta.
(4) Rate of growth in the eastern Atchafalaya delta has apparently reached its peak. However, the Atchafalaya delta should continue to prograde and will eventually cover most of Atchafalaya Bay. In contrast to the modern Mississippi delta, the Atchafalaya should prograde more rapidly and form thinner sand bodies, because it is building into a shallow water body and eventually onto a shallow, flat continental shelf.

(5) The Atchafalaya delta serves as a model for deltas formed in protected embayments (bay head deltas). It is protected from ocean waves by a seaward barrier. In addition, the Atchafalaya delta setting shows the following characteristics that may be applied to other bay head deltas:

1. shallow depositional basin
2. high sediment load
3. small tide range
4. tectonic subsidence less than Mississippi Balize delta
5. bay waters are well mixed

Specific delta characteristics include:

1. a depositional sequence in which levee deposits are dominant
2. grain size segregation such that levees are the coarsest deposits
3. prodelta thin compared to other facies

Modern Gulf coast examples of bay head deltas include the sub-deltas of the Mississippi and the back barrier lagoon deltas of east Texas.
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APPENDIX A.

List of aerial photographs and LANDSAT imagery used in subaerial mapping.

### Aerial Photographs

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### LANDSAT Imagery

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August 4
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November 11
December 17
December 26

1979
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February 29
March 8
May 10
July 3
August 17
November 24

1980
February 4
July 24
August 20
October 4

1981
March 24
APPENDIX B. DEPOSITIONAL ENVIRONMENTS

Delta morphology and stratigraphy are primarily the product of an interplay between fluvial sediment input and reworking by physical processes in the receiving basin (Elliott 1978, Wright and Coleman 1974). Change in major processes is evident from the variation in sedimentary response features which can be observed in sediment cores. For the purpose of discussion, environments of deposition have been divided into two groups based on whether they are predominantly submerged (subaqueous) or exposed (subaerial). This system follows that of Coleman (1976).

Subaqueous depositional environments

1. **Old bay bottom environment.**

   Old bay bottom sediments consist of highly bioturbated blue-gray clays and silty clays with numerous oyster shell fragments (Fig. B1a). These features attest to minimal fluvial input and the dominance of biological reworking processes. The appearance of weakly graded beds in old bay bottom sediments suggests periods of sediment transport under waning currents following passage of major storms (Nelson 1982). Microfossil examination revealed that old bay bottom deposits are dominated by the brackish water ostracod, *Perissocytheridea brachyfonna* (M. Machain unpublished data). The transition from old bay sediments to lower prodelta deposits is rather abrupt (Fig. B1b).

2. **Prodelta.**

   Lower prodelta sediments consist of highly bioturbated brown-grey clays and silty clays (Fig. B2a). They contain brackish water *Rangia* and *Mulinia* shells, amongst others. Fresh water
Figure B1. Radiographs of a) old bay bottom sediments, and b) transition from old bay to lower prodelta.
A. graded bedding
B. shell fragments
Figure B2. Radiographs of a) lower prodelta sediments and b) upper prodelta sediments
A. shell fragments
B. parallel laminations
C. silt layer
D. burrows

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ostracods (Engel and Swain 1967), Candona lactea and Cypridopsis vidua, are common in lower prodelta deposits (M. Machain, unpublished data). The foraminifera, Ammonia beccarii and Elphidium sp., showed marked reductions in numbers from old bay to lower prodelta sediments. The combination of the color change and different faunal assemblages testifies to greater fluvial influence during deposition of lower prodelta clays as compared to that of old bay bottom sediments. Lower prodelta sediments contain one or two layers (greater than 10cm) of shell lag apparently formed in response to major storms (Reineck and Singh 1973). As fluvial processes started controlling deposition in the bay, the upper prodelta stage of delta building was initiated.

The upper prodelta sequence consists of cycles (2-10 cm thick) of red-brown parallel-laminated silty clays and clays that are separated by thin (2 to 3 mm) silt lenses (Fig. B2b). Silt lenses may contain clam shell fragments. Small polychaete worm burrows that originate in the silts penetrate underlying material. A distinguishing characteristic of the upper prodelta facies is its high lateral continuity and low lithologic variation. Because deposition of these clay-rich sediments is almost entirely from suspension and bed shear stress is low, parallel laminations are by far the most common primary structure. Individual cycles appear to be related to annual flood events. The thin silt lenses may have erosional bases and appear to have been deposited in response to storm-induced reworking processes during periods of low fluvial input (Appendix E). As a result of low sedimentation rates, biological activity is accentuated as evidenced by worm burrows.
3. **Distal bar.**

Overlying the prodelta facies is a coarsening upward sequence that varies from silty clays to coarse silt. These deposits constitute the distal bar which is characterized by texturally variable parallel laminations and lenticular laminations. Individual laminations may have attained a thickness of 2 cm. (Fig. B3a). Closer to the Atchafalaya river mouth distal bar deposits become coarser, with small scale cross-laminations, scour and fill, and other similar sedimentary structures. Distinct textural contrasts are present throughout the distal bar facies although lateral continuity is lower than in the prodelta environment. Major storm induced deformation structures are common in distal bar sediments (Fig. B3b).

Distal bar sediments were replaced by clay-rich distal bar deposits once distributary-mouth-bar deposits had started to form at the heads of major bifurcations. Lithologic change reflected segregation of the sediment load as it passed through the distributary network. Coarse fractions originally destined for distal bar locations were being deposited in more upstream locations.

4. **Distributary-mouth bar**

Close to distributary mouths, distal bar sediments are transitional to a shallower and coarser distributary-mouth-bar facies. Although the distributary-mouth-bar deposits also coarsen upward, they consist of upward fining cycles of cross-laminated and parallel-laminated clayey silts which pass into parallel-
Figure B3. Radiographs of distal bar sediments.
A. parallel laminations
B. deformed bedding

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laminated silty clays (Fig. B4). The distributary-bar cycles vary in thickness from 3 to 9 cm and represent flood-related depositional events. Some upper horizons of distributary-mouth-bar deposits contain up to 10 cm thick layers of parallel-laminated silts and clays with numerous erosional surfaces. These deposits resemble lenticular bedding (Reineck and Wunderlick 1968) and indicate tidal and storm related reworking of the higher elevated surfaces of distributary-mouth bars during periods of low river discharge. Deformation structures are common in distributary-mouth-bar deposits (Fig. B4) (Appendix E).

5. Channel fill.

Three distinct types of channel fill material are recognizable. These are clayey-, silty-, and sandy- channel fill.

Clayey- channel fill (Fig. B5a) is generally found in abandoned tertiary channels. Parallel laminations are the most common primary structures. Abandoned tertiary channels are usually flanked by vegetated levees (Fig. 11). For this reason organic matter (leaf litter) is common in clayey-channel fill.

Primary and secondary distributary channels in the eastern delta are undergoing reductions in cross-sectional area by aggradation of channel flanks and general shallowing of the channel (Fig. 12 and 13). The silty-channel-fill material (Fig. B5b) deposited in these channels consists of parallel-laminated silts and clays. Erosional surfaces and polychaete worm burrows are common. Occasionally, thin lenses of cross-laminated silts that represent starved ripples are present. Deposition of fine-grained suspended sediment in primary and secondary distributary channels occurs.
Figure B4. Radiographs of distributary-mouth-bar sediments.

A. upward-fining cycle
B. deformed bedding
C. parallel laminations
D. silty 1973 flood subaqueous levee deposits.
Figure B5. Radiographs of a) clayey, b) silty, and c) sandy channel fill.

A. parallel laminations
B. organics
C. lenticular laminations
D. cross laminations
mostly during periods of low water discharge. During low flow months, channel bottoms can be covered with a maximum of 10 cm of fluid mud. By the onset of the following flood, this material would have undergone an increase in cohesive strength as a result of dewatering (Postma 1968) and possible sub-tidal algal growth. As a result of the increase in shear strength these fine grained channel bottom sediments tend to resist erosion during floods. In addition, high velocities during flood discharges prevents sediment deposition on channel bottoms.

Sandy-channel fill consists of parallel- and cross-laminated grey silty sand (Fig. B5c). This material is only present in locations close to the navigation channel and would seem to represent rapid deposition events. Channel fill of all three types have been found in thicknesses exceeding 1 m although silty-channel fill is the most common.

Subaerial depositional environments

1. Natural levee.

Subaqueous and subaerial natural levee deposits are similar and gradational. For the purpose of discussion they have been considered as one environment because they are most commonly thought of as subaerial features. Natural levee deposits are composed of silts and fine sands with minor amounts of clay and display a variety of sedimentary structures which reflect differing intensities of flood related sedimentation (Fig. B6). Elevation and channel flank location are important factors that help determine unit thickness and structure type.
Figure B6. Radiographs of natural levee deposits created during different sedimentation rates.

A. climbing-ripple cross laminations
B. trough cross laminations
C. simple cross laminations
D. parallel laminations
E. algal layer
Distinct sedimentary structure associations which reflect annual flood deposition rates are recognizable in the eastern Atchafalaya delta. When average sedimentation rate is greater than 0.3 m/flood, as determined from topographical and channel cross section surveys, trough and climbing-ripple cross laminations are the dominant structures recognized (Fig. B6a). These structures have tangential to concave foreset laminae. Exposure in trenches reveals weak to strong festoon shaped cross bed sets. Such features indicate migration of undulatory, linguoid, and climbing ripples with deposition from predominantly suspended loads under moderately high flow strengths with high bed shear stress (Reineck and Singh 1973, Jopling 1965).

When topographic surveys reveal natural levee sedimentation rates between 0.15 and 0.3 m/flood, simple cross laminations are the most common structures found, although trough cross laminations are sometimes present (Fig. B6b). The former bedform results from the migration of straight-crested, small current ripples at low flow strengths, just capable of initiating and maintaining ripple migration (Reineck and Singh 1973, Harms et al. 1975). Trough cross laminations are formed by undulatory small ripples which represent a transition form between low-energy, straight-crested ripples, and higher-energy linguoid small ripples (Reineck and Singh 1973). A combination of these laminations indicates deposition of suspended and bed load material at low flow strengths and medium bed shear stresses (Jopling 1965).
During minor flood years rate of levee buildup is generally less than 0.15 m/flood. Because of the low fluvial input local wind- and tide-induced processes play an important role in dictating the type of sedimentary structure produced. Response features are parallel laminations with minor scour surfaces (Fig. B6c). When sedimentation rates are low algal mats become established. These features are recognized in cores as organic rich layers. Similar types of sedimentary structures are produced in levee environments during the low flow months between major floods when storm-induced reworking processes dominate.

Exposed vegetated subaerial levees also display parallel laminations as sedimentation rate is low. Fig. B6d shows a portion of a core taken from a vegetated subaerial levee in February, 1981. From survey data taken three times a year during the period 1977-1981 it is possible to identify winter and flood deposits since the 1976/1977 winter.

In the winter, material is eroded off the outer flank of the island due to cold air outbreak events (Appendix E) and deposited in more central lobe locations. Where deposited on subaerial levees this sediment consists of clean sands. Sediments deposited during floods at these locations is generally finer grained. In addition, organic content is high due to the rooting activities of marsh plants which flourish in the spring and summer.

2. Back bar algal flats.

Algal flats occur between subaerial levees and usually form the central part of lobes. Generally, algal flat sediments are highly organic and consist of parallel-laminated silts and
Figure B7. Radiograph of back bar algal flat.
A. organic rich layers
B. parallel laminations
C. cross laminations
clays interbedded with thin reduced organic layers (Fig. B7).

Sediments enter these environments by four pathways: levee overtopping, tidal pumping, flood feeder channels, and winter levee erosion. Parallel-laminated silts and clays are deposited through levee overtopping during river floods. Weak tidal currents deposit thin clay veneers during periods of low fluvial input.

Coarse sediments enter the algal flat via overbank feeder channels or through the erosion and redistribution of levee material during storms. Overbank channels, which are activated during floods, transport sediment into the algal flat forming thin cross-laminated algal flat sand lobes (Fig. B7). Sedimentary features indicate rapid sedimentation of predominantly suspended loads under waning but fluctuating flow conditions. The resultant lobes occur only in the vicinity of feeder channel mouths and thus do not cover wide areas. Cross-laminated sands, making up the top part of the cores displayed in Fig. B8, represent levee material that was eroded by wind-induced processes (Appendix E) during cold-front passages in the 1978/1979 winter and deposited over the organic rich back bar algal flat. The result is a coarse grained algal flat sand sheet formed in an environment usually dominated by fine grained sediments. The sand sheet is laterally very continuous, a distinguishable feature from the algal flat sand lobes deposited during floods.

Back bar algal flats, as the name suggests, are sites of algal production specifically during summer and fall. Slow deposition accompanied by low turbidity and shallow waters can result in the accumulation of laterally extensive thick algal
Figure B8. Radiograph of core showing winter response in a back bar algal flat.
A. organic rich layers
B. parallel laminations
C. cross laminations
layers. Once buried they compress readily and are discernable in cores as dark organic rich layers, no more than 2 cm thick (Fig. B7). Algal layers tend to bind the surface sediments and offer protection against storm erosion mechanisms especially in the fall and early winter. Thereafter, field evidence suggests that the combined effects of feeding waterfowl and cold temperatures may destroy the algal mat enhancing the potential to erode exposed portions of the flat. Eventually, back bar algal flats attain enough elevation for colonization by marsh plants. Algal flats overlie distributary-mouth-bar deposits and may attain thicknesses in excess of 1 m (Fig. 16).

Grain size and mineralogy

Results of analysis of bottom grab samples show that median grain size in the eastern half of Atchafalaya Bay coarsened over the eight year period from 1972 to 1980 (Fig. B9). This change reflects delta progradation. Greatest seaward migration of coarse facies was west of the navigation channel because of its greater discharge capacity and redistribution of dredge spoil. The presence in 1980 of sediments with median diameters greater than 125 microns indicates gradual coarsening with bar aggradation as the delta progrades.

Atchafalaya deltaic deposits typically coarsen upward although deviations from the trend are common. The seventeen samples of old bay bottom material (Fig. B10, B11 and B12) have a mean median grain size of 14 microns, although there is a minor vertical increase in grain size and sorting. These trends reflect the mixing of increasing but small amounts of fluvial sediments.
**Figure B9.** Median grain size, Atchafalaya Bay, 1972 and 1980.
with material derived from bay shoreline erosion. Fluvial sediment availability increased due to both the increased capture of Mississippi flow by the Atchafalaya and the progressive filling of Atchafalaya Basin. Thus the coarsening trend is more marked in the lower prodelta sediments which contain local concentrations of coarser storm deposits.

Shell lag storm deposits within the lower prodelta material are coarser grained and extremely poorly sorted. These sediments reflect an intense energy pulse of short duration such as a hurricane, when coarser than normal sediments are transported within the bay.

The appearance of upper prodelta sediments marks the onset of dominance by fluvial processes over wind- and tide-induced reworking of bottom sediments. Because of the prevalence of a fluvial sediment source and associated higher sedimentation rate, tide and wave generated reworking and winnowing of fine material is diminished; prodelta median grain size becomes smaller, and the sediments are better sorted than the underlying lower prodelta and old bay bottom sediments (Fig. B10 and B11).

Distal bar material is coarser and more poorly sorted than prodelta deposits suggesting a greater input of coarser grained sediments. Although distributary-mouth bars are coarser than distal bars, they are generally better sorted, indicating the higher energy regime effecting this environment (Fig. B10 and B11).
Figure B10. Median grain size, sorting and clay mineral composition vs depth for core 1. (See Figure 6 for location).
Silts and fine sands dominate in levee deposits (Fig. B10 and B11). Coarse, well sorted layers are deposited during the winter when sediment is redistributed because of wind effects associated with cold fronts. Although a single outbreak lasts a few days, the combined effects of a whole season of reworking during cold front passages, is to concentrate the coarse fraction of the original fluvial sediment, by winnowing out the fine sediment. Levees formed when sedimentation rates are low are fine grained (median approximately 21 microns). When sedimentation rates exceed 0.3 m/flood levees have a median grain size between 35 and 80 microns (Fig. B10 and B11).

Silty channel fill (Fig. B12) in Natal Channel (Fig. 17) is fine grained (mean median 17 microns) and sorting is better than in other sediments displayed by the three cores. These features support the earlier contention of deposition of fine grained material in distributary channels during low flow periods when a limited grain size distribution of suspended sediments is present in the water column (van Heerden et al. in press).

Results of X-ray diffraction analysis (Fig. B10 through B12) show that there is a trend towards more kaolinite and illite and less montmorillonite in passing from old bay bottom sediments to deltaic sediments. During the period spanned by this section of the cores, Atchafalaya Bay evolved from a marine embayment to one dominated by fresh water and river borne sediment. Greater amounts of montmorillonite may be present in old bay bottom sediments due to differential flocculation. Whitehouse et al. (1960) suggest that this is an important mechanisms in marine settings.
Figure B11. Median grain size, sorting and clay mineral composition vs depth for core 2. (See figure 6 for location).
Figure B12. Median grain size, sorting and clay mineral composition vs depth for core 3. (See figure 6 for location).
According to Hyne et al. (1979) shallow water deltas in settings similar to that of the Atchafalaya Bay should show a decrease in kaolinite and an increase in illite with depth if salt flocculation were the dominant mechanism of fine grained aggradation and sedimentation. Marked fluctuations but no trends in clay composition occur in the fluvially dominated deltaic deposits providing no evidence for salt flocculation during delta development. Mobbs (1981) reached a similar conclusions from clay mineral analysis undertaken along a transect from Atchafalaya River Basin, through the bay and out onto the shelf.

Fluctuations in clay mineral composition may reflect scouring and mixing of older deltaic deposits into the water column as the Atchafalaya River adjusted its course to the major floods of the 1970's; or a link between size of sediment deposited and clay composition. The sediments at the top of each core were deposited during the low water years since 1979 and are finer grained than pre-1979 deposits. The montmorillonite content is higher in the finer deposits suggesting that fluvial regime may influence clay mineral composition in the Atchafalaya delta.

The above description reveals that the environments of deposition associated with progradation of the Atchafalaya delta are extremely complex and highly variable. The various processes active in each environment of the delta result in selective concentration and distribution of sediments. Environments associated with Atchafalaya delta progradation can be divided into two categories. Those associated with the subaqueous delta consist of
sediments that accumulate beneath sea level; those environments associated with the subaerial delta are the deposits that accumulate at or above sea level. Environments associated with the subaqueous delta consist of: (a) old bay bottom, (b) prodelta, (c) distal bar, (d) distributary-mouth bar, (e) subaqueous levee, and (f) channel fill. The environments associated with subaerial delta are: (a) natural levee, and (b) back bar algal flats.
APPENDIX C - SUBSIDENCE CALCULATIONS

An important aspect of interpretation of stratigraphic data when formulating an evolutionary model for the Atchafalaya delta was to assign dates to major depositional events. In order to perform this task the following techniques were combined,

1) ground truth surveys,
2) recognition of major depositional events in cores,
3) interpretation of bathymetric charts, and
4) subsidence calculations.

Several concrete survey bench marks were placed in Atchafalaya Bay by the Corps of Engineers in April 1977. Thereafter, the grid was extended by the author. All benchmarks were triangulated using a theodelite and then leveled to M.S.L. In 1981 a controlled aerial photo mosaic of Atchafalaya delta was constructed by the Corps of Engineers. The earlier survey data, in combination with the mosaic, provided a very good means for ground control in core location. Heights to tops of cores were established from the benchmark system. Topography of delta lobes was determined from ground and channel cross section surveys which were tied into the benchmark system. Times of emergence of lobes was interpreted from the aerial photo and LANDSAT imagery collection (Appendix A).

Ground surveys and aerial mapping revealed the age of lobes after 1973. The recognition of major depositional events in cores aided in interpreting the age of stratigraphic layers. Flood deposits of 1973 were recognized as a major lithological change in sediment cores (Fig. B4) and provided a very good dateline. During the low flow months following the 1973 flood deltaic
environments (especially subaqueous levees) were covered with parallel-laminated silts and clays. The 1974 flood event was initiated by scour of the upper portions of existing deposits followed by deposition of silty material. This sequence of events was repeated in most of the floods since 1973. Thus, individual flood responses could generally be recognized.

Response to major storms (that are datable from the literature) were preserved in the stratigraphic record. Major storms in the later 1950's and 1960's were discernable as laterally continuous erosional surfaces. Earlier storm events were present in lower prodelta material as laterally continuous shell lags.

Impressive changes in fluvial sediment input to Atchafalaya Bay were recognized to have occurred in 1839 and 1952. The reasons for these interpretations, related to dramatic increases in fluvial input, were discussed in the main text.

Additional stratigraphic control was obtained from use of bathymetric survey data and known subsidence rates. Bathymetric surveys in Atchafalaya Bay were performed by the Corps of Engineers in 1952, 1960, 1967, 1972, 1977 and 1981. Delta morphology and growth rate interpreted from these data were discussed in the literature review section. Historical bathymetric charts used in this study included those published in 1750 and in 1858. These charts are archived in Maps Section, Department of Geology, LSU. Subsidence rates were interpreted from the sources listed below.
Source | Period | Rate
---|---|---
Fisk and McFarlan 1955 | 18,000 years | 0.17 cm/yr
Frazier 1967 | 1900 B.P. to 1967 | 0.41 cm/yr
Hicks 1972 | 1940 to 1970 | 1.30 cm/yr

In order to establish the location in cores of sediments deposited in 1952 at a depth of 2 m in the bay (interpreted from bathymetric charts), for example, a correction factor of 39 cm (30 years x 1.3 cm/yr) was added to the original depth of 2 m. This technique was used to establish or confirm date lines. However, the subsidence rate used was decreased with age of surface sought.

Lastly, C\textsuperscript{14} dating techniques were attempted on the shell lag layers present in lower prodelta deposits. Unfortunately no, reliable dates were obtained (F. Kearns pers. comm.).
APPENDIX D - CORE LOGS

Vibracore logs are presented in this Appendix.
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 1 LINE 1
TOP CORE M.S.L -0.03m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 2 LINE 1
TOP CORE M.S.L. - 305m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 3  LINE 1
TOP CORE M.S.L. - 0.00m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
* Upward fining cycles
Erosional surfaces

CORE 5  LINE 2
TOP CORE M.S.L. - 0.28m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 7 LINE 2
TOP CORE M.S.L. +0.20m
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Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 11 LINE 2
TOP CORE M.S.L. -2.00 m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 12 LINE 2
TOP CORE M.S.L. -0.20 m

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Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 13 LINE 3
TOP CORE M.S.L +0.50m
CORE 14 LINE 3
TOP CORE M.S.L - 1.80m

Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
△ Upward fining cycles
∽∽∽ Erosional surfaces

CORE 15 LINE 3
TOP CORE M.S.L. +0.00 m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 16 LINE 4
TOP CORE M.S.L - 0.60 m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 17 LINE 4
TOP CORE M.S.L -0.18m

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Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 18  LINE 4
TOP CORE M.S.L +0.13m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 20 LINE 4
TOP CORE M.S.L. +0.00 m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 21  LINE 5
TOP CORE M.S.L - 1.15m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
△ Upward fining cycles
～～～ Erosional surfaces

CORE 23 LINE 5
TOP CORE M.S.L + 0.30m
Cross laminated silts
Parallel laminated silts
Parallel laminated silts and clays
Parallel laminated clays
Clay plug
Brown-grey bioturbated clays
Blue-grey bioturbated clays
Shell hash
Organics
Deformation structures
Upward fining cycles
Erosional surfaces

CORE 27 LINE 5
TOP CORE M.S.L -0.21m
APPENDIX E - STORM PROCESSES

Cold fronts

Although fluvial processes dominate in Atchafalaya delta, basinal processes, which are generally out-of-phase with the fluval energy regime, have a marked effect on delta morphology. Responses to cold air outbreaks are most marked in the subaerial delta, particularly during low flow years such as 1977 and 1978. A season of cold fronts during a low river discharge year can be responsible for a net loss of almost 3 km² of delta lands (Fig. 5b).

The clockwise rotary wind field with high velocity onshore-offshore modes, associated with winter cold air outbreaks (Fernandez-Partagas and Mooers 1975), greatly affects water levels and discharge in the delta (van Heerden and Roberts 1980a). Fig. E1 illustrates a segment (January 1978) from a tide gage record located at the Amerada Hess platform (Fig. 2) on the western side of the Atchafalaya delta. Water level changes in the bay, associated with a cold front passage and tidal effects, are shown in this figure. Winds preceding a cold front generally blow from a southerly quadrant, which promotes setup or water-level elevation in the bay (Fig. E1, up to 2100 hr on 16 January). It is during this phase that wave action suspends sediments and turbid water moves landward, some into surrounding coastal marshes (Roberts and van Heerden 1982). As the cold front crosses the area from northwest to southeast, winds switch to a northerly quadrant and induce rapid water set down (Fig. E1, after 2100 hr on 16 January). Swift movement of water out of the bay, coupled with wind-wave
Figure E1. A tide gauge record segment from the western Atchafalaya delta (Amerada Hess platform; see Fig. 2) showing set up and set down of bay water levels associated with cold front passage (14-17 January, 1978).
action, is responsible for erosion and redistribution of sediment within the delta. Cold fronts cross Atchafalaya Bay once every 5 to 7 days in the winter for a season total of 25-30 (G. P. Kempers. comm.).

Redistribution of sediment during cold air outbreaks is believed to have occurred in Atchafalaya Bay prior to delta formation. From the early 1500's to mid-1800's Atchafalaya Bay appears to have experienced little change in water depths. Sediment was supplied from shoreline erosion and apparently transported to deeper locations during frontal passage. Evidence for this process included the graded beds sometimes present in old bay bottom sediments (Fig. Bla). The same processes appear to have been responsible for Atchafalaya Bay having a uniform depth by the early 1950's (Fig. 16 and 19).

Cold fronts effects in the subaqueous delta are not very apparent. However, sedimentological indications include minor silt lenses with shell fragments present within upper prodelta clays (Fig. B2). These features were deposited in response to winter storms. Similar response features are present in distal and distributary-mouth-bar sediments (Fig. B3 and B4).

Response to cold front passage is most dramatic in the subaerial environment. Subaerial profiles (Fig. E2) taken across two of the lobes in the study area (van Heerden 1980) illustrate the response of exposed lobes to flood and non-flood events. The highest lobe (Ivor's Island, Fig. E2) experienced shoreline erosion and minor amounts of accretion during the low river years.
Figure E2. Subaerial profiles of two delta lobes (From van Heerden 1980).

$T_1 = \text{May, 1977}$

$T_2 = \text{May, 1978}$

$T_3 = \text{July, 1979}$
of 1977 and 1978. Over the same period, the lower lying lobe (Rodney's Island) experienced a net subaerial loss due to reductions in elevation of up to 0.3 m.

Erosion of subaerial lobes occurs primarily during water level setdown. This prompted Roberts and van Heerden (1982) to determine the average setdown curves for cold fronts crossing Atchafalaya Bay, at three tide stations, between 1 January 1979 and 30 April 1980. Data from the Amerada Hess tide station, which is at the same latitude as the study area (Fig. 2), are presented in Fig. E3. Complete setdown at this station, from an average maximum elevation of 0.75 m above mean sea level (M.S.L.), took approximately 16 hr per front (Fig. E3).

The duration of lobe inundation, during setdown, is related to lobe elevation and determines the response to frontal passage. Prior to the 1979 flood, Rodney's Island had an average elevation of 18 cm above M.S.L. (Fig. E2). If the cold front water level setdown data presented above was typical of the 1976-1978 period, then it is apparent that Rodney's Island was inundated for an average of 13 hr during post-cold front water level setdown. The result of wave action and inundation, during this period, was extensive shoreline retreat and subaerial levee erosion (Fig. E2). Eroded levee material was redistributed over the back bar algal flat as sand sheets (Fig. B8). This process was still active after the general increase in elevation of the lobe following the 1979 flood. Overall, stacked sand sheets with thicknesses of up to 40 cm were incorporated in the back bar algal flat of Rodney's Island from 1976 to 1982. By the end of 1976 Ivor's Island had
Figure E3. Mean cold front related water level setdown curve for Amerada Hess tide station (January 1979 - April 1980). See Figure 2 for location of tide station (Modified from Roberts and van Heerden 1982).
attained relatively high elevations (MSL + 45 cm, Fig. E2). As a result, cold front erosional processes were not responsible for major subaerial stripping as, on average, the island was inundated for only three hours per front passage (Fig. E3). Thus, thick algal flat sand sheets were not formed in the back bar algal flat environments of this delta lobe. The above relationships show that low relief delta lobes are subject to greater amounts of erosion due to extended periods of submergence. However, subaerial land that is eroded is deposited as back bar algal flat sand sheets and provides a platform for future subaerial growth.

Hurricanes

In addition to winter storms, hurricanes were responsible for erosion and redistribution of sediments in the bay. Responses to a number of hurricanes were apparent in the core data. Shell lag deposits in lower prodelta sediment represented eroded oyster reef material that was spread as a veneer in Atchafalaya Bay as a result of hurricanes in the later 1800's.

If upper prodelta sedimentation was initiated in the early 1950's then a response to Hurricane Audrey (1957) should be evident. This hurricane made landfall at Cameron in south-western Louisiana, placing Atchafalaya Bay in its northeast quadrant, the area of maximum wind stress, for a few days. During this period, storm tide height was 2.6 m above MSL in Atchafalaya Bay (Dunn and Miller 1960). Overturned bedding, or an erosional surface overlain by a silt, is present near the top of the upper prodelta sediments. From subsidence calculations (Appendix C), the deposits appear to have been formed in the mid-1950's, about the same time as Hurricane Audrey and, therefore, may be related.
Distal bar sediments usually contain evidence (Fig. B3) of at least two major storms. It is possible that these features represent storm responses to hurricanes Hilda (1964) and Betsy (1965). Hilda made landfall at Atchafalaya Bay. Maximum winds were in excess of 200 kph and storm surge was 3 to 4 m. Hurricane Betsy made landfall 60 km to the east of Atchafalaya Bay. It too had winds greater than 200 kph and created a 3 m storm surge (Neumann et al. 1978). These storms were responsible for creating erosional surfaces, overturned bedding, and silt lenses. Such response features were often found in distal bar sediments in cores and usually consisted of two disturbed horizons separated by a parallel-laminated silty-clay layer. In addition, disturbed horizons could be traced laterally in all directions in the study area and served as useful time lines.

Deformation processes

No evidence for major mass movements of sediment are present in Atchafalaya Bay. However, deformation structures, other than those mentioned in the last section, are common in distributary-mouth-bar deposits. Deformation structures are of two main types: gravity-induced slumps and small scale folds (Fig. 17 and 18). These structures are thought to have been formed by differential overloading and/or slow mass movement of saturated sediments on a slope (Coleman and Gagliano 1965). It is quite easy to picture the above mechanisms operating on distributary-mouth bars of eastern Atchafalaya delta as deposits occur on the edge of channels where slopes approach 30°.
Deformation structures in distributary-mouth bars are not laterally continuous. Events that triggered these deformation processes could have been associated with major floods or hurricanes. Large quantities of sediment were deposited during the major floods of the early 1970's, which could have caused failure due to overloading. Hurricane Edith (1971) made landfall 50 km to the west of the bay and had maximum winds of 175 kph. In 1974, Hurricane Carmen intersected the coast at Atchafalaya Bay (maximum winds 200 kph). Wave activity as well as storm surge associated with these hurricanes could have reworked bay sediments.

Fluvial processes dominate in the bay but storm processes leave their imprint in the stratigraphic record. Response to wind-waves and rapid water level fluctuations, generated during cold front passage, are most marked in the subaerial delta. Storm erosion is most dramatic during low discharge years. Tropical cyclones, making landfall within the vicinity of the bay, rework surface sediments and may induce localized mass movements.
VITA

Ivor Llewellyn van Heerden was born September 21, 1950 in Johannesburg, South Africa. He graduated from Alexandra Boy's High School, Pietermaritzburg, South Africa in 1967. In 1969, he completed his military service with the Corps of Engineers, South African Defence Force, where he trained as a land surveyor.

In 1972, he started a geological program at the University of Natal, Pietermaritzburg, South Africa. He received his B.S. Degree in December of 1975 and in 1976 he obtained his B.S. Honors Degree in sedimentary geology.

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Title of Thesis: DELTAIC SEDIMENTATION IN EASTERN ATCHAFALAYA BAY, LOUISIANA

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