CHAPTER 84

FLUID MUD DYNAMICS AND SHORELINE STABILIZATION: LOUISIANA CHENIER PLAIN

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Abstract

The coast of western Louisiana is presently receiving a new influx of fine-grained sediment from the Atchafalaya River to the east, the first such sediment pulse in recorded history. The major effect of this sediment, which accumulates as fluid mud in the nearshore and at the shoreline, is to attenuate incoming wave energy, thus providing conditions favorable for further sedimentation. Examination of color infrared photography and comparison of observations from aerial overflights and information from ground reconnaissance undertaken periodically since 1969 indicate that mudflat sedimentation is increasing and appears to be moving to the west. When muds move ashore and begin to dewater after becoming "shore attached," they gain strength rapidly and can resist subsequent fair-weather wave scour if their bulk density exceeds 1.20-1.25 g/cm^3. An understanding of why and how these fluid muds accumulate and move subaqueously may provide us with the ability to predict areas of future erosion and accretion along the western Louisiana shoreline.

Introduction

The shoreline of Louisiana is extremely dynamic, and its history is complex. In contrast to the sandy beaches of the east and west coasts of the United States, shoreline sediments in coastal Louisiana are composed mainly of silts and clays that have entered the Gulf of Mexico via the Mississippi River. The predominance of fine-grained coastal sediments, particularly the soft gel-like "fluid muds," play a major role in many of the geologic and oceanographic processes on the inner continental shelf and at the shoreline, such as rate of wave attenuation and rate of shoreline erosion and accretion. This paper examines the source, transportation, and site of accumulation of fluid muds in western Louisiana and their importance to shoreline stabilization.

Traditionally, the coast of Louisiana has been eroding faster than that of any other state (USACOE, 1971), primarily because of the natural processes of wave and current scour, subsidence and consolidation of sediments, and sea level rise. Average annual rates of shoreline change for the period 1812-1954 were determined by Morgan and Larimore (1957) from 1:20,000 aerial photography and are given in Figure 1 for the western half of the state. Only three areas of accretion were reported by Morgan and Larimore, and two of these were the result of sediment entrapment by jetties east of both Calcasieu and Sabine ship channels (Fig. 1). In a third area, west of Marsh Island in the vicinity of Chenier au Tigre, coastal accretion had occurred naturally; much of this accretion resulted from new mudflat development initiated by an influx of muds during the 20-30 years prior to 1954.

Evidence provided in a detailed account of sedimentation on the western Louisiana coast (Morgan et al., 1953), along with results of the present study, indicates that the erosional trend is reversing and that the western half of the state is receiving a new pulse of sediment. This reversal in trend (stabilization and even progradation) is attributed to an influx of fine-grained sediment from the Atchafalaya River, a distributary of the Missisippi River which now carries 30 percent of total flow from the Mississippi. As will be discussed in the following paragraphs, an understanding of the dynamics of this new "fluid mud" in the nearshore and on the inner continental shelf may provide us with the ability to predict areas of future erosion and accretion at the shoreline.

Background and Study Area

The western half of the Louisiana coast, referred to as the chenier plain, has been dominated periodically by pulses of fine-grained sediment from the Mississippi River during the past 5,000 years (Howe et al., 1935; Russell and Howe, 1935). Development of the chenier plain and adjacent shelf was traced stratigraphically from cores using radiocarbon dating techniques (Gould and McFarlan, 1959) and is summarized below. As sea level rose from -5 m to its present level, a transgressive sequence of marine sediments was deposited over the dissected Pleistocene Prairie formation, first filling estuaries, then later spreading across shallow-bay and marsh environments (Fig. 2). High-resolution seismic profiles, such as that reproduced in Figure 2, provide thickness and location of Holocene sediments, older underlying channel fill deposits, silt horizons, and

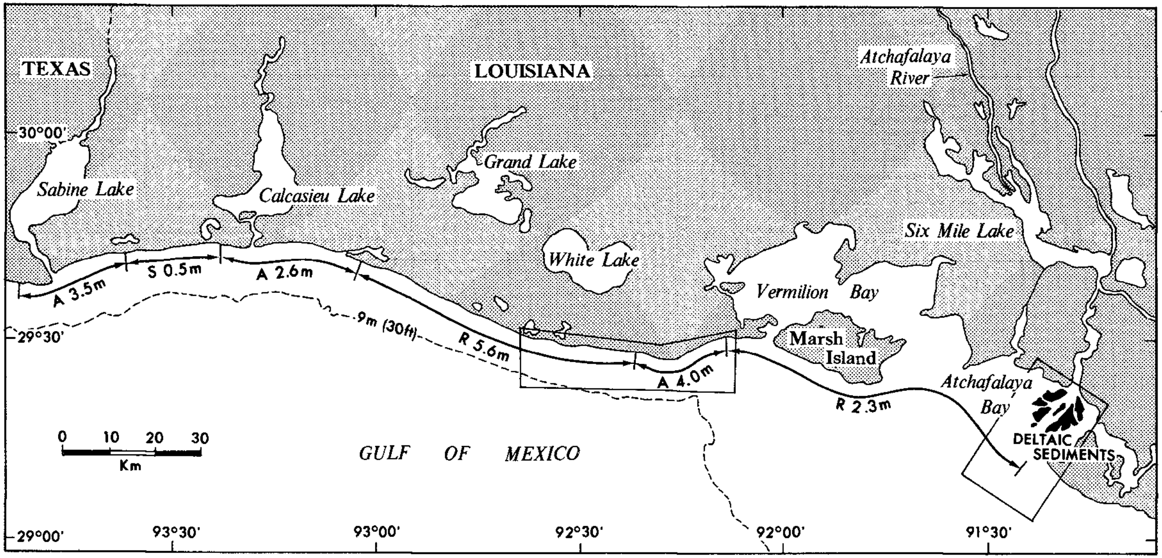

Figure 1. Coast of central and western Louisiana showing average annual rates of shoreline change from 1812 to 1954 (from Morgan and Larimore, 1957). A = accretion, S = stable, R = retreat. Enclosed areas of shoreline are major study sites.

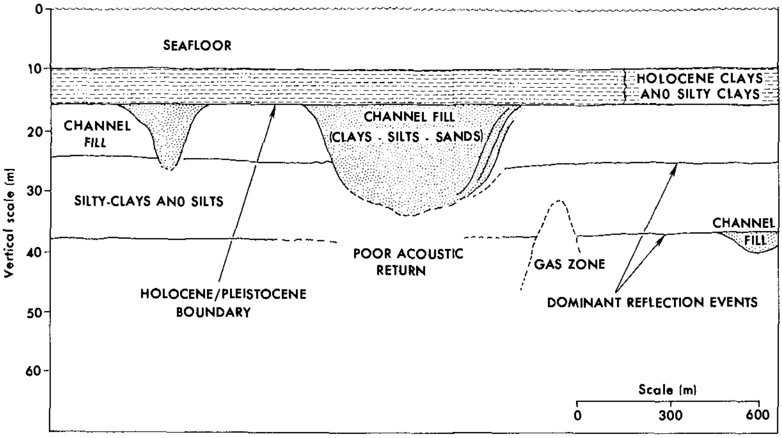

Figure 2. High-resolution seismic profile (E. G. and G. BOOM operated at 300 joules) across the western Louisiana shelf, approximately 10 km seaward of the shoreline south of White Lake. Note that Holocene clays and silty clays are approximately 6 m thick in this area. (Profile courtesy of Jim Hauser, Odom Offshore).

shell lenses.

During the final stage of post-glacial rise in sea level some 3,000 years ago, the chenier plain began to prograde rapidly, and eventually a wedge of recent sediments 6-8 m thick (Fig. 2) was deposited to a distance of 24 km offshore, thus placing the shoreline roughly where we see it today. Pulsations of sediment from the Mississippi River, transported by coast-parallel currents, were responsible for the progradational stage of development. At times when the Mississippi River introduced sediment in the vicinity of the present chenier plain, the shoreline shifted seaward; during periods when its course took the discharge farther east, sediment influx to the chenier plain was low and wave attack was able to slow or halt the advance (Gould and McFarlan, 1959). Cheniers formed during these latter periods and now stand as "islands" in the marsh.

A new pulse of sediment, the first in some 1,000 years, began adding soft muds to the shoreline near Chenier au Tigre in the late 1940s, coincident with the subaqueous development of a new delta in Atchafalaya Bay (Morgan et al., 1953). Although the delivery of sediments from the Mississippi River down the Atchafalaya River had been in progress since the mid-1500s (Fisk, 1952), it was not until the mid-1900s that sedimentation in the bay and areas offshore became noticeable. This large-scale introduction of silts and clays to the coast occurred when the Atchafalaya basin to the north became essentially sediment filled and sediment began bypassing these basin-lakes for areas to the south. In the early 1950s Morgan et al. (1953) documented the occurrence of mud deposition along approximately 50 km of coast from Marsh Island to Rollover Bayou which, in places, formed broad mudflats up to 2 m thick. Today, the chenier plain is backed by extensive brackish and saline marsh and is fronted by ephemeral mudflats along the eastern one-third of its length (Fig. 3). Whereas the coastline and inner continental shelf may appear monotonous to a casual observer, they are in fact, on a small scale, extremely active morphologically.

Present Studies

Shoreline variations and areas of mudflat accumulation were determined from color infrared photographs taken in October 1974 and October 1978 (NASA Missions 74-293 and 78-148, respectively), from 1974 orthophotoquads, and from aerial and ground reconnaissance in 1974 and 1979. Color infrared photography is particularly useful for delineating vegetation/mudflat/open water boundaries since color enhances the vegetation, which during times of low primary productivity is difficult to distinguish from exposed mudflats or turbid water.

Results of these photo and ground comparisons, together with data given in Adams et al. (1978) for the period 1954-1969, are shown in Figure 4. Over the 10-year period from 1969 to 1979 the following patterns have been recognized: 1) simultaneous erosion and accretion at the shoreline,

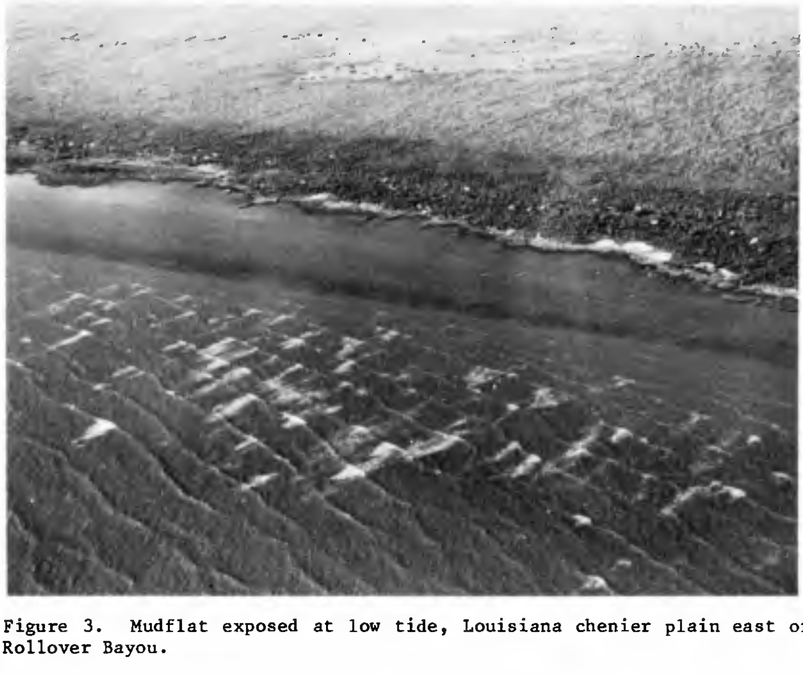

Figure 3. Mudflat exposed at low tide, Louisiana chenier plain east of Rollover Bayou.

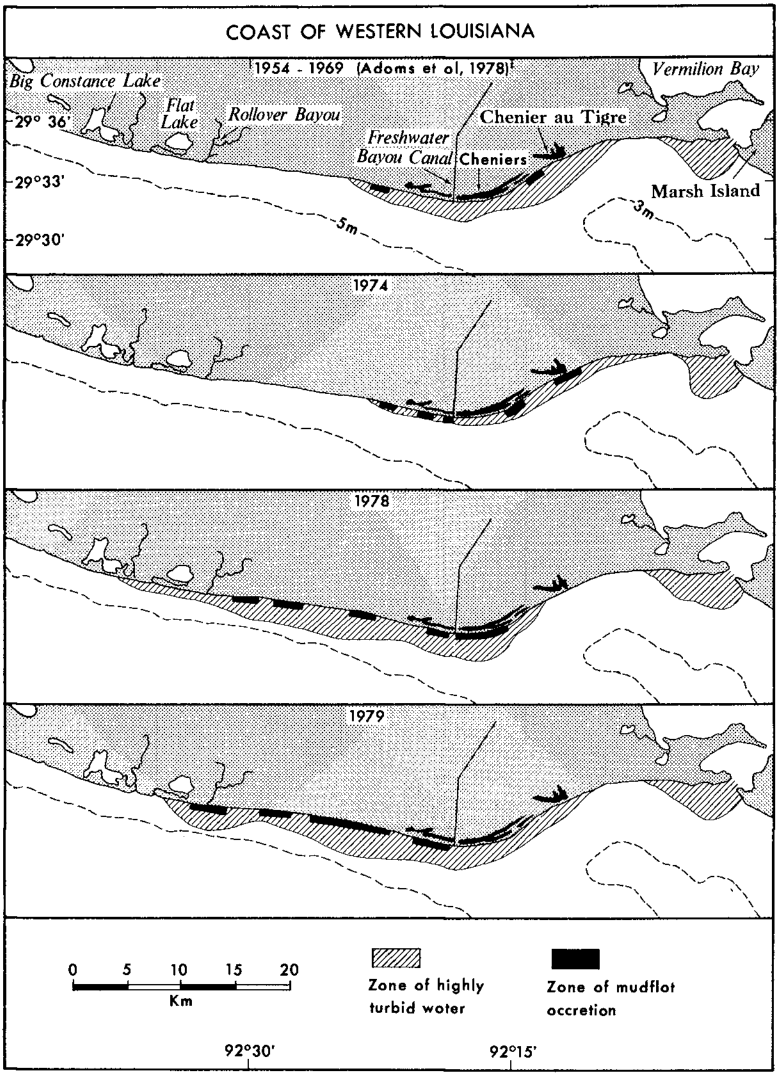

Figure 4. Areas of mudflat accretion from 1969 to 1979, Louisiana chenier plain. Segments of coast between mudflats are generally eroding. Note shift in sedimentation to the west.

2) increasing length of shoreline fronted by mudflats, and 3) shift in the locus of sedimentation to the west. No attempt has been made to plot previous shorelines, and our contention is simply that the presence of mudflats indicates a prograding shoreline. The basic question from an engineering standpoint, given the fact that simultaneous erosion and accretion do occur and that the system of mudflats is enlarging and spreading to the west, is, "How can future sites of erosion and accretion be predicted?" To begin answering that question requires field data from the sediment source, the pathway along which the sediment is carried, and the segments of coast that receive the sediment. To date we consider our findings in these areas to be of a reconnaissance nature.

Sediment source: Atchafalaya River. Field research in Atchafalaya Bay has been in progress for several years (Roberts et al., 1980), with emphasis presently on circulation and sediment transport. Earlier reports by Thompson (1955), Cratsley (1975), Shlemon (1975), and Rouse et al.(1978) have provided additional information on processes and rates of sedimentation, environments of deposition, and the initial phase of subaqueous delta growth. Information used in this and subsequent sections was gathered from many sources, including publications and files of the U.S. Army Corps of Engineers (USACOE), suspended-sediment analysis, current meter moorings, and aerial and ground surveys.

The volume of water delivered to the continental shelf from Atchafalaya River and the concentration of sediment in that water are factors presumed to be important to the growth of mudflats on the chenier plain. At present, nearly all of the sediment supplied to the chenier plain appears to be derived from the Atchafalaya River. Figure 5 shows the volume of sediment-laden water carried down the Atchafalaya River from 1956 to 1975. Mean monthly discharge averaged 5,126 cms from 1938 to 1972 (USACOE, 1974) and average annual peak flow, as shown by the dashed line (Fig. 5) is approximately 12,000cms.

Abnormally high waters were characteristic of the years 1973-1975. Average discharge was 8,864 cms with peak flows of approximately 20,000 cms in April 1973 and 18,000 cms in April 1975 (USACOE, 1975). During this period of high discharge, the Atchafalaya Delta emerged subaerially and evolved rapidly (Fig. 6).

Sediments that enter Atchafalaya Bay consist of fine sand, silt, and clay. Suspended-sediment concentrations at five stations within the bay (Fig. 6) taken during high-water discharge in 1980 show typical values of 200-300 mg/1, with highest concentrations occurring in bottom water (Table 1). Size analysis from USACOE data (Roberts et al., 1980) shows that 75-78 percent of suspended sediment in the river near its diversion point from the Mississippi River is silt and clay, whereas 63 percent of the sediment that eventually enters the bay is silt and clay sized.

Over the past 20 years sediments entering the bay have changed from a dominance of silt and clay to silt and fine sand. It is important to note, however, that, despite the increase in coarse sediment (sand) entering the bay, the volume of fine sediment (clay) also increased, but at a slower rate. The annual load of silt and clay to the bay is 61 x 10^6 metric tons,

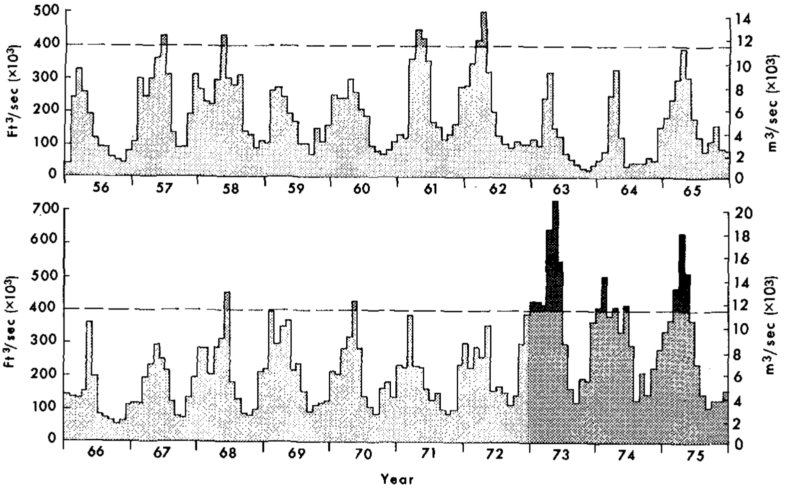

Figure 5. Mean monthly discharge from Atchafalaya River at Simmesport, Louisiana. Dashed line is average annual peak discharge.

or 146 x 10^6 m^3/yr, using a mass to volume conversion of 425 kg/m^3. Volumetrically, if one assumes that 80 percent of silt and clay leaves the bay for the inner shelf, then the shelf waters receive 117 x 10^6 m^3 of fine-grained sediment each year.

The 3 years of abnormally high discharge (1973-1975) were also years of extreme sediment flux into and through the Atchafalaya system (Fig. 7). On average, annual suspended sediment (including sand) into the bay during

TABLE 1.--SUSPENDED-SEDIMENT CONCENTRATIONS IN ATCHAFALAYA BAY, FEBRUARY-JUNE 1980

		Concentration (mg/l)	
Station	Depth	Minimum	Maximum
1	Surface	95	207
	Bottom	115	587
2	Surface	102	416
3	Surface	137	179
	Bottom	230	603
4	Surface	68	238
	Bottom	116	328
5	Surface	89	372

Figure 6. Photomosaic of Atchafalaya River delta 3 years after it first emerged subaerially. Stations 1-5 are locations of water samples used in suspended-sediment analysis.

these 3 years was 11.1 x 10^6 metric tons (261 x 10^6 m^3), nearly double that during the period 1965-1971. These flood events may be important in the subsequent development of mudflats on the chenier plain in that they provide perturbations to the already enormous sediment supply.

Sediment transport: coastal mud stream. Evidence that sediments which enter the Gulf of Mexico from Atchafalaya Bay are transported to the

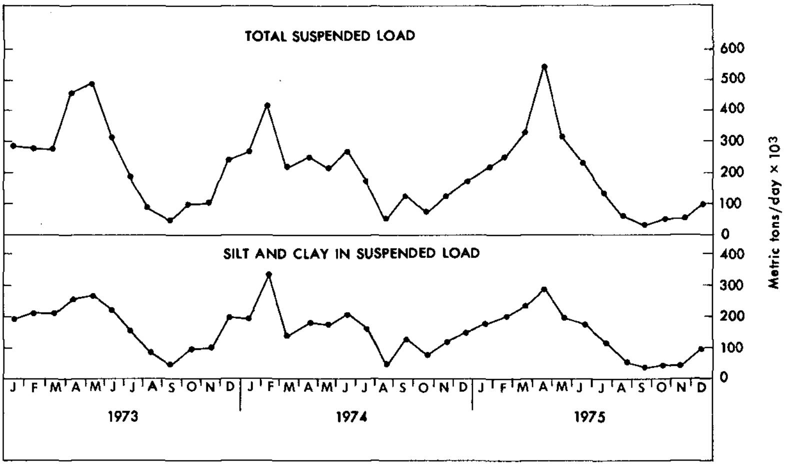

Figure 7. Total suspended load and silt and clay in suspended load during high discharge years 1973-1975.

west is provided by satellite imagery and current meter moorings. Figure 8 shows an ERTS Band 5 image that extends from Atchafalaya Bay to the eastern margin of the chenier plain. A turbid plume of water, shown as white, extends out from Atchafalaya Bay to a water depth of 5-10 m, then moves as a band along the south shore of Marsh Island and the western Louisiana coast. Similar bands of muddy water that originate from large rivers with high discharge of fine-grained sediments, such as those from the Mississippi, Amazon, and Po Rivers, have been referred to as mud streams (McCave, 1972) and we have applied this terminology to the Atchafalaya waters.

Current meter data taken at two stations seaward of Atchafalaya Bay in the spring of 1980 show residual currents to the southwest (parallel to the navigation channel) near the Point au Fer shell reefs and to the northwest farther out on the shelf (Fig. 9). Data at both stations are from mid-depth current meter moorings and were taken with Endeco 174 ducted-impeller, magnetic-recording current meters. Thirty-five days of data were obtained at station 1 and five days at station 2. Current speeds at station 1 are typically 10-30 cm/sec; direction of flow, although setting to the northwest, is influenced strongly by the passage of cold fronts every 5-7 days, which produce winds first from the southwest, then from the northwest. Current speeds at station 2 are 10-50 cm/sec and occur as well-defined pulses related to stage of the tide. Direction, however, does not reverse from tidal effects, but reflects a general flow to the south from Atchafalaya Bay with a strong westerly drift component from coastal waters.

Volume flux of silt- and clay-sized sediment into Atchafalaya Bay and onto the inner shelf is shown in Figure 10. To obtain an order-of-magnitude estimate of sediment transported northwest to the chenier plain, mass transport was calculated as

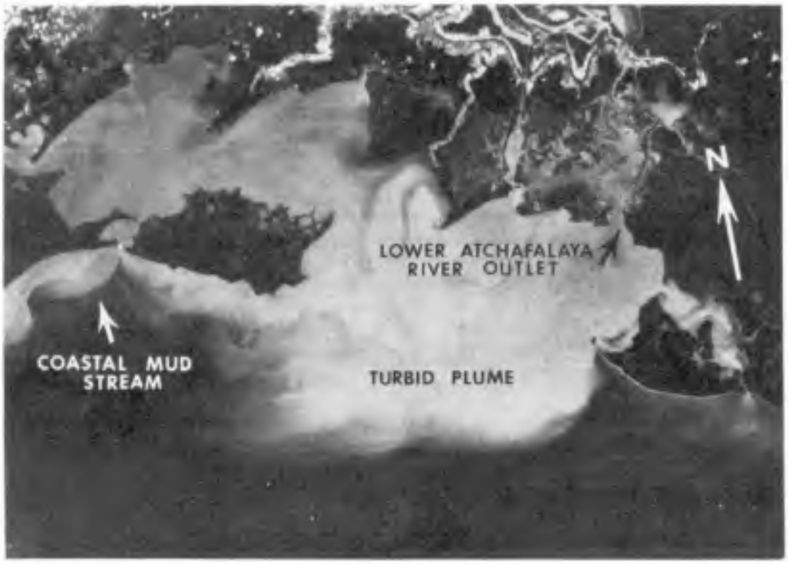

Figure 8. ERTS image (Band 5) of Atchafalaya Bay and central Louisiana coast taken in 1977.

$$T_M = \bar{c} \cdot \bar{v} \cdot A \tag{1}$$

where $\bar{c}$ = average concentration of suspended sediment, $\bar{v}$ = average velocity of residual current, and A = cross sectional area of the mud stream. Taking reasonable estimates of concentration (0.2 kg/m^3) and velocity (0.1 m/sec) through a 16-km-wide cross section normal to the coast resulted in a mass flux parallel to the coast of 640 kg/sec. To obtain an estimate of volume transport from mass transport,

$$T_v = T_m/\rho_c \tag{2}$$

was calculated, where ρ_c is sediment concentration of fluid muds in the nearshore and exposed as tidal flats (375 kg/m^3). When converted to transport per year, the volume of sediment moving in the Atchafalaya mud stream is 53 x 10^6 m^3. This represents nearly one-half of the total sediment that leaves Atchafalaya Bay and is nearly an order of magnitude larger than longshore volume transport rates on high-energy sandy beaches.

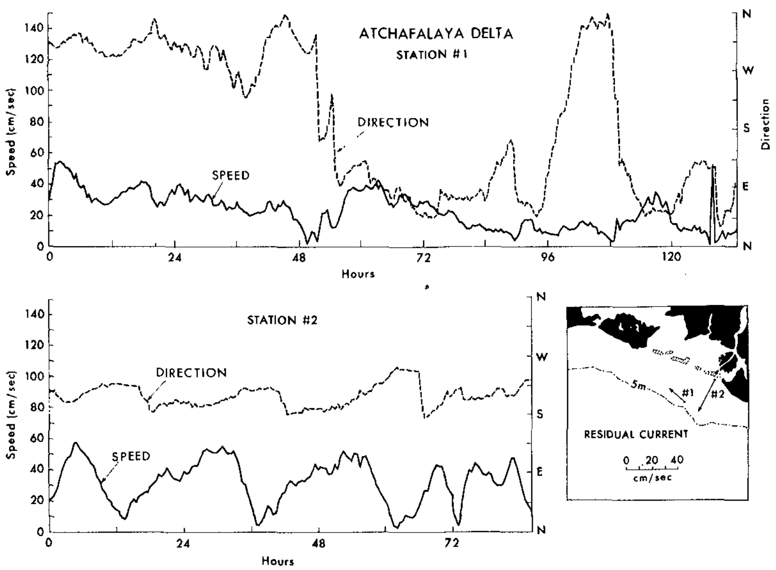

Figure 9. Examples of current speed and direction taken seaward of Atchafalaya Bay (see Fig. 10) in spring 1980. Residual currents are shown on the inset.

Sediment accumulation: chenier plain. Upon reaching the chenier plain, sediments accumulate as mudflats and subaqueous pools of fluid mud in the nearshore region. The initial accumulation of muds in the 1940s was attributed by Morgan et al. (1953) to a decrease in current strength in the vicinity of Chenier au Tigre as a result of the NE-SW shoreline configuration (see Fig. 4). Whereas the early mudflats were concentrated near Chenier au Tigre, they did extend as far west as Rollover Bayou. However, during the following 15 years (1954-1969) the intensity of mudflat progradation appeared to decrease, and, according to Adams et al. (1978), only two small segments of coast showed progradation in this time period (Fig. 4). The rapid mudflat progradation began again between 1969 and 1974.

The time correlation between years of abnormally high river discharge (1973-1975) and renewed mudflat development suggests that accretion, at least at the shoreline, follows sediment pulses from Atchafalaya River flood waters. During the time period between major flood events, sediment reaching the chenier plain may be deposited more gradually on the inner shelf as a blanket of silts and clays. If one computes the volume of a typical mudflat as 1-2 x 10^6 m^3, then 25-50 such mudflats could form each year from the 50 x 10^6 m^3/yr of sediment derived from the Atchafalaya mud stream. Since new mudflats do not form at this rate, much of the sediment from the Atchafalaya River may be deposited as a uniform thin veneer over a

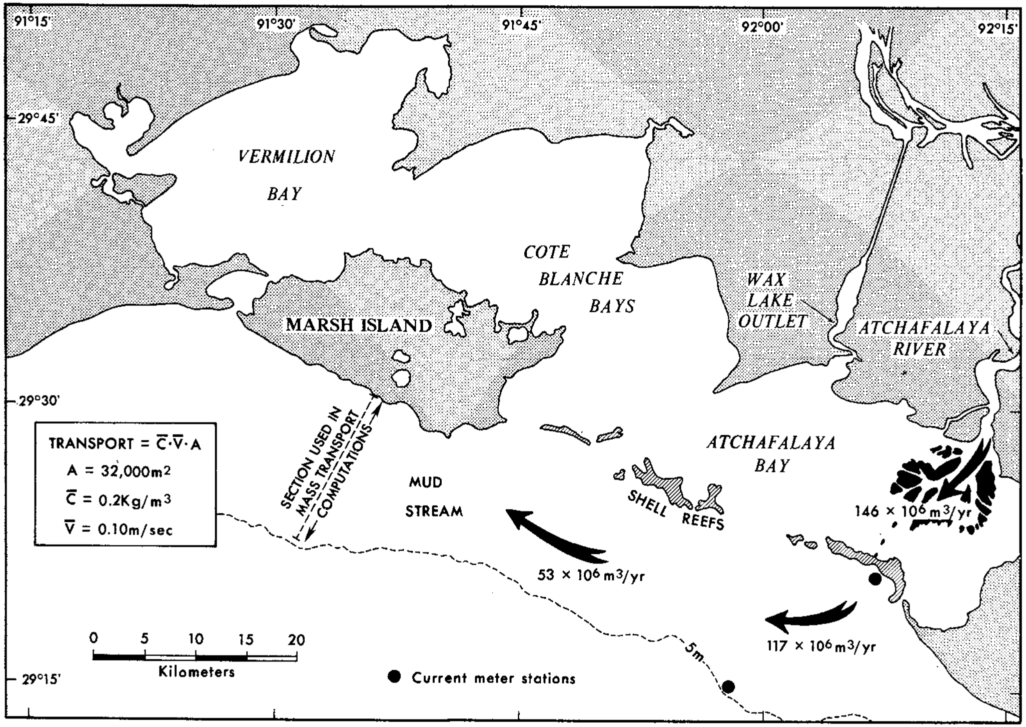

Figure 10. Central Louisiana coast showing computed values of volume flux of sediment into and through the Atchafalaya system. The coastal mud stream carries approximately 50 x 10^6 m^3/yr of silt and clay to the chenier plain.

longshore distance of perhaps 100 km or more.

Longshore currents are responsible for transporting the muds to the west, as shown in Figure 4. These currents are driven by waves arriving at the shoreline from an angle. The most frequently occurring waves on the Louisiana shelf are from the southeast: 42 percent of all waves are 1-1.5 m high and arrive from the southeast with periods of 4.5-6.0 sec (Becker, 1972). Longshore transport of sediment to the west is consistent with currents induced by waves that arrive from the southeast quadrant. Generally, the wave climate is one of low wave energy at the shoreline (Fig. 11).

The clouds of turbid water that can be seen in color infrared photography, ERTS imagery, and aerial overflights are the result of soft, fluid mud which remains partly in a suspended state, even under low wave activity. Because of their low bulk density and high water content (Table 2), new muds are easily eroded and are often ephemeral features. Samples taken in May 1980 show that suspended-sediment concentrations between Freshwater and Rollover Bayous range from 25 to 200 mg/l in surface waters. The input of suspended sediment from local sources on the eastern chenier plain is low, and the sediments in suspension, in addition to being caused by wave scour, reflect the high turbidity of the Atchafalaya mud stream. Field reconnaissance and sampling have revealed areas of dense suspension near bottom and, on occasion, a poorly defined water-sediment interface.

Predicting Future Trends

The basic hypothesis proposed in this study is that, if the dynamics of fluid muds in the inner-shelf environment can be understood, particu-

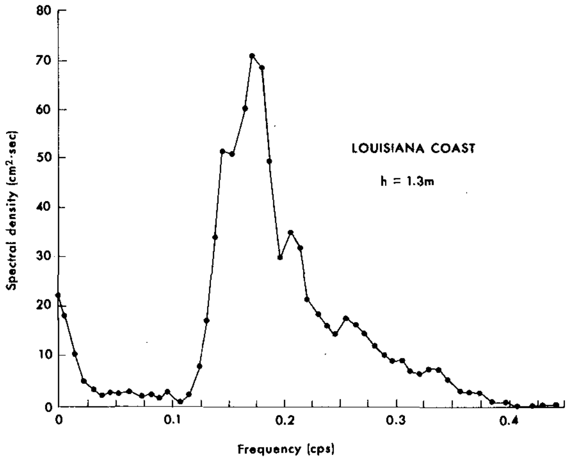

Figure 11. Spectrum of 6-sec waves from the southeast off Freshwater Bayou.

TABLE 2.--PROPERTIES OF COASTAL MUDS, LOUISIANA CHENIER PLAIN

Median diameter	1-5 microns
Bulk density	1.10-1.35 g/cm^3
Organic content	1-5%
Water content	61-89%
Viscosity	0.02-250 poises
Mineralogy	Montmorillonite:illite:kaolinite (3:1:1)

larly the question of where they accumulate and why they move, then areas of future erosion and accretion can be predicted. This hypothesis is based on the following rationale. First, wave energy is strongly attenuated when waves propagate over fluid muds; therefore, accumulation of muds on the inner shelf, such as at the "mud hole" (Morgan et al., 1953), will result in less wave attack at the shoreline itself (Fig. 12). Thus, segments of coast landward of fluid-mud accumulations should be areas of accretion as a result of the more favorable environment for fine-grained sedimentation. Second, fluid muds in the nearshore may periodically move onshore to become "shore-attached," thus causing the shoreline to prograde.

The rate of loss of wave energy on the inner shelf has been quantified from a similar environment in northeastern South America, where fluid muds blanket the bottom in layers 0.1-1.0 m thick (Wells, 1977). Figure 13 shows wave spectra constructed from simultaneous wave records taken at 22, 11, and 4 km offshore. By the time waves reach the station 4 km from shore in a water depth of 1.6 m, 94 percent of their energy has been lost. The shelf gradient in northeast South America is 0.0008, very close to the 0.001 gradient on the western Louisiana shelf. Often, waves never reach the shoreline, but are simply attenuated to nonexistence, without breaking (Wells, 1977; Wells et al., 1979). This sediment-water interaction is a true process-response relationship; muds attenuate waves,

Figure 12. Small waves propagating over a mudflat west of Freshwater Bayou.

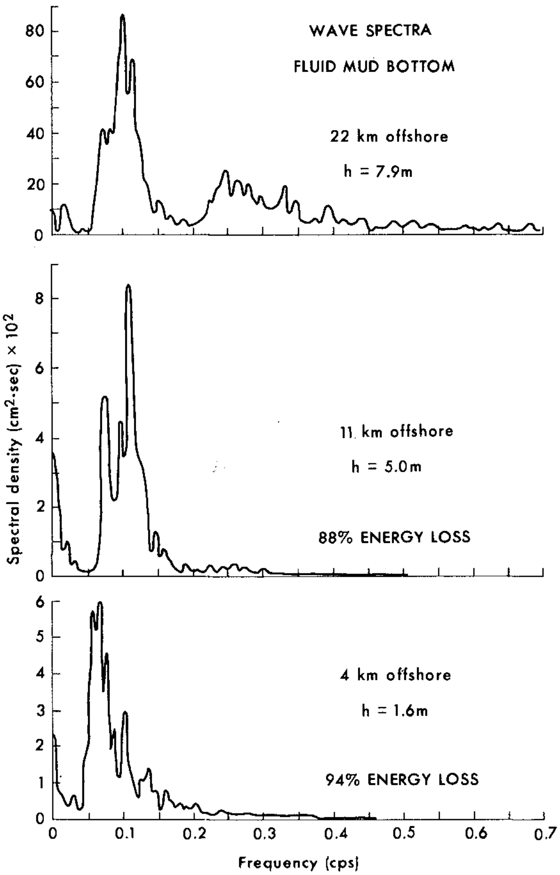

Figure 13. Wave spectra from simultaneous wave records taken off the coast of Surinam, South America. Bottom was blanketed by fluid muds similar to those in Louisiana.

which, because of their energy loss, allow even further sedimentation.

The mechanics of the process whereby muds move ashore are unknown, but have been suggested from results of research in other similar environments. Wells et al. (1979) have proposed that nonlinearity of shallow-water waves over soft muddy bottoms may produce a net drift in the direction of wave travel, thereby moving mud toward shore. The angle of wave approach controls the magnitude of the longshore component, hence the ability to translate muds alongshore, even if waves do not break as spilling or plunging breakers. Others have suggested that inner-shelf circulation may carry highly turbid bottom water shoreward and less turbid surface water seaward, thus "trapping" muds in the nearshore (Cibbs, 1976), and still other researchers have explained mud accumulation on tidal flats as a result of settling lag (Postma, 1954) and scour lag (Van Straaten and Kuenen, 1957).

Once muds are exposed subaerially and begin to dewater, they gain strength rapidly. Figure 14 shows a plot of bulk density versus apparent viscosity for fluid muds in northeastern South America. A small linear increase in density as a result of dewatering and consolidation can lead to a large (exponential) increase in viscosity, which is related to sediment strength (Krone, 1963; Owen, 1970). If muds are exposed to conditions of drying and continue to dewater until density reaches 1.20-1.25 g/cm^3, then shear strength may be sufficient to withstand normal wave attack. Coincident with this early stage of consolidation, vegetation becomes established. Barring catastrophic storm events, vegetation will flourish, and within a year the new mudflat will become permanently attached to form a wedge of Holocene sediments.

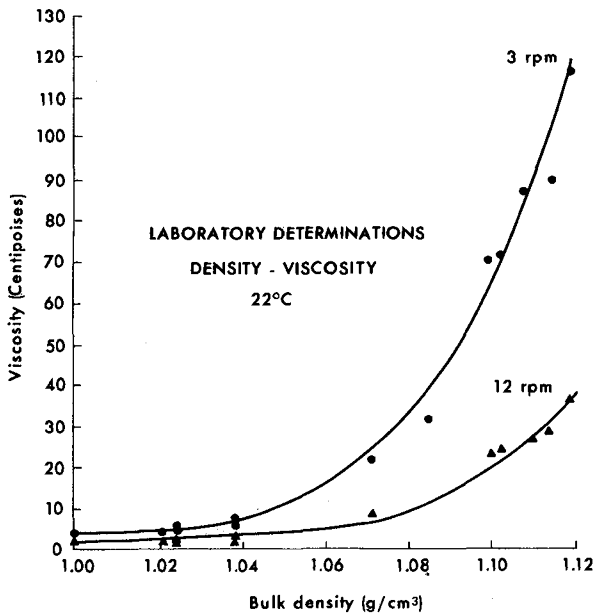

Figure 14. Plot of bulk density versus apparent viscosity in fluid muds from northeastern South America.

The process of mudflat sedimentation described above is altered significantly during major storms and the passage of hurricanes. For example, storm waves associated with Hurricane Audrey in 1957 caused higher than normal retreat rates on the western chenier plain, yet produced in only a few days' time near Freshwater Bayou two mud arcs 300 m wide, 2 m thick, and a total of 7200 m long (Morgan et al., 1958). At present we are unable to predict the effects of storms and hurricanes on coastlines fronted by fine-grained sediments.

Segments of coast between mudflats are typically eroding (Fig. 15), and the processes of erosion and accretion are cyclical in both time and space. Because of this cyclical nature of mudflat development, areas of future erosion and accretion have been predicted with moderate success in northeastern South America (Delft Hydraulics Laboratory, 1962; NEDECO, 1968) by studying locations of fluid mud accumulations. As in coastal Louisiana, conditions that favor fine-grained sedimentation in northeastern South America are 1) large supply of fine-grained sediments, 2) prominent westward drift, 3) strong wave attenuation, 4) shoreward movement of fluid muds, and 5) consolidation and increase in shear strength. Using this knowledge, studies are presently underway in Louisiana to locate and track fluid muds in the nearshore, and it is anticipated that future research into details of how fluid muds move will refine our predictive capabilities.

Acknowledgments

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Figure 15. Eroding marsh near Rollover Bayou.

Office of Naval Research, Arlington, Virginia 22217. Illustrations were prepared by Mrs. Gerry Dunn.

References

Adams, R. D., Banas, P. J., Baumann, R. H., Blackmon, J. H., and McIntire, W. G., "Shoreline Erosion in Coastal Louisiana: Inventory and Assessment," Final Report to Louisiana Department of Transportation and Development, 1978, 139 pp.

Becker, R. E., "Wave Energy Studies along the Louisiana Coast," Report No. 12, Coastal Resources Unit, Center for Wetland Resources, Louisiana State University, Baton Rouge, 1972, 22 pp.,

Cratsley, D. W., Recent Deltaic Sedimentation, Atchafalaya Bay, Louisiana, M.S. Thesis, Louisiana State University, Baton Rouge, 1975, 142 pp.

Delft Hydraulics Laboratory, Demerara Coastal Investigation, Delft, The Netherlands, 1962, 240 pp.

Fisk, H. N., 1952, "Geological Investigations of the Atchafalaya Basin and the Problem of Mississippi River Diversion," U.S. Army, Corps of Engineers, Mississippi River Commission, Vicksburg, Vol. 1, 1952, 145 pp.

Gibbs, R. J., "Amazon River Transport in the Atlantic Ocean," Geology, Vol. 4, 1976, pp. 45-48.

Gould, H. R., and McFarlan, E., Jr., "Geologic History of the Chenier Plain, Southwestern Louisiana," Transactions, Gulf Coast Association of Geological Societies, Vol. IX, 1959, pp. 1-10.

Howe, H. V., Russell, R. J., McGuirt, J. H., Craft, B. C., and Stevenson, M. B., "Reports on the Geology of Cameron and Vermilion Parishes," Bulletin 6, Louisiana Geological Survey, 1935, 242 pp.

Krone, R. B., "A Study of Rheologic Properties of Estuarial Sediments," Technical Bulletin No. 7, Commission on Tidal Hydraulics, U.S. Army Corps of Engineers, 1963.

McCave, I. N., "Transport and Escape of Fine-grained Sediment from Shelf Areas," Shelf Sediment Transport: Process and Pattern, D. J. P. Swift, D. B. Duane, and O. K. Pilkey, eds, Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, 1972, pp. 225-248.

Morgan, J. P., and Larimore, P. B., "Changes in the Louisiana shoreline," Transactions, Gulf Coast Association of Geological Societies, Vol. VII, 1957, pp. 303-310.

Morgan, J. P., Nichols, L. G., and Wright, M., "Morphological Effects of Hurricane Audrey," Technical Report No. 10, Coastal Studies Institute, Louisiana State University, Baton Rouge, 1958, 53 pp.

Morgan, J. P., Van Lopik, J. R., and Nichols, L. G., "Occurrence and Development of Mudflats along the Western Louisiana Coast," Technical Report No. 2, Coastal Studies Institute, Louisiana State University, Baton Rouge, 1953, 34 pp.

NEDECO, Surinam Transportation Study, Netherlands Engineering Consultants, The Hague, 1968, 293 pp.

Owen, M. W., "Properties of a Consolidating Mud," Report No. INT 78, Hydraulics Research Station, Wallingford, England, 1970, 40 pp.

Postma, H., Hydrography of the Dutch Wadden Sea, Thesis, Croningen. Arch. Neerland. Zoologie, X, 4e Livaison, 1954, 106 pp.

Roberts, H. H., Adams, R. D., and Cunningham, R. H. W., "Evolution of Sand-Dominant Subaerial Phase, Atchafalaya Delta, Louisiana," Bulletin American Association of Petroleum Ceologists, Vol. 64, 1980, pp. 264-279.

Rouse, L. J., Roberts, H. H., and Cunningham, R. H. W., "Satellite Observation of the Subaerial Growth of the Atchafalaya Delta, Louisiana," Geology, Vol. 6., 1978, pp. 405-408.

Russell, R. J., and Howe, H. V., "Cheniers of Southwestern Louisiana," Geographical Review, Vol. 25, 1935, pp. 449-461.

Shlemon, R. J., "Subaqueous Delta Formation--Atchafalaya Bay, Louisiana," Deltas, M. L. Broussard, ed., Houston Ceological Society, 1975, pp. 209-221.

Stratten, L. M. J. U. van, and Kuenen, Ph. H., "Accumulation of Fine-Crained Sediments in the Dutch Wadden Sea," Ceologie en Mijnbouw, Vol. 19, 1957, pp. 329-354.

Thompson, W. C., "Sandless Coastal Terrain of the Atchafalaya Bay Area, Louisiana, Finding Ancient Shorelines, J. L. Hough and H. W. Menard, eds., Special Publication No. 3, Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma, 1955, pp. 52-76.

U. S. Army Corps of Engineers, National Shoreline Study: Inventory Report--Lower Mississippi Region, New Orleans District Report, 1971, 57 pp.

U.S. Army Corps of Engineers, Preliminary Draft Envirionmental Impact Statement, Atchafalaya Basin Floodway, New Orleans, 1974.

U.S. Army Corps of Engineers, "Stages and Discharges of the Mississippi River and Tributaries in the New Orleans District," Annual Volumes 1973-1975, New Orleans, 1975.

Wells, J. T., Shallow-water Waves and Fluid-Mud Dynamics, Coast of Surinam, South America, Ph.D. dissertation, Louisiana State University, Baton Rouge, 1977, 99 pp.

Wells, J. T., Coleman, J. M., and Wiseman, Wm. J., Jr., "Suspension and Transportation of Fluid Mud by Solitary-like Waves," Proceedings, 16th Conference on Coastal Engineering, Hamburg, Germany, 1979, pp. 1932-1952.