RESEARCH ARTICLES

FACIES AND EVOLUTION OF THE MODERN BRAZOS DELTA, TEXAS: WAVE VERSUS FLOOD INFLUENCE

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ABSTRACT: **In order to better define the facies architecture and processes controlling the evolution of wave-dominated deltas, a detailed sedimentary and geomorphologic study was undertaken on the Brazos Delta, Texas. The delta has formed since 1929, when the Brazos River was diverted by the U.S. Army Corps of Engineers. The Brazos Delta is composed primarily of fine-grained sediments. Prodelta clay constitutes more than half of the sediment volume. Thick sands are restricted to the narrow delta-front environment, whereas back-bar lagoonal clays are a significant component of the delta-plain sequence. The facies architecture is not representative of the classic strandplain model for wave-dominated deltas. This is due to the strong influence of floods on deltaic evolution.**

In early 1992, statewide flooding gave rise to a major constructional phase of the delta. Significant quantities of fine-grained sediments were deposited in the prodelta. One year after the onset of flooding, a channel mouth bar emerged offshore of the river mouth and enabled progradation of the delta. Similar flood events that occurred during 1941, 1957, and 1965 were recorded as ridge–trough pairs in the delta headland. The Brazos delta is therefore fluvially influenced during floods and wave influenced during intervening periods.

INTRODUCTION

The well-known ternary delta classification system indicates that delta morphology and three-dimensional structure is dominantly controlled by river discharge, tidal range, and wave energy (Fisher 1969; Fisher et al. 1969; Coleman and Wright 1975; Galloway 1975). According to this classification, the subaerial shape of wave-dominated deltas is cuspate, whereas fluvial-dominated deltas are elongate to lobate. On the basis of these criteria, the Brazos delta has previously been classified as a wave-dominated delta (Galloway 1975). Although this classification scheme accurately describes the gross controlling factors for subaerial delta morphology, it makes inaccurate assumptions concerning the mechanism for emplacing sands, and the extent of prodelta facies.

Sedimentological investigations of modern wave-dominated deltas have concentrated mainly on the onshore portions of these deltas (Van Straaten 1959; Lagaaij and Kopstein 1964; Bernard et al. 1970; Psuty 1967; Oomkens 1970; Coleman and Wright 1975; Dominguez 1996). On the basis of these studies, the dominant facies of wave-dominated deltas include beach-ridge, interridge-swell, and eolian deposits. In most cases, offshore facies relationships for these deltas were inferred because of a lack of data collected from the subaqueous delta environments. The results of outcrop and subsurface studies indicate that ancient wave-dominated deltas may have distinct and widespread marine facies and that the preservation potential of these marine facies is high (Fisher 1969; Fisher and McGowen 1969; Ricoy and Brown 1977; Bebout and Loucks 1978; Foss 1979; Weise 1979).

The objective of this study was to identify and describe the active (onshore and offshore) depositional environments, facies architecture, and stratigraphy of the modern Brazos wave-dominated delta. The facies architecture and idealized depositional sequence for the delta were derived by examining the near-surface lithofacies of the delta's active environments. This stratigraphic model was tested by examining the onshore part of the delta, where, because of delta progradation, a complete succession of delta facies has evolved.

The modern Brazos Delta is located in east Texas (Figs. 1, 2A). Detailed sedimentological work on the onshore part of the delta during early development was conducted by Bernard et al. (1970), and provided an important framework for our work. During the course of our investigation, the Brazos River experienced the longest-lived flood in historical times, and the delta underwent a series of dramatic changes in response to this event. This investigation was drawn out over a period of five years so that the influence of this flood could be studied.

STUDY AREA

The coastal zone encompassing the Brazos Delta is a climatically dynamic region. Since 1900, the zone experienced the effects of tropical storms or hurricanes once every two years, on average. Average annual rainfall ranges from 103.7 centimeters to 124.87 centimeters, with large deviations during flooding and tropical-storm-induced precipitation. Winds are dominantly southeasterly, averaging 5–15 knots. Extratropical northers affect the area as frequently as 15 to 20 times per year, generating high-velocity (15–50 knots) northeasterly winds (McGowen et al. 1977). The dominant southeasterlies set up waves trending northeast–southwest, which approach the shore in a northwest direction. The prevailing longshore currents flow from east to west.

The Brazos River leads all Texas rivers in rates of flow. Its watershed encompasses 118,000 square kilometers and includes large sections of north-central Texas and eastern New Mexico. The average annual suspended-sediment yield of the Brazos is the highest of all rivers in Texas, 39 metric tons per square kilometer (Curtis et al. 1973). The sediments of the Brazos River have a distinctive red color and are characterized by fine grain sizes; most of the sediment load is of clay size. These sediments are derived mainly from Triassic red beds located in the upper reaches of the drainage basin in northwestern Texas and northeastern New Mexico.

The Brazos Delta is located immediately southwest of Freeport, Texas at coordinates 28° 52′ N lat and 095° 23′ W long (Figs. 1A, 2A). It is approximately 35 km² in area and extends seaward to water depths of 20 meters. The delta has formed since 1929, when the Brazos River was diverted by the U.S. Army Corps of Engineers in an effort to reduce flooding and shoaling at Freeport (Seelig and Sorensen 1973).

The morphologic outline of the coast at the delta is lobate, with a significant headland on the western flank of the delta (Figs. 1A, 2A). Deposition is asymmetrical, and the delta accretes to the west along the projecting headland. Overall morphology is controlled by sediment flux and wave energy and is extremely dynamic. The east flank of the delta is composed of a series of amalgamated beach ridges at the former (pre–river diversion) shoreline position, a large lagoon immediately seaward, and another set of beach ridges parallel and adjacent to the shore (Fig. 2A). The west flank of the delta is composed of a series of ridges that occur as amalgamated and non-amalgamated ridge sets (Fig. 2A). In addition, tidal channels and washover channels are common throughout the area. Water depths in the interridge troughs are tidally controlled, averaging 0.25 to 0.5 meters. The orientation of the beach ridges is a result of wave refraction

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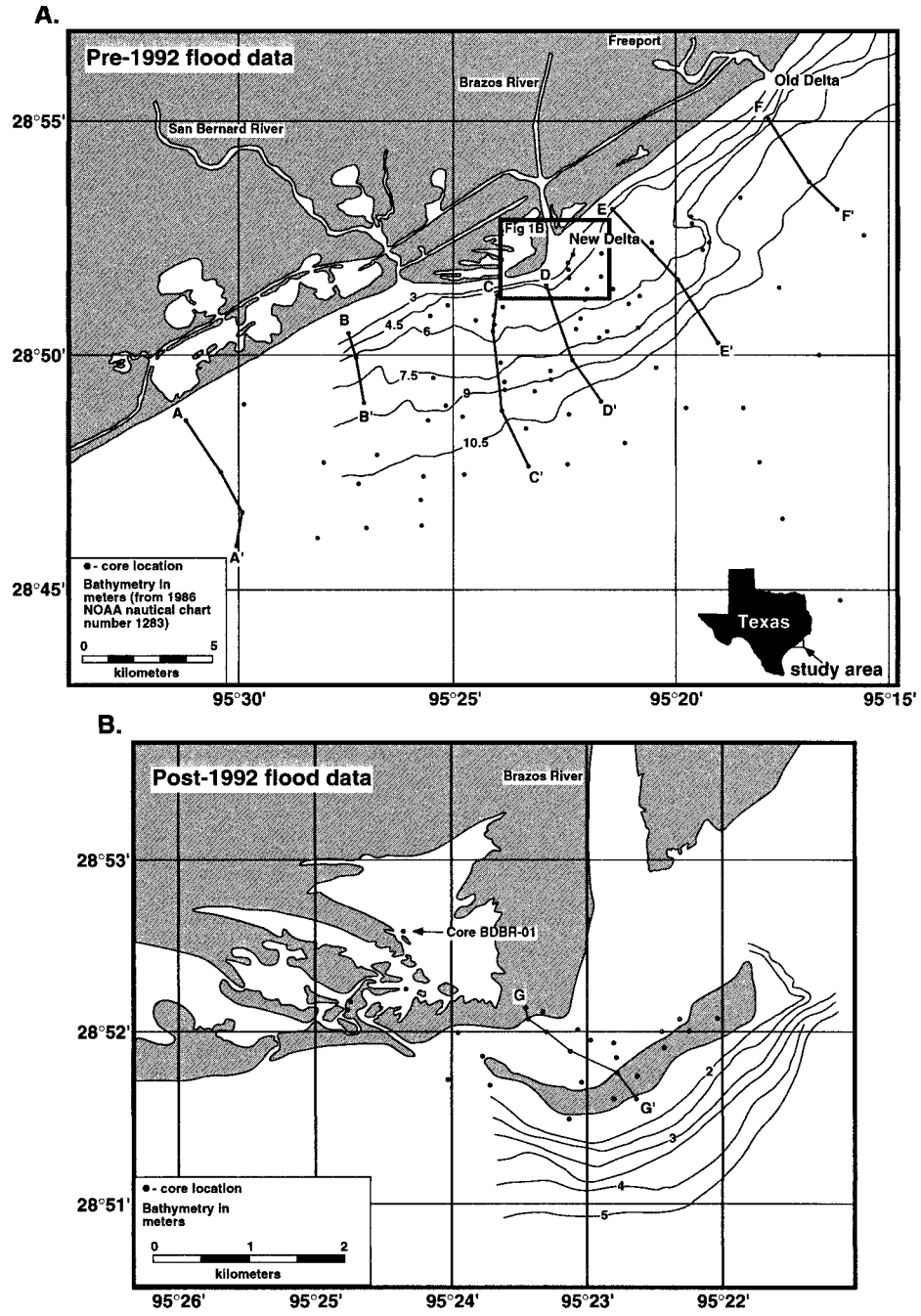


FIG. 1.—Maps of the study area showing locations of cores and transects referred to in this paper. Bathymetry taken from the National Oceanic and Atmospheric Administration nautical chart number 1283 dated 1989.

around the headland. The subaqueous delta is located mainly to the west of the river mouth and is present along shore for approximately 10–15 kilometers (Fig. 3). In all, the subaqueous delta comprises nearly 70% of the total area of the delta.

METHODS

Approximately 120 cores were collected for this study (Fig. 1A, B). Vibracores were collected onshore and in shallow waters, and a pneumatic hammer coring device was used offshore. Cores were described immediately after cutting and stored in a refrigerated storage facility. Analyses of sediments included descriptions of color, sedimentary structures, determination of total water content, grain-size analysis, determination of gross mineralogy, and cursory paleontologic examination. An automated settling tube was used for grain-size analysis.

Historical coastal navigation maps dating to the early 1900s and historical aerial photographs were used to examine the delta's development from its inception in 1929 to the present. Additional aerial photographs were acquired as part of this study. Photographs were taken at altitudes of 150 meters (500 feet) to 2500 meters (8000 feet).

DELTAIC PROCESSES

Prior to 1929, the Brazos Delta was located east of Freeport near Surfside Beach at coordinates 28°55.5′ N lat. and 095° 17.5′ W long. (Fig. 2B). More detailed descriptions of shoreline changes since 1850 in the vicinity

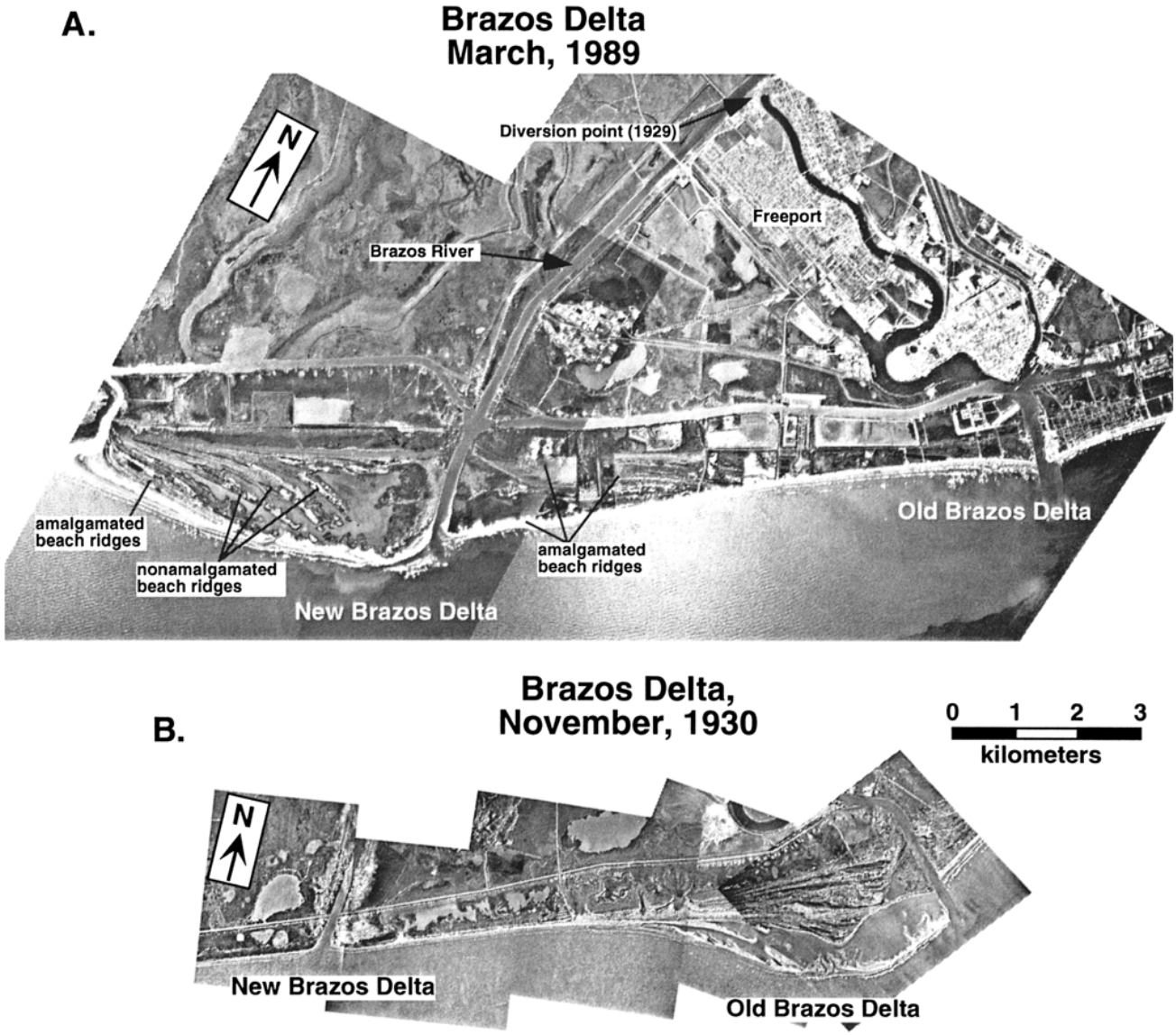


FIG. 2.—Scaled aerial photographs of the Brazos delta taken in **A)** 1989 and **B)** 1930. The 1930 delta photo was taken shortly after river diversion and depicts the early stage of delta reworking. The photos illustrate the significant amount of sediments eroded from the old delta and deposited at the new delta following river diversion.

of the Brazos River Delta can be found in Seelig and Sorensen (1973) and Morton and Pieper (1975). A synopsis of the historical evolution of the delta is presented here to highlight periods of delta progradation and reworking, and to link periods of progradation to significant floods.

The first detailed bathymetric survey of the area was carried out by the National Ocean Survey in 1852 and indicates that the Brazos River had only a small subaerial delta with a major channel mouth bar to the west of the river mouth (Seelig and Sorensen 1973). After the Freeport Jetties were constructed in 1881, a delta immediately began to expand (Seelig and Sorensen 1973). Although wave energy has significantly reworked this old delta, an aerial photograph from 1930 reveals a morphology similar to that of the new delta (Fig. 2A, B). (''old'' is used to describe the Brazos Delta location prior to river diversion in 1929, and ''new'' is used to describe its current location.) The old delta was approximately 30–35 km^2 in area and extended seaward to 20 meters water depth. Similarly to the new delta, the old delta was asymmetrical to the west, with amalgamated ridges on the eastern and western flanks (Fig. 2A, B). The morphology of the shoreline was also lobate, with a significant headland on the west flank.

Time reconstructions based on the National Oceanic and Atmospheric Administration nautical chart number 1283 (Fig. 3) trace the development of the delta over the last six decades. Prior to diversion, as seen in the 1922 map, the Brazos entered the Gulf southeast of Freeport. The delta had an asymmetrical lobate shoreline with the west flank dominant. This morphology was largely due to the construction of the Freeport Jetties and the longshore current direction (east to west). A significant subaqueous lobe also existed and prograded into water depths of at least −10.5 meters. The river diversion occurred in 1929, and by December 1931 the subaerial part of the pre-1929 delta was already being reworked (Fig. 3). Sands from the old delta lobe were moved along shore and deposited near the east flank of the new delta, creating an extensive low-lying subaerial delta plain. By 1940, few remnants of the old delta remained and headland progradation of the new delta was extensive (Fig. 3). Net headland accretion of the new delta has occurred more or less continuously since that time, but at a slower rate. The onshore part of the delta has prograded approximately 6.5 kilometers since 1929.

Throughout the history of the new delta, a prominent channel mouth bar

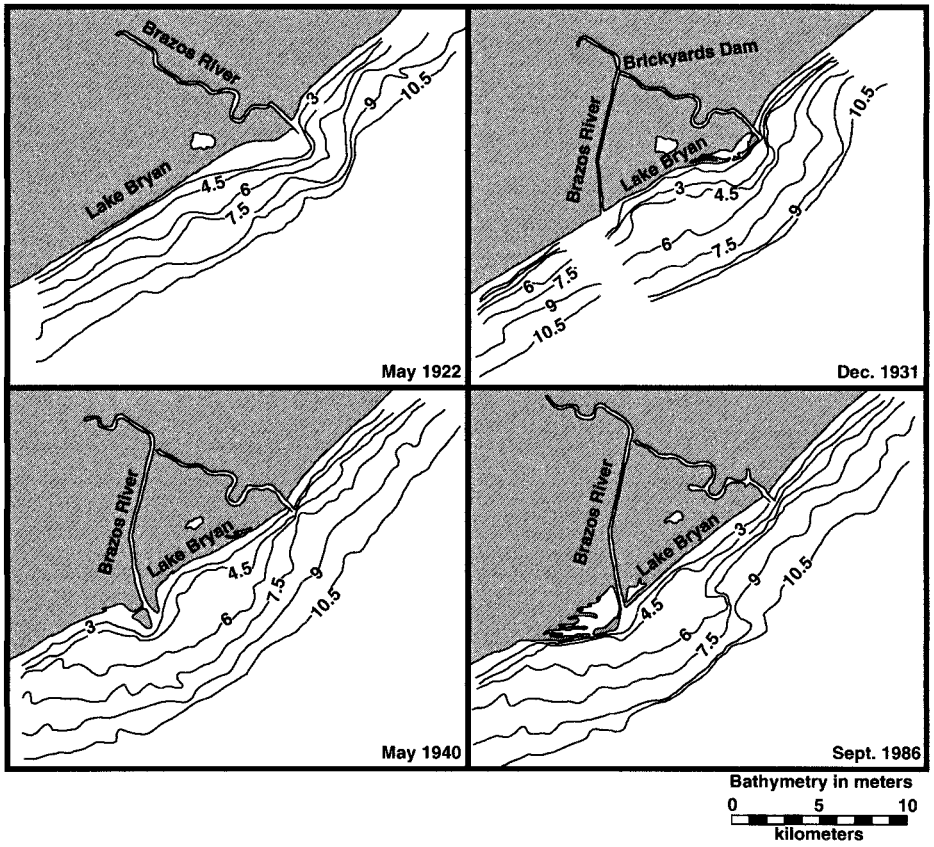


FIG. 3.—Evolution of the Brazos delta since 1922 based on the National Oceanic and Atmospheric Administration nautical chart number 1283. These charts show rapid erosion of the old delta at depths greater than 10 meters following river diversion. By 1940 the old delta had no bathymetric expression.

and associated back-bar lagoon have appeared and disappeared on several occasions. Examination of historical aerial photographs and U.S. Geological Survey river discharge data (Richmond, Texas gauging station number 08114000) revealed that episodes of expansion and emergence of the channel mouth bar were associated with major floods that occurred in 1941, 1957, 1965, and 1992 (Figs. 4, 5, 6, 7). Figures 6 and 7 show emergent channel mouth bars that were enlarged as a result of the 1965 and 1992 floods.

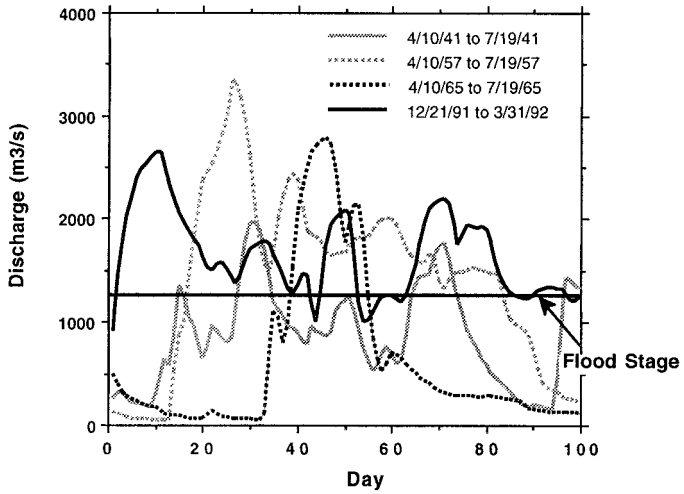


FIG. 4.—Time versus discharge for the Brazos River. Data acquired during the largest floods of this century are plotted. Discharge data were obtained from the U.S. Geological Survey gauging station, Richmond, Texas, number 08114000.

Other floods in addition to the 1941, 1957, 1965, and 1992 events have affected the Brazos River. That these floods did not significantly prograde the delta is mainly due to their shorter duration. The more time the river is above flood stage, the more pronounced the effect the flood has on delta progradation. The floods that occurred in 1941, 1957, 1965, and 1992 are among the longest-duration floods of this century. The Brazos River was at flood stage for about 80 days during the 1992 flood.

Following each episode of bar development, the bar was reworked shoreward and westward by waves, and eventually its western edge welded to the shoreline (Figs. 6, 7). As the offshore bar migrated landward, the preflood shoreline was preserved within the headland as a ridge; the offshore bar became the new shoreline. The back-bar lagoon was also preserved within the headland as a trough, separating the ridge from the newly formed shoreline. Each ridge within the delta headland represents the location of a previous shoreline (Fig. 5). One complete flood cycle for the delta spans from flood initiation to the preservation of a ridge/trough pair within the western delta headland and typically takes about six years (Figs. 5, 6). During intervals between large floods, shoreline growth is characterized by amalgamation of beach ridges due to waves reworking and redistributing sands on the western delta headland (Fig. 5). River discharge data indicates that between 1965 and 1992 no significant floods affected the area. This is expressed as amalgamated beach ridges located on the western delta headland in the March 1989 aerial photograph (Fig. 5).

Storm frequency is another important factor affecting delta progradation. A well-timed hurricane or tropical depression may remove an emergent channel mouth bar before it has time to evolve into a new shoreline. Seelig and Sorensen (1973) examined the impact of storms on delta morphology and concluded that the onshore environment (the ridges, troughs, and beach) has not been altered by storms; however, storms have affected the delta-front environment. Hurricane Carla struck the Brazos Delta in 1961

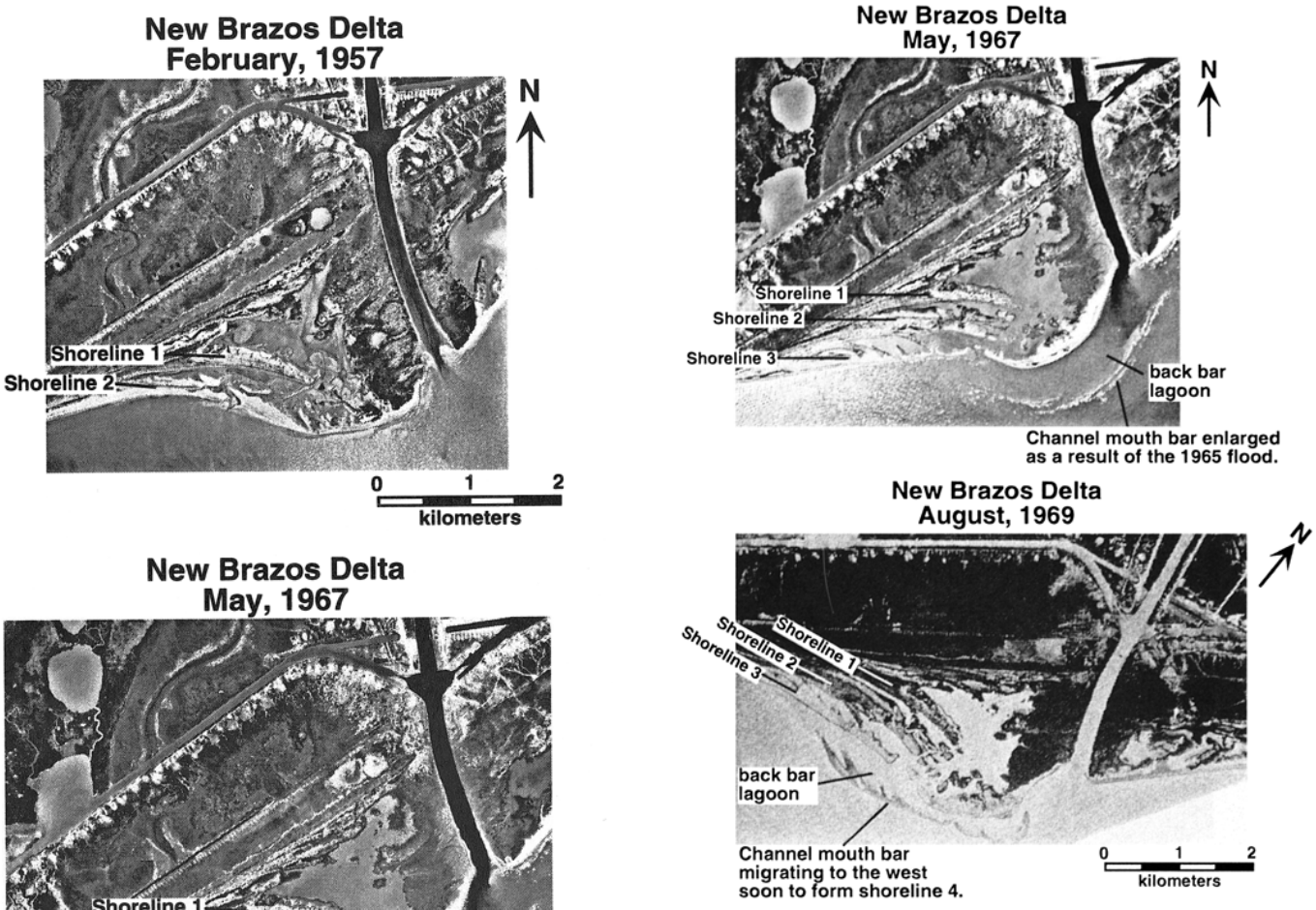


FIG. 6.—Scaled aerial photographs of the New Brazos delta illustrating the progradation event that resulted from the 1965 flood (modified after Seelig and Sorensen 1973).

and swept away sand bars from the delta-front environment (Seelig and Sorensen 1973). If this storm had struck in 1969 it might have removed the emergent channel mouth bar created from the 1965 flood (Fig. 6). Two tropical depressions affected the Brazos Delta in 1998. At that time the channel mouth bar had become welded to shore but had not yet formed a new shoreline (Fig. 7D). The channel mouth bar was completely removed by these storms. Therefore, floods are important progradational mechanisms for the delta, but a well timed storm may remove all traces of the flood event.

The most recent episode of bar emergence occurred eight months after the 1992 flood (Figs. 1B, 7). During this event, the bar formed in water depths of between 3 and 4 meters. In January 1995 it was approximately 0.3 kilometers wide and 2.5 kilometers long. Relief on the bar exceeded 2.5 meters, with average elevation at 0.5 meters above sea level (Fig. 7A). Bar evolution during the period between 1992 and 1997 was monitored by routine reconnaissance flights and trips to the delta, including reoccupation of coring sites and GPS transects across the bar. These combined observations have revealed extensive changes, particularly to the bar area and onshore sections. These include migration of large-scale bedforms, creation

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FIG. 5.—Scaled and oriented aerial photographs of the New Brazos delta illustrating delta progradation. Following each large flood a new ridge/trough pair was preserved in the western delta headland.

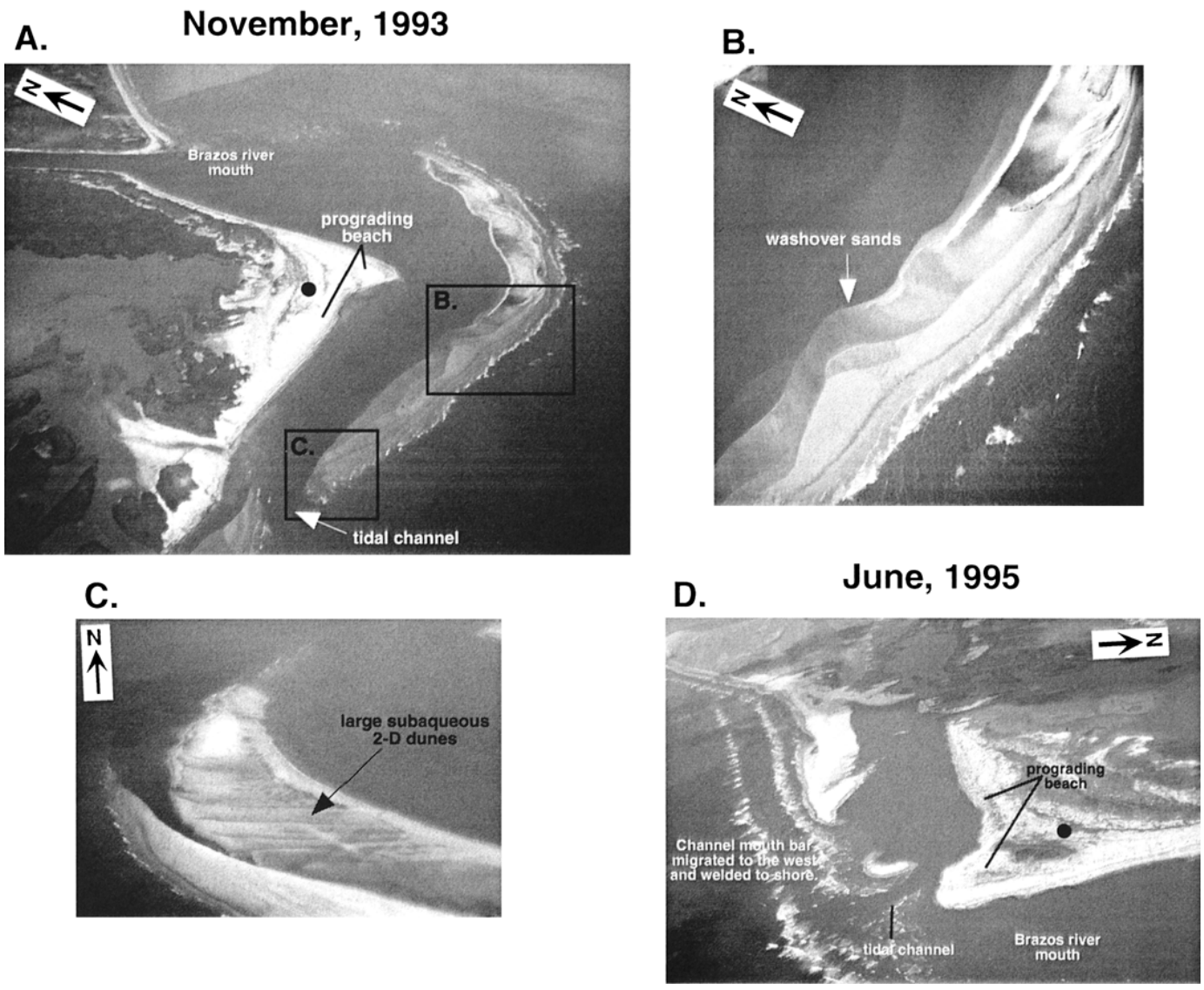


FIG. 7.—Unscaled aerial photographs of the offshore emergent bar. The bar is located to the southwest of the river mouth (A) and is made up of smaller bars amalgamated together (B). Washover deposits frequently inundate the back-bar lagoon (B). The southwestern part of the bar contains large subaqueous 2-D dunes migrating towards shore as the bar welds to the shoreline (C). By June 1995 (D) the bar had completely welded to the shoreline and was in the process of becoming the new shoreline. The dot located on the western delta headland (A, D) marks the same location in both photos.

and destruction of tidal channels, washover during storms, and eventually the bar welding itself to the mainland (Fig. 7D). These observations, coupled with detailed descriptions of each delta facies, were used to examine the sedimentological evolution and facies architecture of the delta.

DEPOSITIONAL ENVIRONMENTS AND LITHOFACIES

Detailed examination of approximately 120 vibracores and pneumatic hammer cores (located in Figure 1A, B) revealed both the modern facies and the overall stratigraphy of the Brazos delta. This study focused mainly on the offshore and nearshore parts of the delta (Fig. 1A, B), because that is the least understood part of this and other wave-dominated deltas. The sediment cores show a fairly systematic change in facies with increasing distance from shore and water depth. Figure 8 illustrates the offshore distribution of the various depositional environments, and Figures 9 and 10 show representative core transects across the delta. Many cores bottomed out in a mottled green and red, very stiff (shear strength > 1.0 kg/cm^2) Pleistocene (Beaumont Formation) clay (Fig. 9). This unit is unrelated to the Brazos Delta and therefore was not examined in detail. Seafloor gradients increase rapidly west and east of the river mouth (Figs. 1A, 9). The following is a general description of the main sedimentary environments and facies.

Onshore Environments

The onshore part of the delta comprises beach ridges separated by interridge troughs and associated tidal creeks, washover fans, and the beach. Beach ridges are the dominant geomorphic element (Fig. 5).

Beach Ridge.—Beach-ridge sands are more mature (texturally and mineralogically) than beach sands, as a result of winnowing by eolian and washover processes. They have a dominant grain-size mode of 2.75–3.0 phi and are moderately sorted (Fig. 11B). Root casts are common. The intertidal sediments on the margins of the ridge are sandy, but have approximately 10% mud by mass.

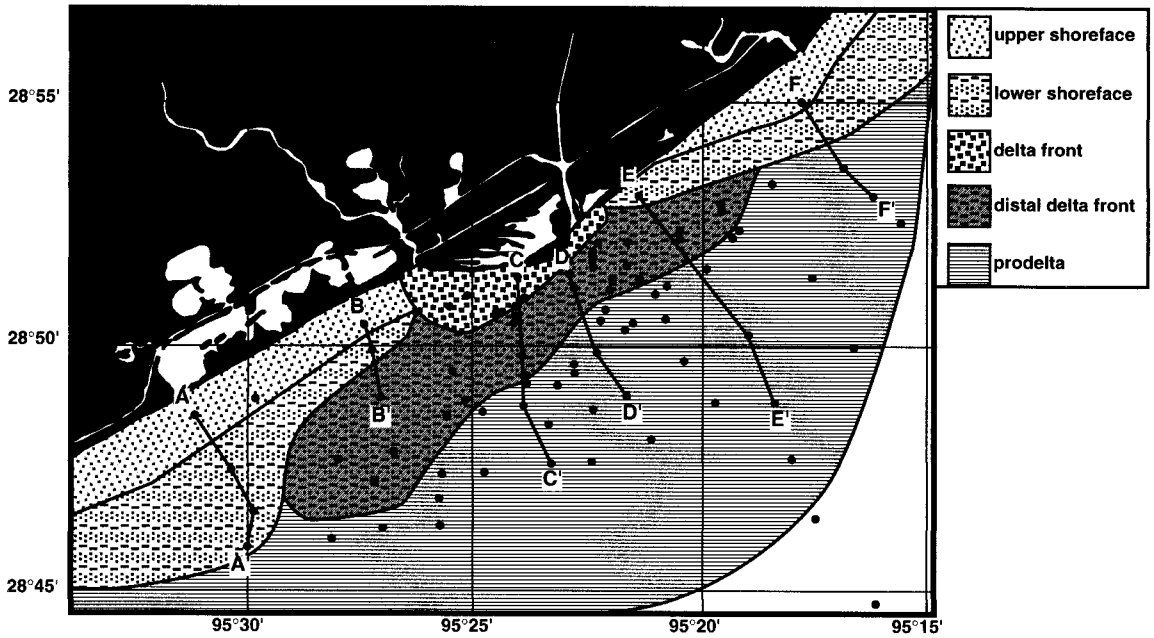


FIG. 8.—Surficial facies of the Brazos Delta with core transect locations indicated. All data were collected during a two-week period prior to the 1992 flood (see Fig.1A).

Interridge Trough.—The interridge troughs are tidally influenced, with water depths of less than 0.5 meters. Tidal flow has created a web of channels between troughs (Fig. 5). The sediments of the interridge troughs are predominantly clay, with abundant laminae and very thin beds of sand. Large sand-filled burrows crosscut interbed boundaries, often making boundaries less distinct. Small (generally less than two meters in diameter) oyster colonies are widespread.

Mainland Beach.—The mainland beach is very diverse sedimentologically and geomorphologically. The beach contains ripples, beach cusps, shell-armored clay balls, exposed marsh deposits, storm berms, abundant logs, washover channels, and scattered debris of human origin. On a larger scale, the beach is part of the accreting headland on the west flank and includes a series of accreting spits and tidally exposed bars (Fig. 5). Beach sands have a mean grain size of 2.68 phi (modal size = 2.0 phi) and are poorly sorted (sd = 2.06 phi; Fig. 11B). Burrows are common. The beach prograded seaward and facilitated the enclosure of the back-bar lagoon (Figs. 7A, 10).

Delta Front

The delta front encompasses the area just seaward of the river mouth and beach (Fig. 8). This sandy environment is extremely dynamic, including the channel mouth bar, which episodically emerges, creating a back-bar lagoon. Prior to the 1992 flood, the nearshore setting of the new Brazos Delta was characterized by a gently dipping offshore profile extending to a subaqueous channel mouth bar situated approximately 90 meters offshore in about 2 meters water depth. Eight months after the 1992 flood, and during extreme low (spring) tides, the offshore channel mouth bar initially emerged into a prominent sand body that was located between 0.9 and 1.2 km offshore and extended for approximately 1.5 km along shore (Fig. 7A). The emergent channel mouth bar was a highly dynamic feature. It was composed of numerous amalgamated bars and underwent dramatic changes with seasonal tidal cycles (Fig. 7B). During spring tides the channel mouth bar was partially submerged and large subaqueous two-dimensional sand dunes formed on its western end (Fig. 7C). Storm overwash was common (Fig. 7B). During neap tides the channel mouth bar attained relief of nearly 1 meter on the landward-facing beach. Several core transects were collected from the onshore beach to the seaward side of the emergent channel mouth bar (Figs. 1B, 10).

Channel Mouth Bar Crest.—Channel mouth bar crest sands are the coarsest sands in the region (2.5 to 3.0 phi; Fig. 11B). They are moderately sorted with negative skewness values due to shell fragments and heavy minerals. Heavy-mineral concentrations in the swash zone can reach up to 15%, compared to $<1\%$ for adjacent beach sands. Thickness of the bar deposit ranged from 1 m on the west end to 3 m in the east. Ripples, laminae lined with organic debris, and convolute bedding are the dominant sedimentary structures (Fig. 10). Bioturbation and silt- and mud-filled burrows are common throughout. Armored mud balls are common along the seaward side of the bar.

Distal Channel Mouth Bar.—Distal channel mouth bar facies exist seaward of the river mouth and delta headland out to approximately -4 m water depth. This facies is characterized by laminated sands and interbedded sands and muds (Fig. 10). The sediments are (by mass) 85% sand. This facies underlies the channel mouth bar crest and the back-bar lagoon (Fig. 10).

Back-Bar Lagoon.—Associated with emergence of the channel mouth bar in 1992 was the formation of a back-bar lagoon. Water depth in the lagoon averaged between 0.5 to 1.5 m. The central lagoon was the site of rapid accumulation of fine-grained, wet, muddy sediments. The muds have less than 10% sand, and up to 50% water by mass. Bioturbation is noticeably absent, and significant numbers of logs that accumulated in the lagoon often prevented core penetration. The lagoonal environment is also strongly influenced by fluvial input, washover, and tidal and eolian processes, which are responsible for deposition of sand layers within the lagoon (Figs. 7, 10).

Offshore Environments

Shoreface.—The shoreface deposits recovered in cores consist of upper-shoreface massive sands that grade offshore into lower-shoreface laminated sands interbedded with mud and muddy sand layers (Fig. 9). Shoreface deposits are more extensive to the west and east of the delta. Generally, shoreface sands are texturally mature, with rounded to subrounded well-sorted grains. Upper-shoreface sands are similar in mean grain size to low-

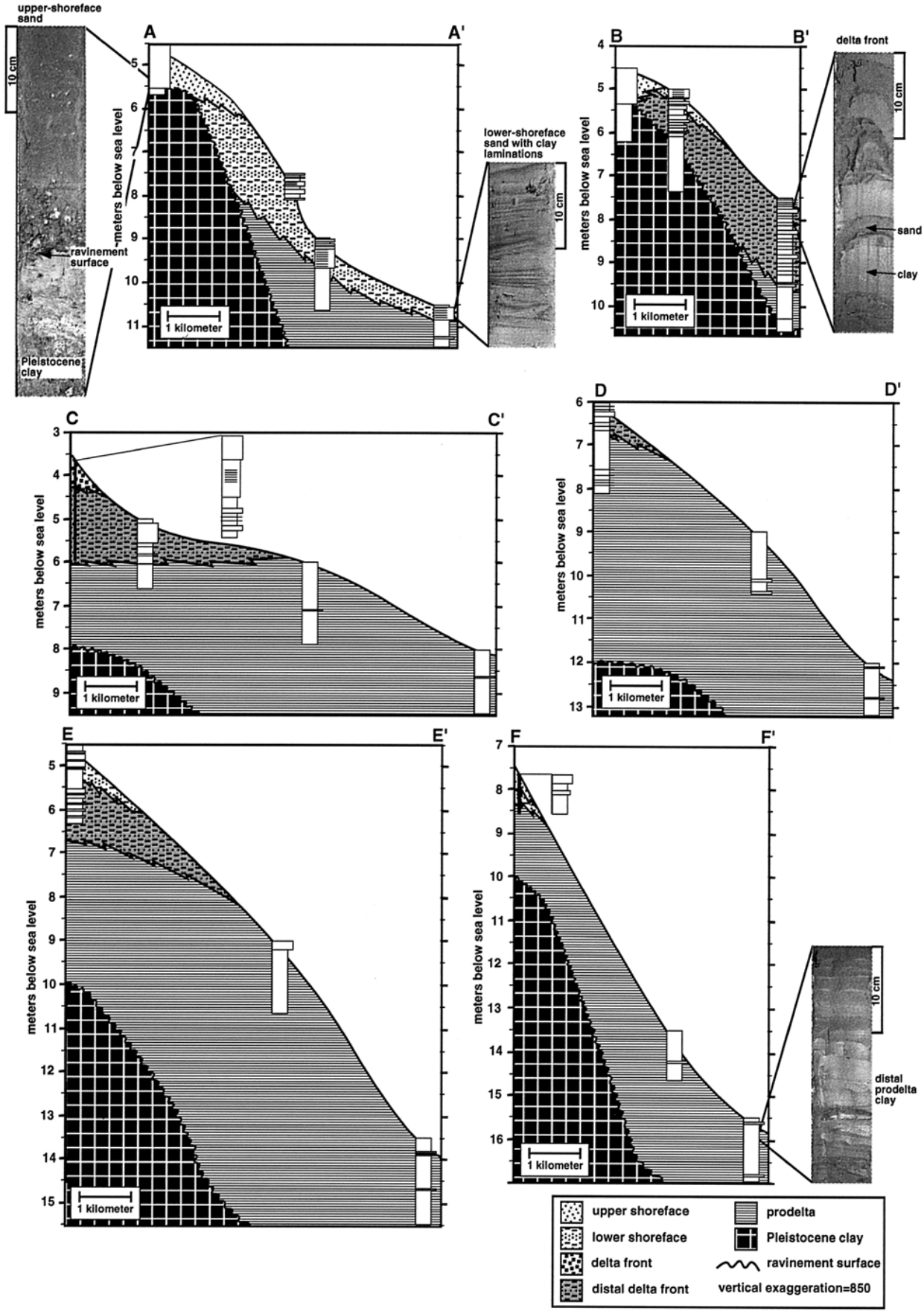


FIG. 9.—Offshore core transects through the Brazos Delta with representative core photographs of each facies. These cores were collected prior to the 1992 flood. Transect locations are indicated in Figures 1A and 8.

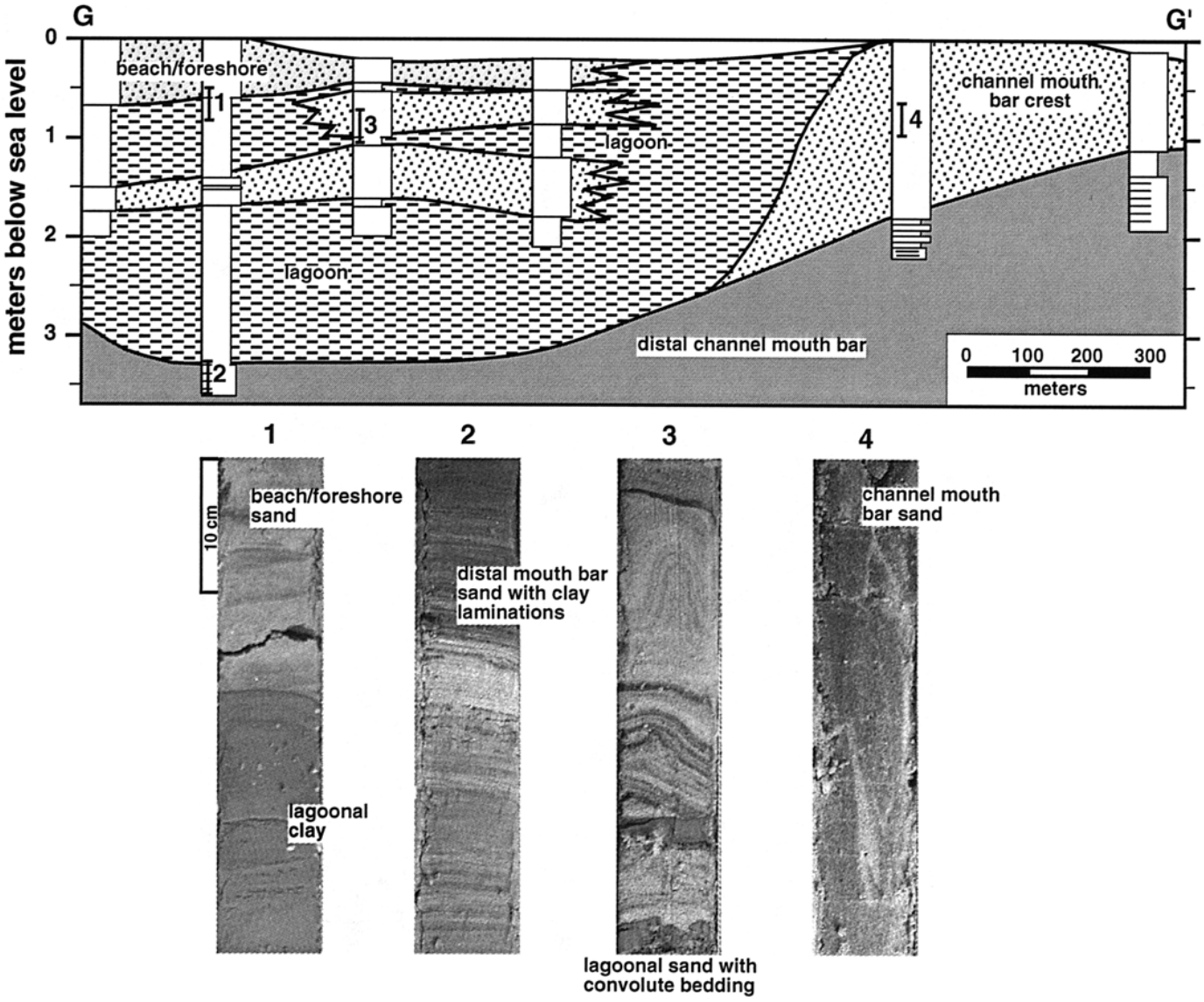


FIG. 10.—Nearshore core transect through the Brazos Delta acquired after the 1992 flood, when the offshore bar was emergent, but prior to significant landward migration of the bar. Representative core photographs of each facies are indicated by number on the transect. Transect location is indicated in Figure 1B. The vertical exaggeration of this cross-section is 160.

er-shoreface sands (around 3.2 phi) but have a slightly coarser dominant mode (3.25 versus 3.5 phi; Fig. 11A). Bounding surfaces between sand and mud layers in the lower shoreface are highly erosional. Muddy sands and sandy muds of the lower shoreface have a mixture of properties: variable muddiness, high bioturbation, and variegated color. Shell fragments are scattered throughout the shoreface and within vertically oriented burrows. In the absence of grain-size data, the lower shoreface may be difficult to distinguish from the distal delta-front environment (Fig. 11A).

Distal Delta Front.—Reddish-brown clay with very fine laminae of silty clay is the dominant sediment type in the distal delta front. This clay generally has less than 10% silt and sand but is often interbedded with sandier and siltier units (Fig. 9). Sands in the distal delta front are coarser than shoreface sands (2.8 phi; Fig. 11A) and occur as thin beds (Fig. 9). Organic material (mostly wood fragments) is scattered throughout the clay and occurs as individual beds ($<$ 5 cm).

Prodelta.—Delta-front facies grade offshore into thinly interbedded olive-gray clay and reddish-brown clay facies of the prodelta (Fig. 9). This facies illustrates the episodic nature of sedimentation in the delta. With each pulse of sediment into the delta, a new layer of reddish-brown clay is deposited in the prodelta. When the fluvial discharge decreases, a layer of offshore marine sediments consisting of shell-bearing, bioturbated, olive-gray clay is deposited. Although the prodelta is characterized dominantly by mud, thin ($<$1 cm) layers of very fine sand were sampled (Fig. 11A).

In all, prodelta muds constitute 50–60% of the total sediment volume of the delta. The distribution of prodelta fine-grained sediments is mostly dependent on proximity to the river mouth; however, longshore currents and geostrophic currents also affect prodelta deposition and produce an architecture asymmetric to the west (Fig. 3). Areas east of the river mouth experience appreciable prodelta deposition only during times of increased discharge or during brief periods in the summer when longshore currents may shift to the northeast (Curray 1960). The prodelta occurs at -6 to -15 m water depth. This is below the level of wave erosion for most of

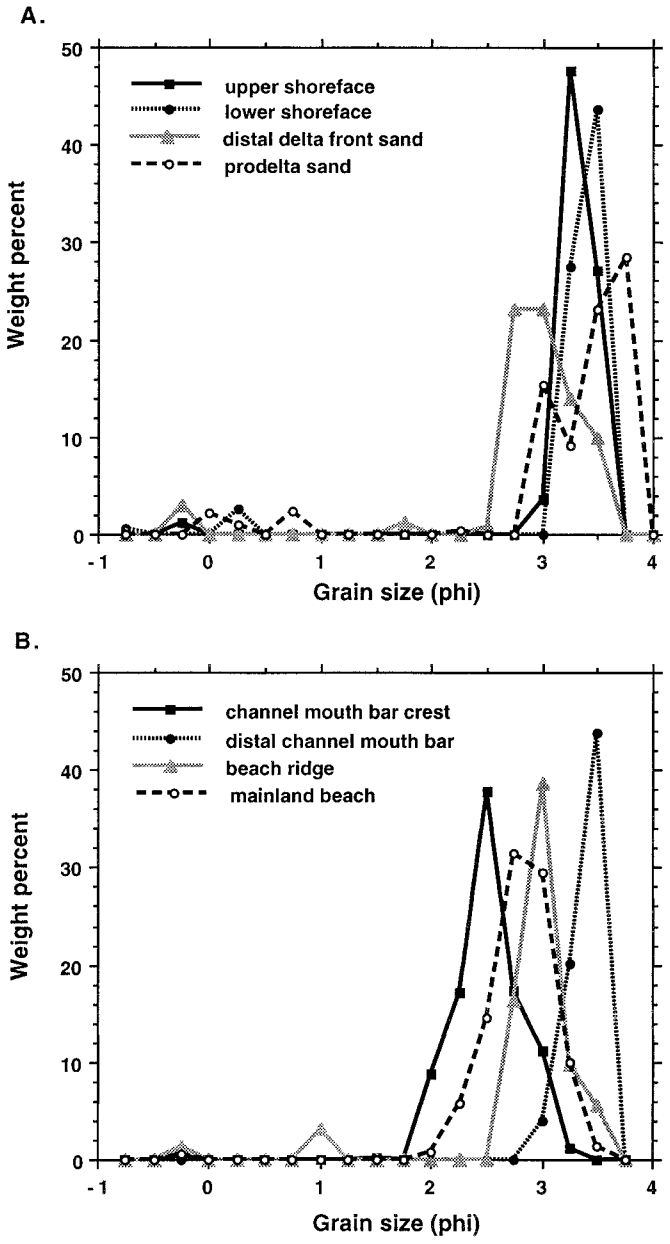


FIG. 11.—Grain-size frequency curves for sands from the A) offshore and B) nearshore Brazos Delta environments.

the east Texas coast, which is situated at between −8 and −10 m water depth (Siringan and Anderson 1993). The offshore extent of the prodelta is variable, but generally occurs between 1.2 km and 7 km.

Comparison of bathymetric maps that predate and postdate deltaic input (Fig. 3) to the area, and sediment cores that penetrated the prodelta (Fig. 9), show that approximately five to six meters of prodelta sediment have accumulated since 1929. This is equivalent to an estimated total sediment volume of 84,000,000 m^3. Cores collected after the 1992 flood in the prodelta indicate 50 cm of vertical accumulation in some places (Hamilton 1995).

FACIES ARCHITECTURE

The combined offshore core transects (Fig. 9) show a typical progradational deltaic succession comprising proximal facies overlying distal facies, and an overall coarsening-upward lithologic sequence. Sea-floor gradients decrease toward the river mouth because of increased accumulation of thick delta-front and prodelta sediments (Figs. 1A, 9). The delta-front and distal delta-front facies are the most restricted, extending only 7 km northeast and 13 km southwest of the river mouth. The distal delta-front facies represents a transitional unit separating the sand-dominated environments of the delta front from the clay-dominated prodelta.

The first flood affected the new Brazos delta 12 years after river diversion. Prior to this, significant delta progradation occurred largely in response to erosion of pre-1929 delta sediments and deposition of these sediments in the New Brazos Delta. It was not until after the 1941 flood that the first lagoon was preserved in the western delta headland (Fig. 6). After the old delta had been eroded, floods became the primary mechanism enabling delta progradation.

Figure 12 presents a simplified model illustrating delta evolution through one complete flood cycle. Prior to flooding (Fig. 12, stage 1) no emergent offshore bar exists. The shoreline is lobate, with a series of beach ridges separated by interridge troughs on the western delta headland. After the flood, the delta-front environment expands and the channel mouth bar emerges, enabling formation of the back-bar lagoon (Fig. 12, stage 2). The channel mouth bar rests above distal mouth-bar facies.

The Richmond gauging station indicated that during the 1992 flood 90% of suspended sediments were finer than sand. However, significant erosion of point bars did occur following the 1992 flood. This, plus the grain-size data, indicates that channel mouth bar sands were derived from the river and transported to the delta via traction or saltation. Sand transported during the 1992 flood was most likely deposited near the river mouth, where decreased competence of the flow facilitated sand deposition. The high concentration of suspended silts and clays increased the viscosity of the flood plume to a point where it damped waves, thus protecting nearshore sands from being reworked (Fig. 13). The lag time between initiation of the flood and emergence of the channel mouth bar can be explained by the relatively slow transport rate of sand as bedload, and the time needed for waves to rework nearshore sands into an emergent channel mouth bar. The emergent channel mouth bar is subsequently reworked by waves and migrates landward, welding its western end to the shoreline (Fig. 7D).

As the bar migrates landward over the back-bar lagoon, the seaward part of the underlying distal mouth bar facies is extensively reworked, and a part of the seaward side of the back-bar lagoon is eroded. However, the landward parts of these environments are preserved below the delta headland (Figs 10, 12). Significant headland accretion and progradation occur on both the eastern and western sides of the river mouth. During stage 3 (Fig. 12) the pre-flood shoreline and back-bar lagoon become preserved as a ridge–trough pair within the western delta headland, and the bar becomes the new shoreline.

Core BDBR-01 (Fig. 14) was collected from a beach ridge that was preserved in the delta headland following the 1941 flood (Fig. 1B). This core tests the model presented in Figure 14 by illustrating the stacking pattern of nearshore facies after a complete flood cycle. The location of this core with respect to the model is indicated in Figure 12, stage 3. The core sampled beach-ridge sands resting on lagoonal facies. This was the result of an offshore bar being reworked landward. The distal mouth bar sediments at the base of the core were deposited prior to bar emergence and represent the pre-flood shoreline. Bernard et al. (1970) examined a 10-m-long core collected from the beach on the western side of the Brazos delta (core R3660). This core, collected in 1954, shows the same facies succession as core BDBR-01, but the core collected by Bernard and his colleagues was long enough to penetrate the entire delta succession. Although Bernard et al. (1970) used different facies terminology, this core sampled approximately 1 m of distal delta-front sediments and 2.6 m of prodelta sediments below the distal channel-mouth-bar facies, and bottomed out in the Pleistocene Beaumont Formation (Bernard et al. 1970).

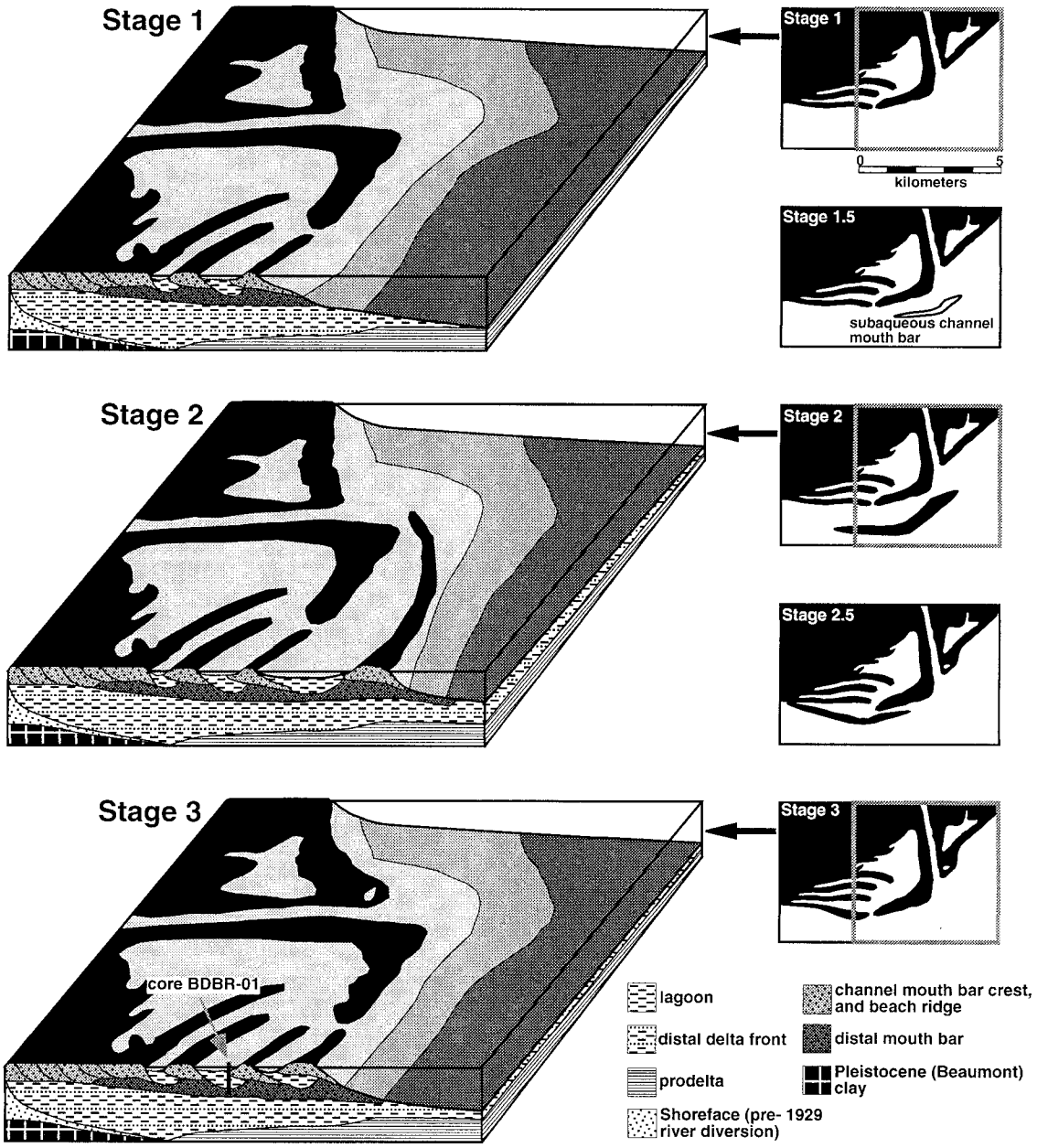


FIG. 12.—Brazos Delta evolutionary model illustrating the morphologic and sedimentologic changes during one complete flood cycle.

CONCLUSIONS

The modern Brazos Delta has experienced two phases of evolution. During the first two decades following diversion of the river, sands swept from the old delta were transported by longshore currents, reworked shoreward, and deposited as amalgamated ridges near the mouth of the new delta. This early phase of evolution was more typical of the classic wave-dominated delta (Bernard et al. 1970). Once the sand supply of the old delta was depleted, the delta assumed a new morphology, characterized by alternating ridges and interridge lagoons. This phase of delta evolution has been highly episodic, characterized by rapid phases of sediment discharge and growth during and immediately after major floods, and slower delta growth and reworking during intervening periods. Major floods occurred in 1941, 1957, 1965, and 1992. During each of these events the channel mouth bar experienced significant growth and a back-bar lagoon was formed. Following each flood the bar migrated onshore and to the west, was welded to the shore, and became the new shoreline. The old shoreline, in addition to part of the back-bar lagoon, was preserved within the western delta headland. These flood cycles have resulted in the alternating beach-ridge sands and mud-filled troughs that characterize the delta headland. Prodelta development was also enhanced by floods. During non-flood periods, shoreline growth is characterized by accreting sand ridges that amalgamate at the western delta headland; no troughs are created during non-flood periods. Since 1965 a wide area of accreted sand ridges has formed in the westernmost part of the delta headland (Figs. 2, 5). These ridges are sourced from reworked delta front sands and/or sands carried from the east by longshore currents.

The new Brazos delta contains a suite of depositional environments from clayey prodelta to sandy delta front. The most striking feature of the Brazos

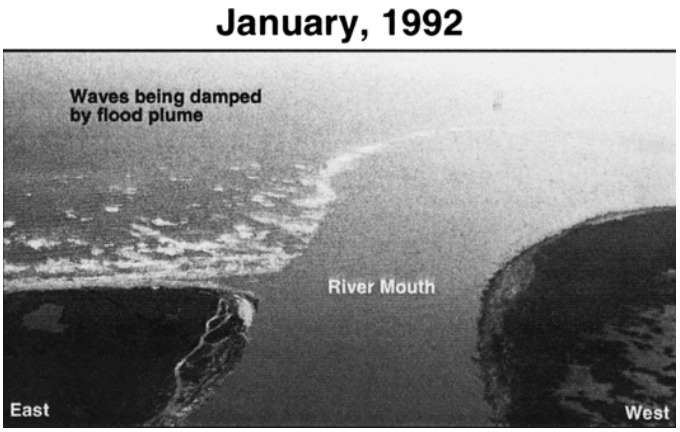


FIG. 13.—Aerial photograph of the Brazos Delta flood plume taken from approximately 150 meters looking south. The higher viscosity of the plume damps the incoming 1 to 1.5 meter waves.

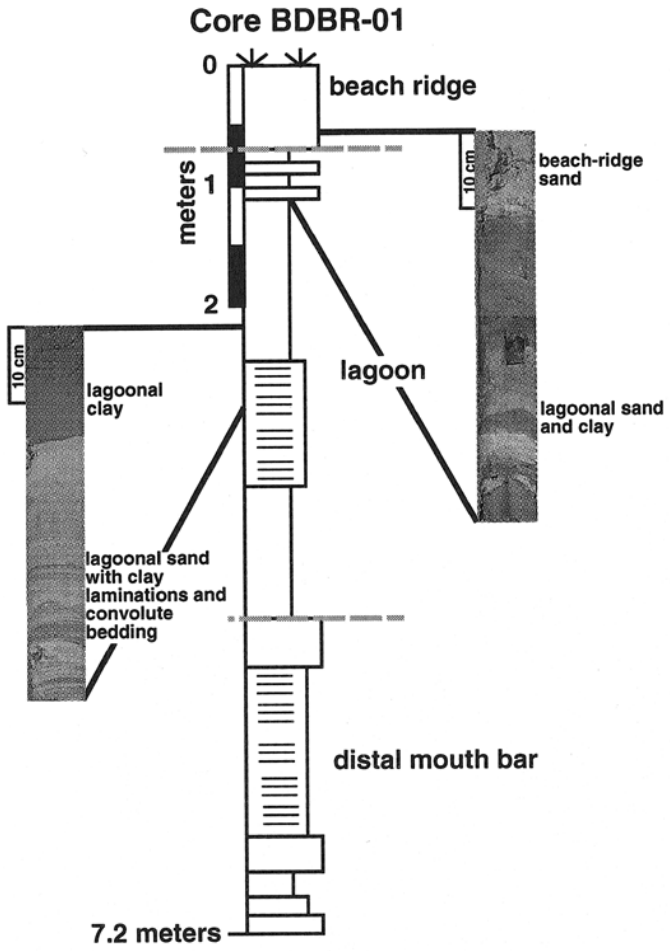


FIG. 14.—Core BDBR-01 illustrates the stacking pattern of nearshore environments after one complete flood cycle. Core location is indicated in Figure 1B. Figure 12 illustrates the delta processes leading to this facies stacking pattern and the location of the core.

delta is its large prodelta. The offshore prodelta constitutes nearly 60% of the delta's volume. The prodelta and distal-delta-front environments have the highest preservation potential given the present-day depth of wave erosion (-8 to −10 m). Under different conditions, however, for example where subsidence rates are higher, the sandy delta-front environment would have a high preservation potential.

Although the coastal outline is similar to the classically postulated wave-dominated delta, the Brazos Delta has internal complexities that are not immediately recognizable strictly from geomorphology. These features include the back-bar lagoonal deposits preserved within the onshore troughs, the continuous distal mouth bar facies, which underlies the onshore part of the delta, and the extensive prodelta environment. Psuty (1967) and Coleman and Wright (1975) contend that wave-dominated systems are composed of flanking strandplains, thereby implying that beach ridges are amalgamated. The Brazos Delta does not follow this model, in that it is composed dominantly of preserved shorelines (ridges) separated by troughs. These troughs contain previously unrecognized lagoonal clay. Lack of sand-body connectivity in our model versus the classical wave-dominated delta model is important to reservoir quality. Although the dominant process controlling Brazos delta morphology is waves, at times (during floods) it is fluvially dominated. The floods and associated delta-prograding events are episodic. Preservation of these events within the delta headland is largely dependent upon the duration of the flood and the timing of post-flood storms. Thus, the Brazos Delta may justifiably be termed wave dominated (Galloway, 1975); however, it is the combination of wave, fluvial, and to a lesser extent even tidal processes that influence the facies architecture.

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