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RECORD OF HISTORICAL GULF OF MEXICO STORMS PRESERVED IN THE STRATIGRAPHY OF GUM HOLLOW DELTA, NUECES BAY, TEXAS, U.S.A.: AN EXAMPLE OF TROPICAL-CYCLONE-INDUCED HYPERPYCNAL DEPOSITION

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ABSTRACT: **Gum Hollow Delta is a small microtidal, aggradational to slightly progradational, hyperpycnal, tropical-cyclone-dominated delta in Nueces Bay (Texas). The delta formed over the past 80 years following anthropogenically diverted, high sediment-laden stream runoff through Gum Hollow Creek into Nueces Bay. Gum Hollow Delta formed episodically due to high runoff and increased discharge in Gum Hollow Creek and temporarily elevated sea level during Gulf of Mexico tropical cyclones. The delta is 600 m long, 1000 m wide, and 1.6 m thick.**

Fifty-one vibracores were taken along four dip transects and two strike transects to delineate the internal sedimentology, architecture, and geochronology of the delta. The delta consists of nine bedsets (tempestites) representing deltaic growth events. Internal stratigraphic correlations were constrained by the identification of significant widespread flooding surfaces and by ^{137}Cs geochronology.

Flooding surfaces formed as storm surges produced short-term base-level rises in Nueces Bay, which were followed by rapid hyperpycnal sedimentation events. Tropical cyclones such as the 1933 Hurricane (Hurricane Eleven), 1945 Hurricane (Hurricane Five), and the 1949 Hurricane (Hurricane Ten) and named hurricanes Alice (1954), Carla (1961), Beulah (1967), Celia (1970), Allen (1980), and Bret (1999) produced significant base-level rises and deltaic depositional events. Distributary-channel avulsions are also associated with the landfall of these tropical cyclones. Comparison of the timing of the deposition of these hyperpycnal tempestites, constrained by ^{137}Cs geochronology, historical aerial photographs, and the historical record of Gulf of Mexico tropical cyclones indicate that the Gum Hollow Delta preserves an 80-year record of storminess.

INTRODUCTION

Deltas are defined as discrete shoreline protuberances formed where rivers enter steady bodies of water and supply sediment more rapidly than it can be redistributed by basinal processes (Elliott 1986; Bhattacharya 2006). Modern and ancient deltas are generally well understood and have been studied thoroughly (Coleman and Wright 1975; Giosan and Bhattacharya 2005; Bhattacharya 2006). The morphological and sedimentological characteristics of a delta are controlled by sediment supply, accommodation space, and wave and tide energy (Fisher et al. 1969; Galloway 1975; Bhattacharya and Walker 1992; Bhattacharya 2006).

Many studies of ancient delta systems have demonstrated that the fundamental stratal element of a delta is a shoaling-upward succession of beds or bedsets. This shoaling-upward succession of beds or bedsets, bounded by marine-flooding surfaces and their correlative surfaces, was defined by Van Wagoner et al. (1990) as a parasequence. These successions can be generated by (1) an increase in water depth due to prodelta mud compaction, (2) a rise in relative sea level due to tectonically induced subsidence, or (3) a eustatic rise in sea level (Van Wagoner et al. 1990). Therefore, these shoaling-upward successions within a delta record rises in relative base level.

Most records of storms over the past few millennia were obtained from studies of barrier-island washover fans (e.g., Buynevich et al. 2004; Donnelly and Woodruff 2007; Scileppi and Donnelly 2007; Garrison et al. 2010; Woodruff 2009), backbarrier ponds (e.g., Donnelly 2005), lake sediments (e.g., Liu and Fearn 2000), and beach dune ridges (e.g., Garrison et al. 2012).

In this study, we use vibracores to delineate flooding surfaces within the 80-year-old Gum Hollow Delta in Nueces Bay, Texas, U.S.A., in an attempt to construct a record of storminess by comparing the timing of the storm-induced deposition of beds and bedsets bound by flooding surfaces, constrained by ^{137}Cs geochronology, historical aerial photographs, and the historical record of storms using the NOAA North Atlantic HURDAT dataset (Landsea et al. 2004). We use the term *tempestite* to refer to these storm-induced deposits because the deposition is restricted to a period of storminess associated with the landfall of a single tropical cyclone. This usage of tempestite does not conform to the generally accepted usage of the term to describe a storm-reworked subaqueous deposit, although it is clearly consistent with the dictionary definition as a *storm deposit* (Allaby and Allaby 1999).

STUDY AREA

Gum Hollow Delta is a small microtidal, asymmetric-lobate delta that built into Nueces Bay, Texas over the past 80 years following

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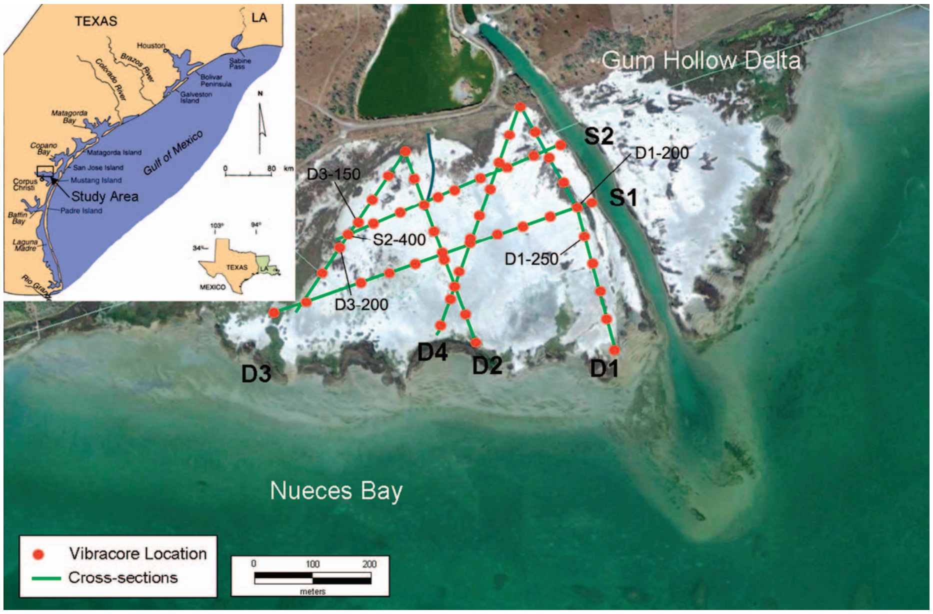

FIG. 1.—Map insert showing the location of the study area along the northern coast of the Gulf of Mexico (modified from Morton et al. 2000). The photograph shows the Gum Hollow Delta study area. The locations of the cross-section lines are shown as green lines, and the locations of the vibracores are shown as red solid circles. Vibracores described in this study are identified by transect and are numbered sequentially by distance from the northernmost vibracore on the transect (e.g., D1-250). Vibracores in Figures 4, 5, 6, and 7 are denoted. Photo from Google Earth$^{\mathrm{TM}}$.

anthropogenically diverted, high sediment-laden stream runoff through Gum Hollow Creek into Nueces Bay (Fig. 1). Gum Hollow Delta is located along the north shore of Nueces Bay, approximately 3.2 km west of Portland, Texas (Fig. 1). The north shore of Nueces Bay is a 10 to 12 m erosional escarpment that was produced by the incision of the Nueces River during a sea-level fall during the last Pleistocene glacial–interglacial cycle (Garrison and McCoy 2007). North of the escarpment is a flat, partially vegetated Pleistocene (Beaumont Formation) surface utilized primarily for agriculture.

To prevent flooding of farm land, drainage was diverted into Gum Hollow Creek in the late 1920s. The catchment area of Gum Hollow Creek is 44 km^2, and its drainage consists of both natural and artificial channels. The daily discharge rate (Q_{av}) is estimated to be < 0.04 m^3 s^{-1}. A Texas Water Development Board study found that Gum Hollow Creek can reach flood discharge rates (Q_{flood}) of 115 to 235 m^3 s^{-1} during heavy rainfall associated with tropical cyclones (HDR and Naismith 1987).

By the early 1930s, sediment transported by Gum Hollow Creek, during periods of very high rainfall associated with major storms, resulted in the formation of Gum Hollow Delta. The delta is 600 m long and 1000 m wide and has a maximum thickness of 1.6 m. The delta has a maximum elevation of 1.04 m above mean sea level (NADV 88); mean elevation is 0.68 m above mean sea level. During the landfall of major tropical cyclones, storm surge covers the delta with 1 to 5 m of water for 2 to 3 days.

In the vicinity of Gum Hollow Delta, Nueces Bay averages 0.6 m in depth. The mean diurnal tide range in Nueces Bay is 0.15 m (Breier and Edmonds 2007). Mean monthly rainfall is 6.5 cm. The total rainfall during the landfall of tropical cyclones can range from 13 to 76 cm. Prevailing southeasterly winds average 25 km h^{-1}, but wind speeds up to 40 km h^{-1} are common. Mean annual wave height in Nueces Bay is 0.3 m, with wave heights up to 0.9 m common during periods of high wind. Near Gum Hollow Delta the mean salinity of Nueces Bay is 25.7 ± 7.6 psu. The salinity of Nueces Bay ranges from 1 to 10 psu during periods of heavy rain to a maximum of 45 psu during periods of prolonged drought (Division of Nearshore Research 2012).

McGowen (1971) studied the origin and development of Gum Hollow Delta to determine the mechanics of its development and the relationship between sedimentary processes and structures that were observed. He also documented changes in the form of the delta and related these changes to geologic and meteorological processes, including tropical cyclones. In this paper, we build upon the framework of McGowen (1971) to document changes in delta morphology and architecture since 1967 and, in addition, examine in detail the hydrodynamic processes operating during the landfall of tropical cyclones.

Historical aerial photographs show that Gum Hollow Delta was formed episodically during periods of high stream runoff into Gum Hollow Creek during major tropical storms (Fig. 2). Sixty-eight tropical cyclones made landfall in or near Texas since 1925, of which twelve were the named hurricanes: Alice (1954), Carla (1961), Beulah (1967), Celia (1970), Allen (1980), Alicia (1983), Bret (1999), Claudette (2003), Emily (2005), Rita (2005), Dolly (2008), and Ike (2008).

MORPHOLOGY, SEDIMENTOLOGY, AND STRATIGRAPHY

Fifty-one vibracores were taken along four dip transects and two strike transects to delineate the internal sedimentology, architecture, and geochronology of the delta (Fig. 1). Vibracores were taken approximately every 50 meters along each transect. Internal stratigraphic correlations were constrained by the identification of significant widespread flooding surfaces in cores and by ^{137}Cs geochronology. Historical aerial photographs are used to quantify and document the changes in delta geometry and morphology over the past 80 years.

Morphology

According to McGowen (1971) Gum Hollow Delta has the general characteristics of a fan delta, which he defined as a modern terrigenous clastic deposit that is lobate in plan shape and wedge-shaped in cross section which progrades into a body of water from an adjacent area of high relief. To a first approximation, Gum Hollow Delta has the general characteristics of a fan delta (Figs. 1, 2). Furthermore, Gum Hollow Delta does not fit the McPherson et al. (1987) definition of a fan delta, namely, a gravel-rich delta formed where an alluvial fan is deposited directly into a standing body of water from an adjacent highland. Gum Hollow Delta fits none of the McPherson et al. (1987) criteria for a fan delta. More importantly, the term “fan” generally refers to natural alluvial systems, and therefore it is not suitable for Gum Hollow Delta, which formed only after the anthropogenic creation of a larger drainage system. Prior to this, although sediment-starved Gum Hollow Creek emptied into Nueces Bay, Gum Hollow Delta did not exist. Therefore, in

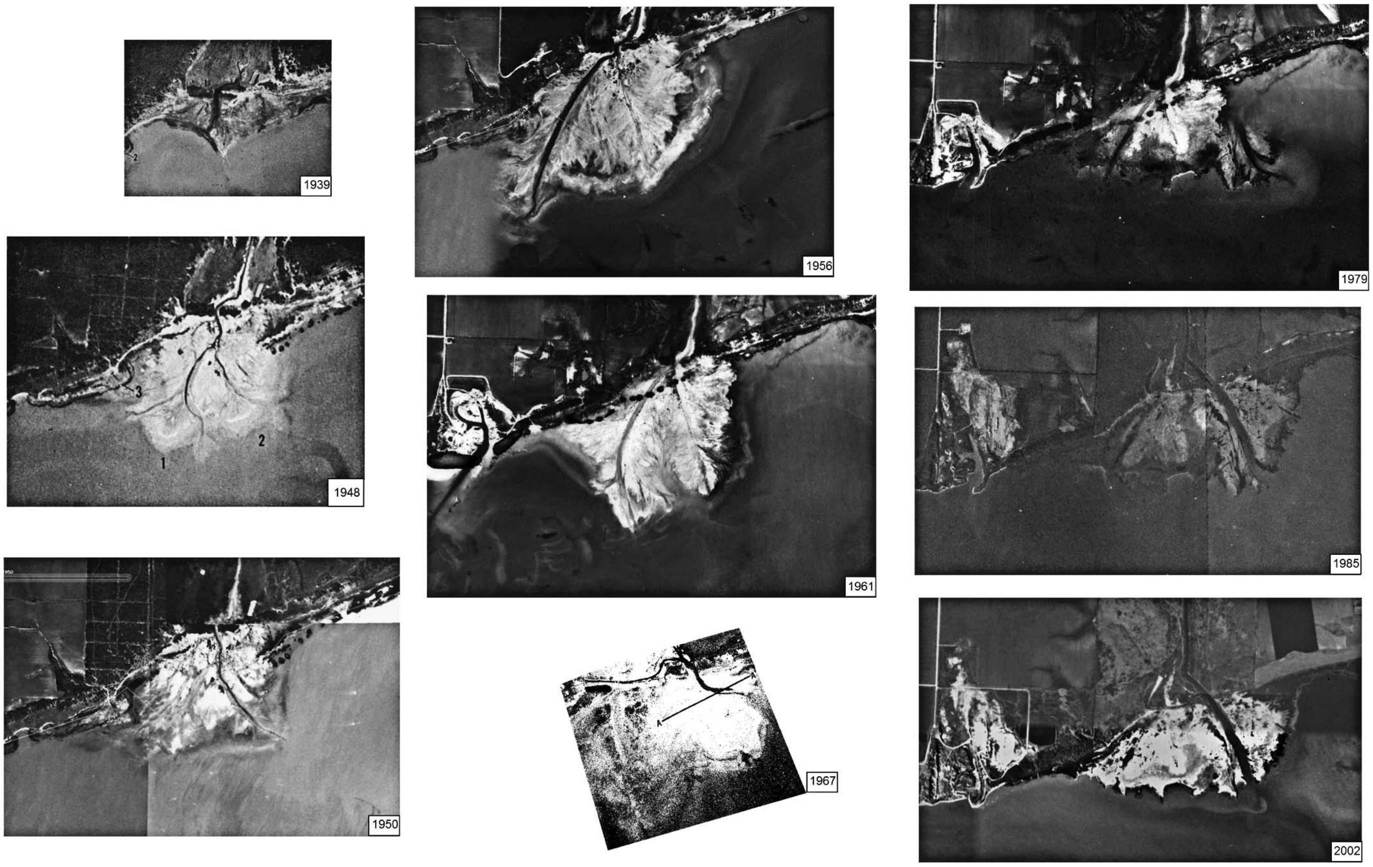

FIG. 2.—Historical photographs of Gum Hollow Delta showing the changes in delta geometry and channel position since 1939. Photos from McGowen (1971) and Google Earth™.

this study Gum Hollow Delta is considered a tropical-cyclone-dominated delta.

Evidence of minor wave reworking exists along the outer boundaries of the Gum Hollow Delta (Fig. 1). The shape of the delta has an asymmetric geometry, with the area on the western side of the main channel greater than on the eastern side, and distal portions of the delta are scalloped and smoothed. The larger area on the western side of the delta is a consistent with a deflection of sediment by the prevailing southeasterly winds and the resulting wind swells. The seaward margin of the subaerial delta plain has southeast–northwest-oriented reentrants also consistent with erosion by the prevailing wind swells.

Historical Morphological Evolution

The growth of Gum Hollows Delta and the periodic avulsions of Gum Hollow distributaries were mapped using a time series of aerial photographs taken from 1939 to 2008 (Figs. 2, 3). During the history of the delta, the depocenter(s) were shifted seven times due to channel avulsions and channel abandonments. In the early 1930s, Gum Hollow Delta began to prograde into Nueces Bay. In 1939, Gum Hollow Delta was prograding south-southwest with a single channel. Prior to 1948, the channel avulsed, creating three distributaries, and progradation was dominantly to the south. Gum Hollow Delta prograded southward until around 1950, at which time the western most distributary was abandoned, shifting the depocenter slightly south-southeastward. Before 1956, Gum Hollow Creek avulsed shifting the depocenter to the southwest. By 1958, the creek had avulsed, producing a second distributary to the east, again shifting the depocenter. In 1961, this eastern distributary was abandoned and the depocenter shifted back to the southwest. In 1967, the creek avulsed again, producing another eastern distributary and creating another depocenter to the southeast. By 1968, this distributary was abandoned, shifting the main depocenter back to the southwest. Sometime after 1979, the creek avulsed again to the southeast, causing the southwestern channel to be abandoned and shifting the depocenter to the southwest to its present position. The course of this post-1979 channel has been anthropogenically maintained since it formed.

Sedimentology

Tempestites.—Figure 4 shows vibracore descriptions for two selected vibracores (D1-200 and D1-250) illustrating the internal stratigraphy and heterogeneity of the deltaic facies of Gum Hollow Delta. Figure 5 shows the vibracore photograph of core D1-250 (Fig. 4B). The delta consists of nine bedsets that are referred to in this paper as tempestites (denoted T1 to T9), since delta deposition and growth is restricted to the time of the landfall of major tropical cyclones. The tempestites are from 0.20 m to 0.52 m in thickness. The lowermost tempestites overlie shelly sands and muds. These sands and muds contain abundant oyster shells (*Crassostera virginica*), indicative of bay facies.

Figure 6 presents a core photograph and a detailed sedimentological description of tempestite T4 (Fig. 5). An interpretation of the hydrodynamics of the medial part of tempestite T4 is also shown. The tempestites are bipartite bedsets. Beds range in thickness from 5 cm to 35 cm. The lower portion of a tempestite generally coarsens upward and consists of beds of very fine to fine sand, silt, and mud. The finer-grained beds are generally horizontally laminated. The sandy beds contain

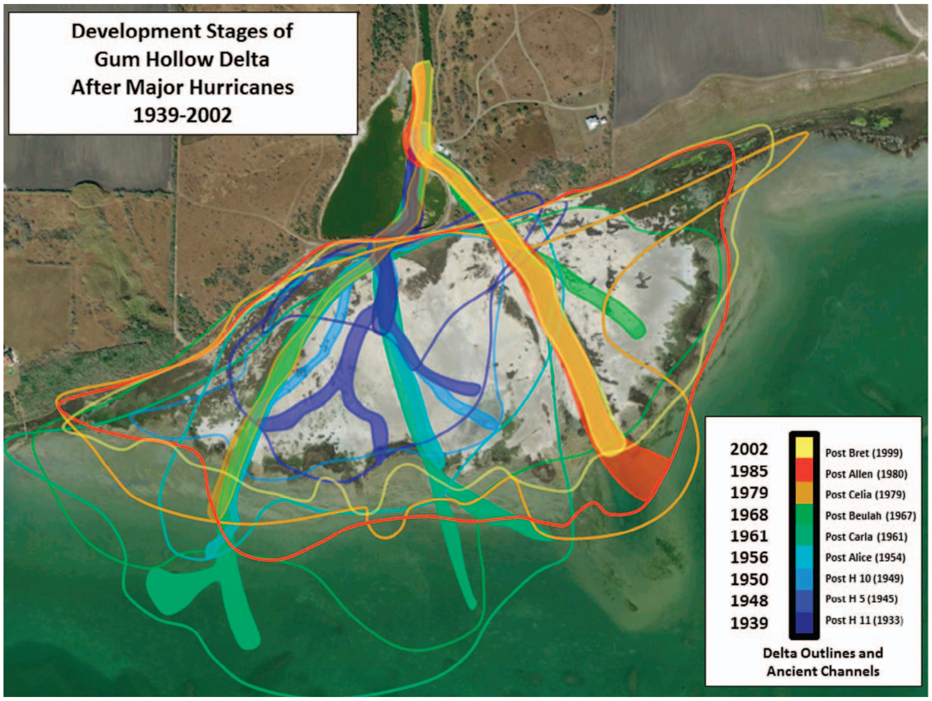

FIG. 3.—An aerial photograph (2009) of Gum Hollow Delta upon which the delta outline changes and distributary locations since 1939, as determined from a time series of aerial photographs, are summarized. Photo from Google Earth^{TM}.

horizontal to climbing-ripple stratification and may have muddy laminae. Muddy rip-up clasts are common near the bases of tempestites. Individual beds within the lower portions of the tempestite may exhibit either a coarsening-upward or a fining-upward grain-size trend (Fig. 6). The upper part of a tempestite is generally finer grained than the lower part and generally fine upward in grain size and consist of beds of very fine to fine sand, silt, and mud, although in the proximal portions of tempestites both the upper and lower parts of the tempestite may consist of dominantly sand, with thin mud laminae. These beds are generally horizontally stratified. The tempestites are interpreted to be bounded above by marine flooding surfaces. The upper surface of the tempestite upper unit may be wave-rippled, rooted, and/or bioturbated, although locally may be a subaerial erosional or hiatal surface.

Hydrodynamics of Tempestites.—Figures 5 and 6 show the fining-upward and coarsening-upward units of the tempestites which depict the hydrodynamics of their deposition. These tempestites represent distinct and episodic deltaic growth events associated with the local landfall of tropical cyclones (Figs. 2, 3). The sedimentology of the Gum Hollow Delta tempestites suggests that a conceptual model for tempestite deposition is bipartite consisting of waxing-flow and waning-flow phases (Figs. 5, 6). During the initial phase of tempestite formation, deposition results in horizontally to climbing-ripple stratified, coarsening-upward beds of mud and sand suggesting increasing stream discharge and flow velocity, occasionally reaching upper-flow-regime velocities, accompanied by rapid deposition of sand. During the deposition of the upper portion of the tempestite the fining-up deposition of mud or sand, containing thin horizontal laminae of mud, indicates sedimentation during a decrease in stream discharge and flow velocity.

The bipartite coarsening-upward and fining-upward units of the tempestites and the high freshwater discharge and sediment load of Gum Hollow Creek, during the landfall of tropical cyclones, suggest that Gum Hollow Delta tempestites have sedimentology, hydrodynamics, and origin similar to that of the hyperpycnal deposits produced by fresh-water floods, jökulhaups, dam breaks, and lahars (Mulder and Syvitski 1995; Mulder et al. 2003; Zavala et al. 2006; Bhattacharya and MacEachern 2009). The hyperpycnal deposits described by Mulder and Syvitski (1995) and Mulder et al. (2003) consist of a basal coarsening-upward unit (Ha) deposited during increasing discharge and a top fining-upward unit (Hb) deposited during waning flow. The Gum Hollow Delta hyperpycnal deposit consists of multiple hyperpycnal beds suggesting that the discharge rate is not constant during either waxing or waning stages. The type hyperpycnite described by Mulder et al. (2003) in a core from the Var deep-sea fan also shows similar grain-size patterns also indicating variable discharge rates over the period of hyperpycnite deposition.

Channel Facies.—Channel facies occur in several of the recovered vibracores. Figure 7 illustrates the channel-fill facies of two Gum Hollow Delta channels (Fig. 3). The channels are characterized by fining-upward sandy beds and bed sets. Mud-filled abandoned channel facies are also locally present in some vibracores.

The grain size of the sandy channel facies ranges from very fine to fine. Sandy channel-fill deposits contain horizontal to slightly inclined (low-angle trough) stratification (Fig. 7). The beds within the channels range in thickness from 2 cm to 20 cm. The thickness of the channel-fill deposits ranges from 0.10 m to 0.40 m. The channels commonly burrowed, and some contain abundant oysters. The present-day post-1979 channel contains small oyster patch reefs at its base. Rooting by sea grass and salt grass is common at the tops of channel-fill elements.

Multiple beds or bedsets can make up the channel fill, suggesting that a channel episodically fills during multiple storm events. Stratification suggests that in-channel deposition is a combination of high-energy sheet flow and a lower-energy channelized flow during the final waning stages of the storm event.

Stratal Architecture

The dip cross section shown in Figure 8 and strike cross section in Figure 9 define the stratigraphy in the western portion of the delta (Fig. 1). The base of the delta rests on estuarine sand and mud deposits of Nueces Bay. The tempestites have a slightly progradational to aggradational stacking pattern. The historical photographs in Figure 2 show that in the early stages of delta development that depositional events were progradational. After 1948, delta growth was dominantly aggradational.

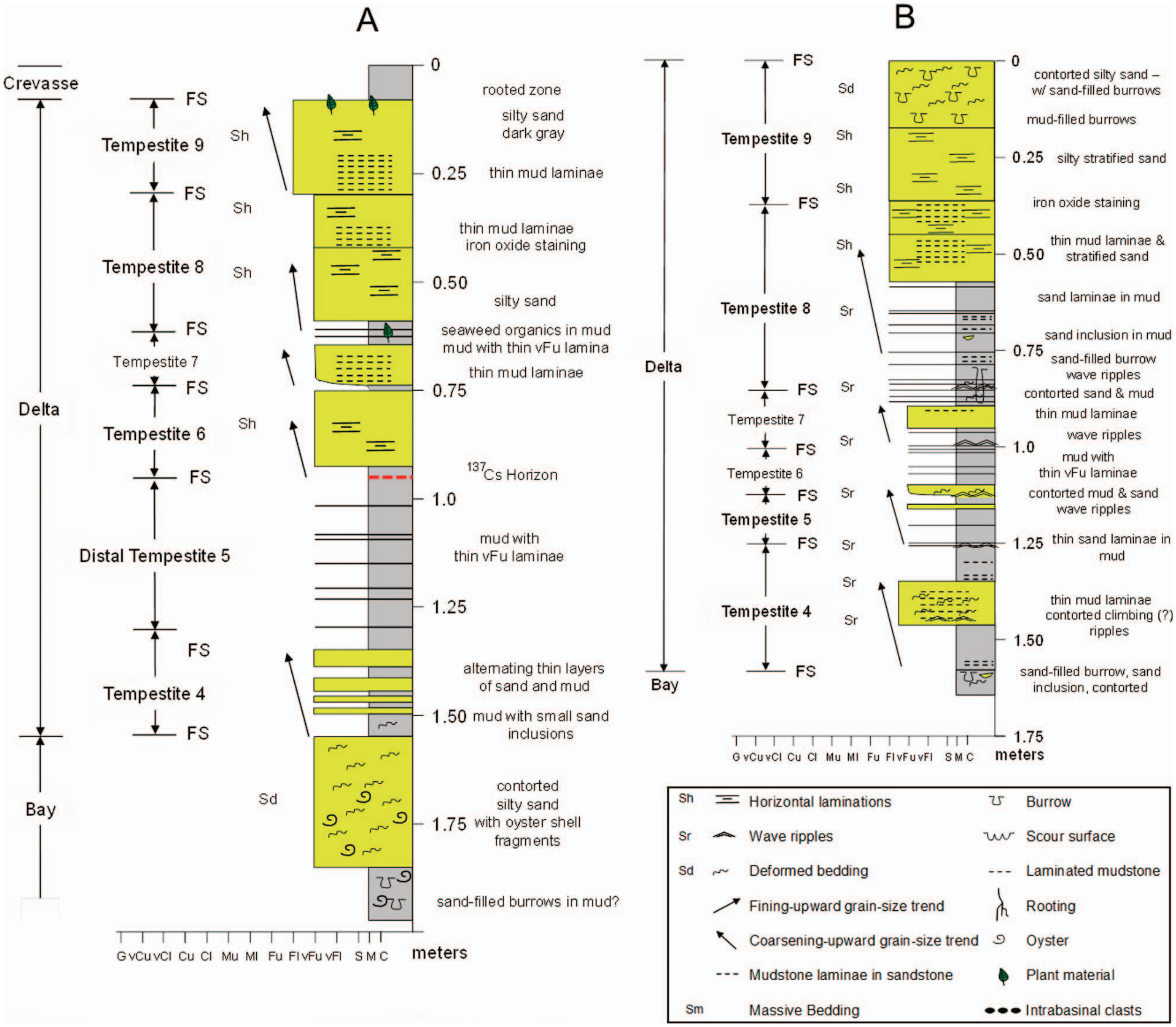

FIG. 4.—Descriptions of vibracores D1-200 and D1-250, located 200 m and 250 m from the north end of the cross-section line (Fig. 1), showing the delineation of parasequences within the Gum Hollow Delta.

^{137}Cs Geochronology.—^{37}Cs geochronology uses the fallout from the injection of radioisotopes into the atmosphere during atmospheric nuclear testing, mainly in the late 1950s and mid 1960s (Krishnaswami et al. 1971). The largest amount of radioisotopes entered the atmosphere during atmospheric nuclear testing during 1959 and 1963. This radioactive fallout is preserved in modern sediments and soils and is used as a marker to sedimentary particles laid down during the time of this fallout. ^{137}Cs has a half-life of 30 years and is among the few fission products produced during this radioactive fallout which are still detectable today.

In all examined Gum Hollow Delta vibracores, the entire ^{137}Cs marker zone occurs within a single 1 cm interval, rather than the typical decimeter-scale interval commonly encountered in cores, making it impossible to determine the vertical ^{137}Cs profile over time. This confinement to a very thin interval suggests that, during the period of the accumulation of the ^{137}Cs interval, either part of the ^{137}Cs horizon was not preserved or a portion of the ^{137}Cs interval occurs within a sandy unit, which is unsuitable for ^{137}Cs geochronology.

The thin nature of the ^{137}Cs interval does not allow the determination of a precise age date for the ^{137}Cs event. Major storm surge and depositional events occurred in Nueces Bay with Hurricane Carla in 1961 and with Hurricane Beulah in 1967 and could have affected the preservation of the total thickness of the ^{137}Cs interval. Based on this assumption, the authors suggest that the tempestite above the ^{137}Cs interval was probably produced by Hurricane Beulah.

RELATIONSHIP OF GUM HOLLOW DELTA STRATAL ARCHITECTURE AND GROWTH TO THE INCIDENCE OF TROPICAL STORMS

Based on historical photographs, historical storm records, and ^{137}Cs geochronology, it is possible to correlate the record of tropical cyclones that made landfall in or near Texas since 1925 with major Gum Hollow

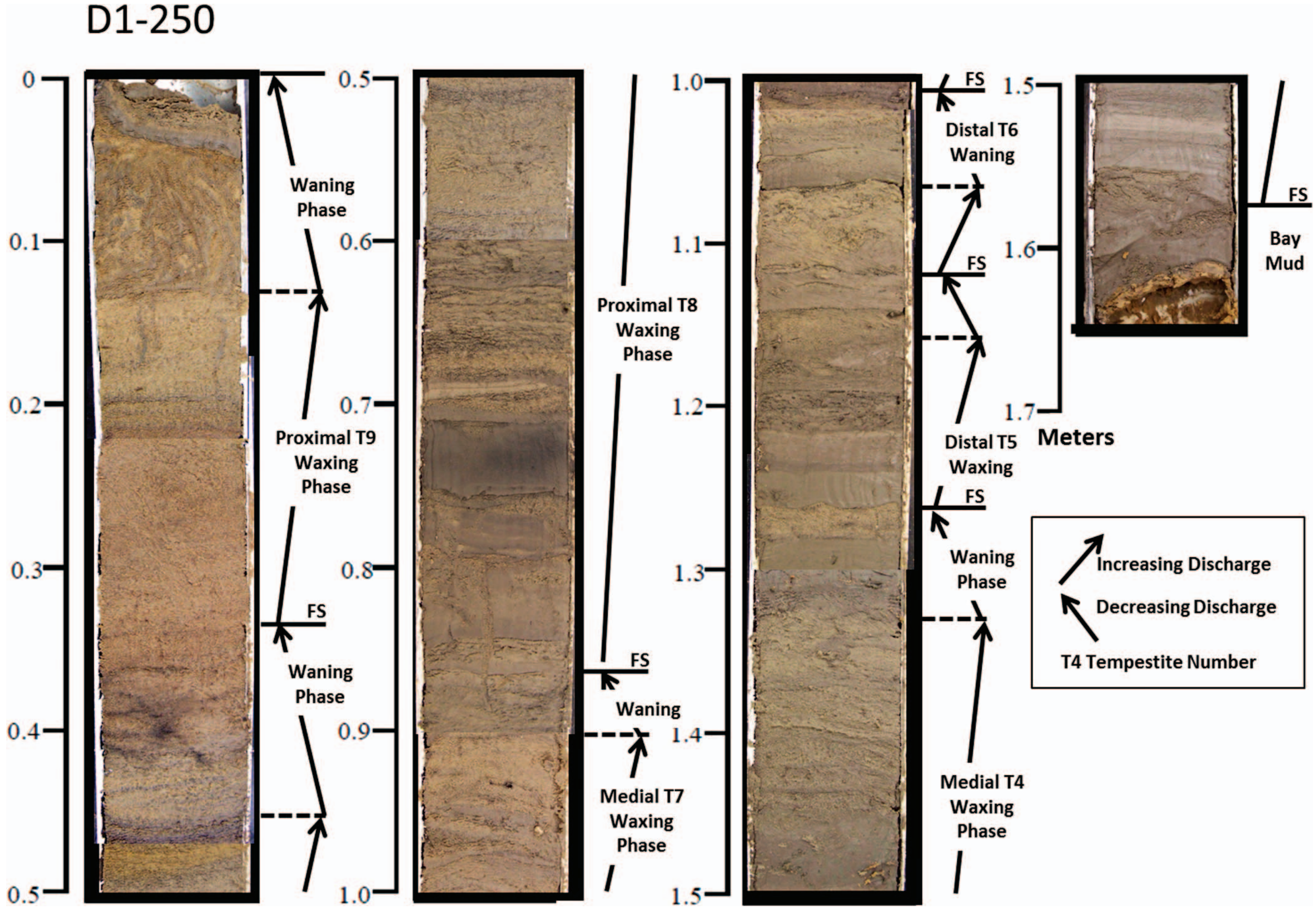

FIG. 5.—Vibracore photograph of vibracore D1-250 illustrating the tempestite sedimentology and internal stratigraphy and heterogeneity of the delta. The core description of D1-250 is shown in Figure 4A. The hydrodynamic interpretation of the tempestite core is also shown.

delta tempestite deposits (Figs. 8, 9). Based on the historical records of tropical cyclones from the HURDAT dataset (Landsea et al. 2004), the avulsions and depocenter shifts discussed above (Figs. 2, 3) are attributed to the occurrence of the following eight tropical cyclones: Hurricane Eleven (1933), Hurricane Five (1945), Hurricane Ten (1949), Alice (1954), Carla (1961), Beulah (1967), Celia (1970), and Allen (1980). The tracks of these storms are shown in Figure 10, and a summary of their characteristics, including storm size, surge height, and rainfall, are given in Table 1. Included in the last row of Table 1 is Hurricane Bret (1999), which produced a significant depositional event in the delta but anthropogenic channel maintenance prevented avulsion of Gum Hollow Creek.

The conceptual model for Gum Hollow Delta tempestite deposition and historical delta growth implies that flooding surfaces formed as storm surges produced by the landfall of Gulf of Mexico tropical cyclones resulted in short-term 2 to 6 m base-level rises in Nueces Bay (Fig. 11). These short-term base-level rises are responsible for the marine flooding surfaces recognized in the vibracores. These tropical cyclone landfalls were immediately followed by heavy local rainfall (13 to 76 cm), which resulted in increased stream runoff and rapid sedimentation events at the site of Gum Hollow Delta. These short-term rainfall events produced rainfall over a 1 to 2 day period that is two to ten times the average monthly rainfall. Normal rainfall produces a minimal increase in stream discharge and no significant increase in sediment load, which is not enough to result in a net deposition of 20 to 52 cm of vertical sediment accumulation at the delta, as recorded following the landfall of tropical cyclones.

The occurrence of hyperpycnal deposits within Gum Hollow Delta, suggesting high stream discharge and sediment load, is consistent with the rapid increase in stream discharge and sedimentation events, known to occur during the landfall of tropical cyclones. According to the criteria of Mulder and Syvitski (1995), the rapidly increased sediment load within the freshwaters of Gum Hollow Creek, accompanying the rapid increase in discharge entering the marine to brackish salinity waters of Nueces Bay, are ideal for the enabling Gum Hollow Creek to go hyperpycnal, during the landfall of tropical cyclones. Mulder and Syvitski (1995) suggest that small, dirty to moderately dirty rivers with average discharges (Q_{av}) < 190 m^3 s^{-1} commonly produce hyperpycnal underflows. They further state that only rivers with flood sediment concentrations (Cs_{flood}) > 300 kg m^{-3} can produce hyperpycnal plumes. Using the equations and the nomogram of Mulder and Syvitski (1995), it can be shown that during the landfall of tropical cyclones, Gum Hollow Creek with a Q_{flood}/Q_{av} ranging from 2875 to 5875 and an average sediment load (Cs_{av}) of 0.71 kg m^{-3}, clearly has a tendency to produce hyperpycnal plumes. The lowering of the brackish salinity of Nueces Bay during heavy rainfall events increases this tendency.

Sedimentation rates at Gum Hollow Delta average 2.0 m per century, for the past 80 years, similar to local sedimentation rates reported by Mulder et al. (2003) for the Var deep-sea fan (1.2 to 1.6 m per century). The tempestite deposits of Gum Hollow Delta indicate that over the past

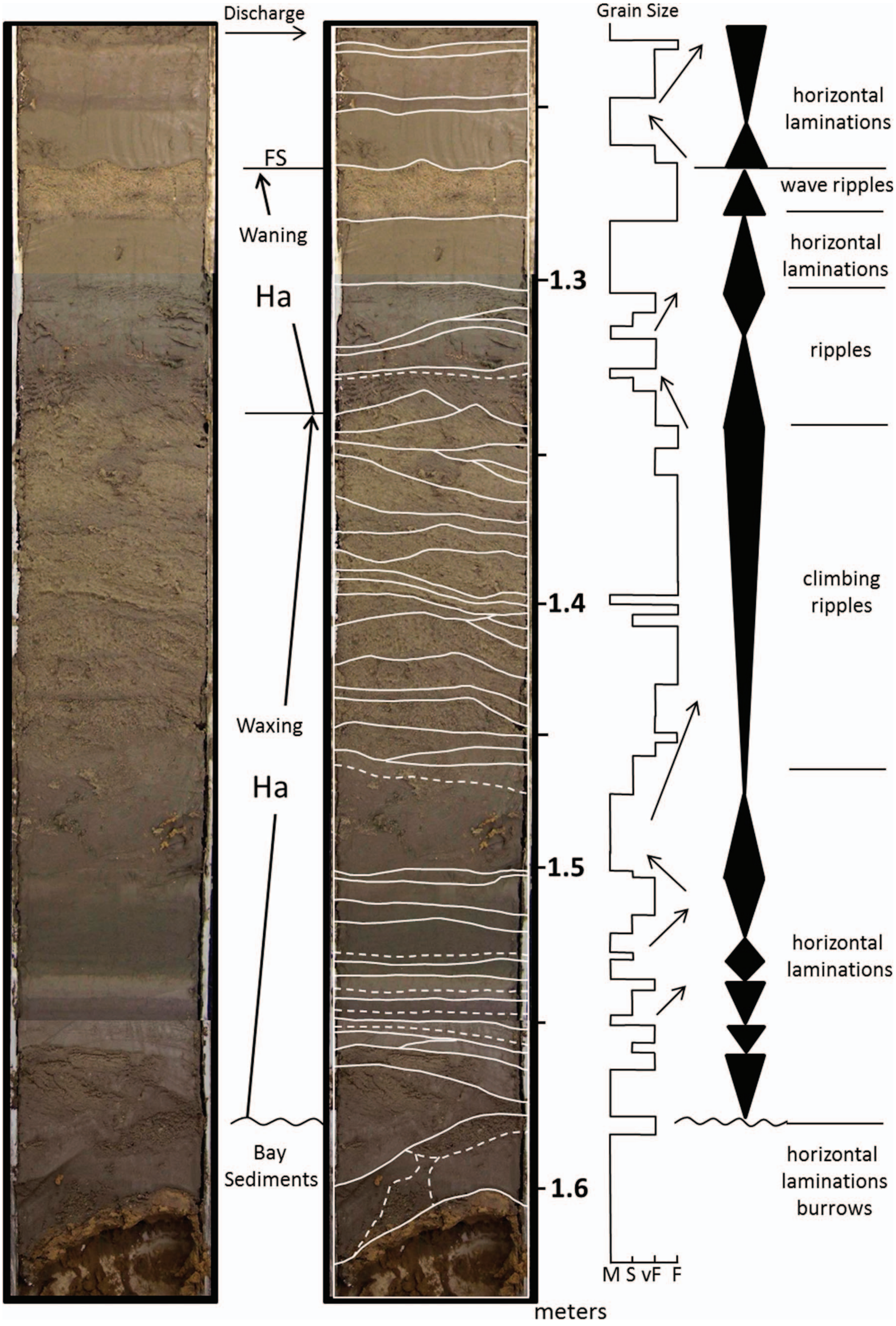

FIG. 6.—Vibracore photograph and a detailed sedimentological and hydrodynamic interpretation of type tempestite T4 (Fig. 5). Black triangles illustrate grain-size trends.

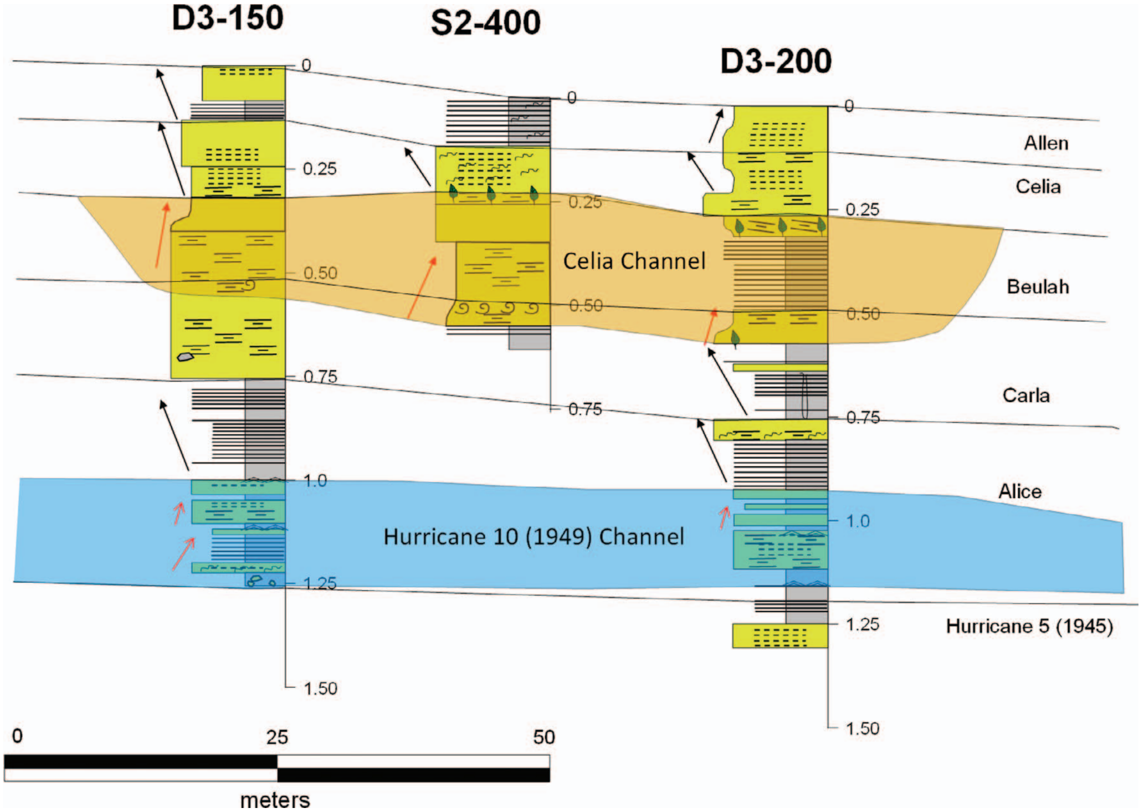

FIG. 7.—Cross section through vibracores D3-150, S2-400, and D3-200 illustrating the sedimentology of distributary channel-fill facies.

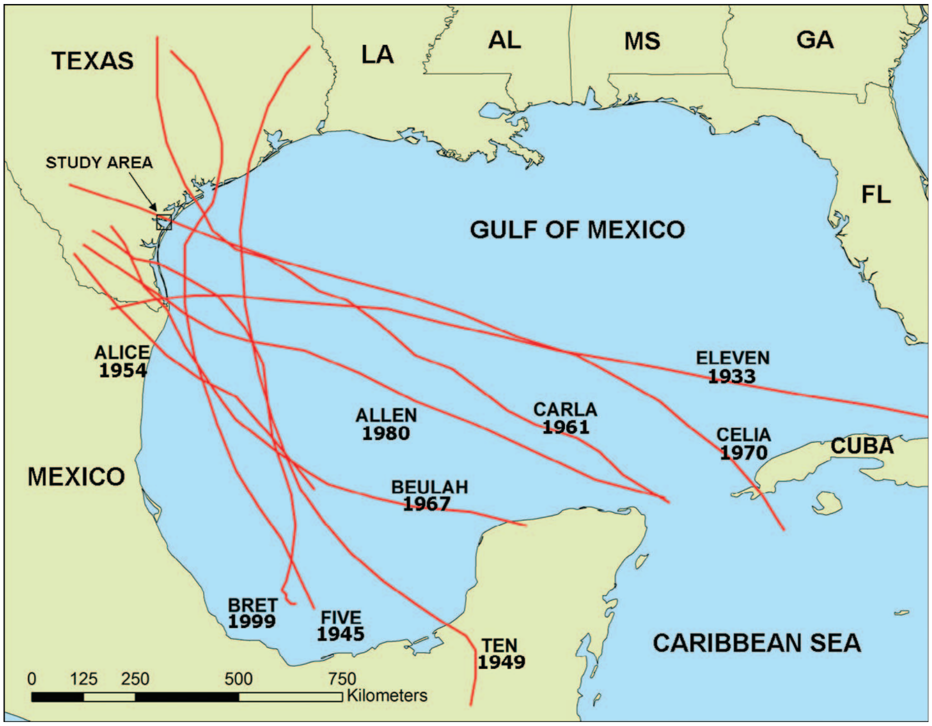

FIG. 10.—A map of the Gulf of Mexico area which shows the tracks of tropical cyclones known to have affected the Gum Hollow Delta from 1933 to present.

TABLE 1.—*Hurricanes affecting Gum Hollow Delta, Nueces Bay, Texas.*

Day	Month	Year	Storm Name	Category	Storm Diameter (km)	Corpus Christi Storm Surge (m)	Corpus Christi Rainfall (cm)	Distance to Landfall of Eye Wall (km)	Gum Hollow Sediment Thickness (cm)	Hurricane Reference
5	September	1933	Hurricane Eleven	3	400	3	38	200 S	33	NOAA (2010)
27	August	1945	Hurricane Five	4	160	5	76	120 SW	20	Sumner (1946)
4	October	1949	Hurricane Ten	2	160	2	37	270 NE	25	Zoch (1949)
25	June	1954	Alice	1	160	4	66	200 S	31	WRC (2010)
11	September	1961	Carla	4	480	3	13	120 SW	27	Hayes (1963)
20	September	1967	Beulah	5	640	6	69	200 S	37	Roth (2007)
3	August	1970	Celia	3	320	3	18	0	52	Tinsley (2010)
9	August	1980	Allen	3	320	4	51	200 S	37	NOAA (2010)
23	August	1999	Bret	4	160	3	15	90 S	20	TDI (2009)

80 years Gum Hollow Creek had hyperpycnal flow every 8.9 years on average. This frequency of hyperpycnal flow events is similar to that reported by Mulder et al. (2003) for the Var deep sea fan (5.0 to 7.5 years).

Based on the role of hyperpycnal deposition in its evolution, Gum Hollow Delta is best classified as a (aggradational to slightly progradational) tropical cyclone-dominated hyperpycnal, wave-influenced delta. Gum Hollow hyperpycnite deposits record the incidence of tropical cyclones (i.e., storminess) in the study area. In fact, Mulder et al. (2003) also suggested that hyperpycnite deposits are useful tools for the deciphering of climate (storminess) records in sedimentary rocks.

IMPLICATIONS FOR RECORDING STORMINESS IN BAYS AND ESTUARIES

Studies of barrier island washover fans (e.g., Buynevich et al. 2004; Donnelly and Woodruff 2007; Scileppi and Donnelly 2007; Woodruff 2009; Garrison et al. 2010), back-barrier ponds (e.g., Donnelly 2005), lake sediments (e.g., Liu and Fearn 2000; Lambert et al. 2007), and beach dune ridges (e.g., Garrison et al. 2012) have revealed records of past storms. Most of these studies have constructed multi-millennial-scale storminess records using materials age dated using ^{14}C techniques. Chanton et al. 1983, Lambert et al. (2007), and Garrison et al. (2012) have constructed sub-centennial-scale records of storminess from sediments, conditioned by historical records of storms. This study provides a new approach to determining ultra-high-frequency storminess records from sediments, using tropical-storm-induced hyperpycnal deposits in storm-dominated deltas. This approach is applicable to a variety of estuarine and lagoonal deltas which are fed by small streams, with limited drainage basins that are frequently subjected to the influence of tropical cyclones.

In addition this study suggests that tempestite bedsets (i.e., hyperpycnites) in small estuarine and lagoonal deltas can form during short-term tropical cyclone landfalls. Flooding surfaces that cap these hyperpycnal tempestites form as storm surges produce short-term base-level rises in estuaries and lagoons. This base-level rise is followed by a rapid hyperpycnal deltaic sedimentation event as a result of high runoff as tropical-cyclone rain bands increase precipitation rates by 1 to 2 orders of magnitude. Therefore, using the sedimentological model described above combined with ^{137}Cs geochronology, optically stimulated luminescence (OSL) geochronology, or ^{14}C geochronology, a record of storminess can be constructed by delineating and age dating the hyperpycnites within both modern and ancient estuarine and lagoonal deltas.

CONCLUSIONS

Gulf of Mexico hurricanes Eleven (1933), Five (1945), Ten (1949), Alice (1954), Carla (1961), Beulah (1967), Celia (1970), Allen (1980), and Bret (1999) produced significant base-level rises and deltaic hyperpycnal depositional events (hyperpycnal tempestites) in Gum Hollow Delta in Nueces Bay, Texas. Comparison of the timing of the deposition of stratigraphic units, constrained by ^{137}Cs geochronology and historical aerial photographs, and the historical record of storms in the Gulf of Mexico indicate, that the Gum Hollow Delta preserves an 80-year record of tropical cyclones.

Tempestites in small estuarine and lagoonal deltas can form during tropical-cyclone landfalls. Flooding surfaces capping the tempestites form as storm surges produce short-term base-level rises in estuaries and lagoons. This base-level rise is followed by a rapid deltaic sedimentation event as a result of high runoff from tropical-cyclone rain bands.

The bipartite sedimentological structure of tempestite deposits, produced by the high freshwater discharge and sediment load of Gum Hollow Creek during the landfall of tropical cyclones, indicates that Gum Hollow Delta tempestites have sedimentology, hydrodynamics, and origin similar to the hyperpycnal deposits described by (Mulder et al.

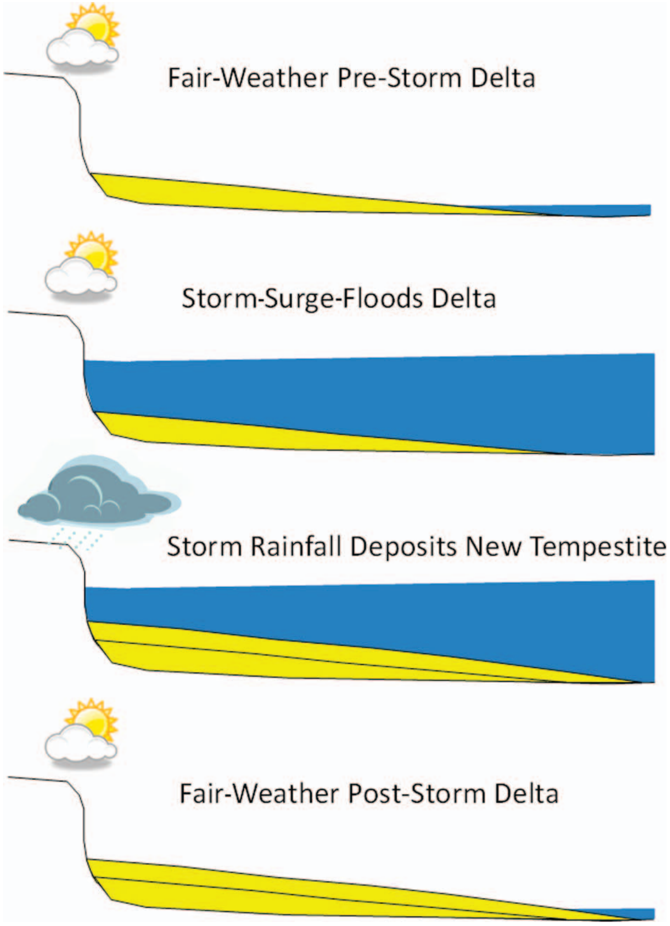

FIG. 11.—Conceptual model for the development and growth of Gum Hollow Delta during tropical cyclones.

2003) and can be used as a tool to investigate climate records in sedimentary rocks.

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