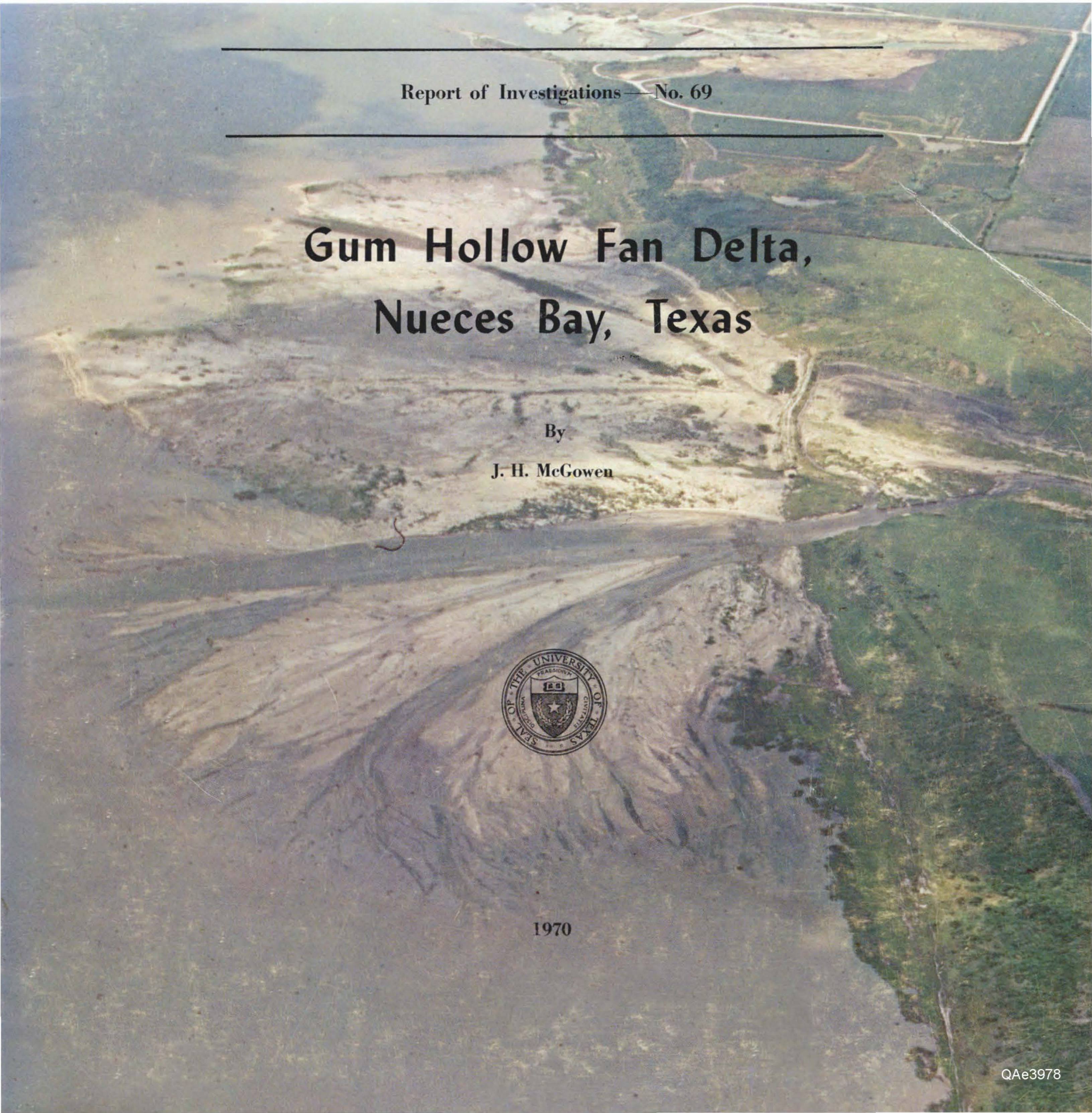
BUREAU OF ECONOMIC GEOLOGY

The University of Texas at Austin

Austin, Texas 78712

Peter T. Flawn, Director



Report of Investigations—No. 69

Gum Hollow Fan Delta, Nueces Bay, Texas

By

J. H. McGowen

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ABSTRACT

Gum Hollow fan delta, located on the mainland side of Nueces Bay, west of Portland, Texas, has been built in the past 30 years by discharge of a partly artificial drainage system. Construction of Gum Hollow fan delta began in the early 1940s. On-site field observations began in 1964; prior history is based on aerial photographs.

Gum Hollow fan delta is tri-lobate. Western and middle lobes were active from initial construction until after Hurricane Carla in 1961. The active lobe resulted from man-made diversion of the discharging channel; its size and shape resulted from three principal depositional events: (1) heavy spring rains in 1966 under normal sea level conditions, (2) heavy rains associated with Hurricane Beulah in fall 1967, accompanied by a 5-foot rise in sea level, and (3) aftermath rains triggered by Hurricane Candy in summer 1968.

Under conditions of normal sea level and relatively low discharge resulting from local thunderstorms, dispersal on the fan is by means of braided streams; the fan progrades. Under conditions of high discharge resulting from exceptionally high rainfall accompanying hurricanes or tropical storms, dispersal on the fan occurs as sheetfloods; the fan aggrades because water level in the bays is highest at this time. During destructional periods the fan delta is reworked by beach, sheet wash, and aeolian processes.

Gum Hollow fan delta consists of four main depositional areas: (1) fan plain, the principal emergent part of the fan delta; (2) distal fan, situated between the fan plain and open bay; (3) main channels, which extend from the apex of the fan delta, cut across fan plain and distal fan, and terminate at the bay margin; and (4) prodelta, which borders the distal fan on the bay side. The fan plain is characterized by longitudinal bars and shallow braided channels. Dominant stratification types of the fan plain are parallel laminae, trough-fill cross-stratification, and small trough sets. The distal fan is shaped by fluvial, alternating fluvial and wind tidal, or beach processes, depending upon position relative to the bay or fan plain. Main channels are cut into fan plain and distal fan deposits; sedimentary structures of the main channel fill are similar to those of the fan plain. Erosional relationships, thicker sedimentation units, and associated slope wash and pond deposits distinguish channel from fan plain deposits. Alternating small trough sets and mud drape units dominate prodelta deposits; wave ripples and burrows are minor features. Sediment of the subaerial fan is dominantly fine sand derived from the Beaumont Formation; prodelta deposits are mud and sand.

Biological activity on subaerial parts of Gum Hollow fan delta is minor. Distal parts of the inactive fan are being invaded by low marsh vegetation. An infauna of worms, mud shrimp, and angel-wing clams is present in prodelta sediment of abandoned lobes.

INTRODUCTION

Fan deltas are basically alluvial fans that prograde into a body of water from an adjacent highland. The term fan delta is used in the sense that Holmes (1965) applied it to a delta at Lynmouth (north shore of the Bristol Channel, Devon, England). Although mechanics of fan development and distribution of surface sediment of alluvial fans in arid regions have been studied by geomorphologists, fan deltas have not been studied to determine the kinds of processes operating during their construction and the sediment characteristics of the various depositional areas. To date there are no published data on geometry of facies of these features, nor has the occurrence of an ancient fan delta been recorded, probably not because they are absent in the rock record but because criteria for their recognition have not been available.

A study of Gum Hollow delta, a modern fan delta along the north shore of Nueces Bay, Texas, was undertaken to determine the mechanics of fan development and the relationships between sedimentary processes and structures. In addition this study provides criteria that can be utilized in recognizing ancient fan delta deposits and in making a distinction between ancient fan and bayhead deltas. Further, the study documents changes in form of the fan and relates these changes to specific geologic processes. Observations were made on the active fan segment regularly from the spring of 1966 through early summer of 1967 and after hurricanes or exceptionally heavy rainfall since early summer 1967. Data obtained from observations made on the active fan segment, in conjunction with a series of photomosaics (beginning in 1939 and continuing through 1963), were used in the interpretation of depositional conditions prevailing during construction of the presently inactive fan segments.

ACKNOWLEDGMENTS

This report is based on a dissertation by the writer at The University of Texas at Austin. Dr. Alan J. Scott supervised this work, and Drs. John C. Harms, of Marathon Oil Company, and W. C. Bell and Robert L. Folk, of the Department of Geological Sciences, The University of Texas at Austin, served on the dissertation committee. To these gentlemen go special thanks for their many helpful criticisms.

Appreciation is expressed for the support and interest of Dr. Peter T. Flawn, Director, Bureau of Economic Geology, The University of Texas at Austin, during the course of this study. Drs. W. L. Fisher and P. U. Rodda critically read the manuscript and made helpful suggestions. Miss Josephine Casey and Mrs. Elizabeth Moore processed the manuscript; illustrations were prepared under the supervision of J. W. Macon.

Several students at The University of Texas at Austin made significant contributions to this study. E. R. Killian, R. A. Hoover, P. B. Andrews, J. A. Miller, and J. L. Carew assisted in various stages of the field work. H. S. Chafetz read the manuscript, and C. G. Groat provided much of the background data on alluvial fans.

Finally, a debt of gratitude is owed to Mr. W. T. Pulliam for granting access to the study area.

GEOLOGIC SETTING

Gum Hollow fan delta is situated along the north shore of Nueces Bay, about 2 miles west of the town of Portland, San Patricio County, Texas (fig. 1). Both Nueces Bay and Corpus Christi Bay lie behind a barrier island chain. Mustang Island forms the barrier along the eastern part of Corpus Christi Bay.

An erosional escarpment, produced by the meandering Nueces River when sea level was lowered during the Pleistocene Epoch (Price, 1933), forms the north shore of Nueces Bay in the Portland vicinity. Relief on the escarpment in the Gum Hollow area is 35 to 45 feet. North of the escarpment is a flat, relatively featureless surface that has a gentle east to northeast slope of 3 to 5 feet per mile. Short, relatively high-gradient streams (10 to 50 feet per mile) that drain into Nueces Bay are the only natural drainage systems present between the escarpment and U. S. Highway **181**.

Most of the Gum Hollow drainage is through several artificial channels constructed to accelerate runoff of the flat farm land. Only the southern 2½ miles of the drainage system is a natural channel (fig. 2). Gum Hollow drainage area, including natural and artificial channels, comprises an area of approximately 17 square miles, and most of the system lies within a cultivated area. Average stream gradient of Gum Hollow is about 8½ feet per mile.

The fluvial system is entrenched into the Pleistocene Beaumont Formation, which is the source of the terrigenous sediment of the fan delta. Drainage area of Gum Hollow fan delta cuts across the ancestral Atascosa-Nueces delta (Price, 1933). These Pleistocene deposits are predominantly mud; however, some of the distributary channels transect the area, and they are the major source of sand size material.

Nueces Bay is the basin into which the fan delta is prograding. The bay is relatively small and extremely shallow, with a maximum depth of 3 feet. Because of the shallow nature of the bay a relatively small volume of sediment delivered to the depositional site during a brief period of time causes rapid progradation.

DEVELOPMENT OF GUM HOLLOW FAN DELTA

The purpose of this section is to provide a chronological framework for the main body of text that emphasizes mechanics of fan development, sedimentary processes, and sediment characteristics of the Gum Hollow fan.

Conditions favorable for fan development, adjacent highland and lowland, existed along the north shore of Nueces Bay following the rise in sea level to its present position, about 3,000 years B.P. Extensive fan development did not occur immediately because of poorly developed drainage on the Beaumont Formation and the abundant plant cover. In fact, the present size and shape of the fan delta have been attained in less than 30 years.

Photographs taken of the Gum Hollow fan area in 1939 show a small salient feature at the mouth of Gum Hollow Creek (Pl. I,A). That sediment accumulation was slow until this time is indicated by a dense cover of marsh vegetation. Erosion in the source area was inhibited by vegetation and by the fact that the natural drainage system of Gum Hollow was, prior to the 1930s, very small. With a given amount of rainfall, erosion will be slight if the source area is densely vegetated; the coarser sediment will be trapped (Schumm, 1968) and mostly clay and silt will be transported through the drainage system.

Beginning in the early 1930s fundamental geomorphic processes were accelerated through the intervention of man. An artificial channel system was constructed to drain the area lying between Portland and Taft (fig. 2). Native vegetation was subsequently removed and the area was converted to farm land, thereby accelerating erosion in the source area and rates of sediment accumulation at the mouth of Gum Hollow.

Gum Hollow fan growth dates from the completion of the drainage system, and initial deposits accumulated in the area referred to as the western and middle lobes (Pl. III). Photo coverage is not available between 1939 and 1948, and it can only be said that fan development began sometime during that period. The first fan deposits were laid down as an apron of oyster shell and mud-pebble to small cobble gravel. The apron extended about 600 feet south beyond the fan apex. Subsequent deposits were dominantly fine sand laid down by shallow braided streams. After several inches of sediment had accumulated a single channel was scoured through the fan, either as water level in the bay lowered following a flood, or, as discharge decreased, one of the braided streams carried most of the flow and was enlarged by erosion. Deposition at mouths of the main channels occurred when floods were of small magnitude and during winter months when sediment was scoured from the channel floor.

By 1948 two distinct lobes had developed (Pl. I,B). These features maintained their relative positions, but not their form, throughout the period of time this fan section was in the constructive phase. Maintenance of lobes was related to the more or less stable courses of the two main channels. First one and then the other channel carried all, or most, of the discharge. This is indicated by aerial photographs (Pl. I, C, D, E, and F) that show one lobe being better developed than the other, thus lengthening the main channel; subsequent floods were then diverted down the channel with the shorter course and relatively higher gradient. Main channels had relatively stable positions because they were entrenched into somewhat resistant, older, fan plain sediment. Progradation after entrenchment of channels was through development of smaller fans at distal ends of main channels. The main channels served the same function as entrenched channels on alluvial fans.

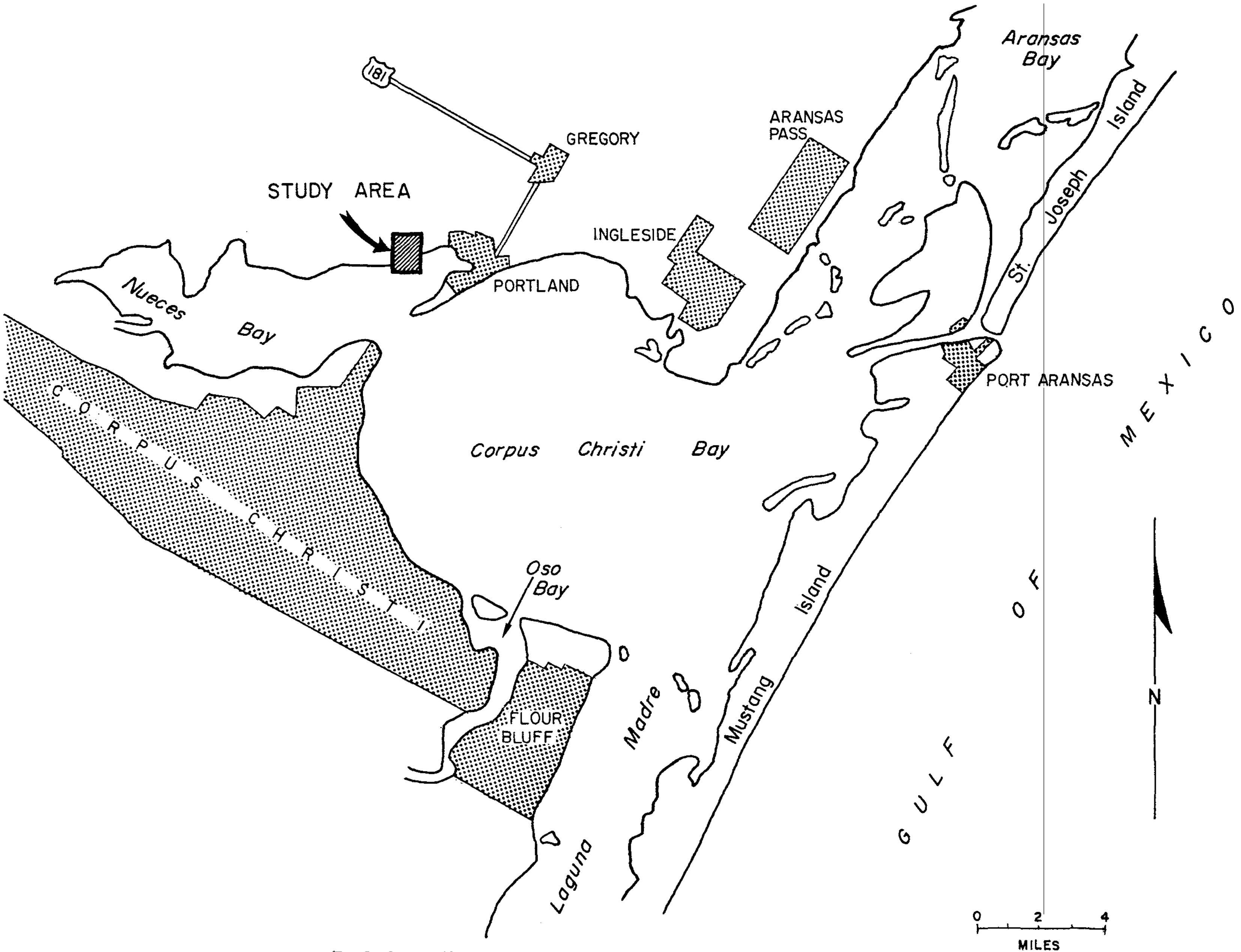


Fig. 1. Corpus Christi Bay–Nueces Bay region showing location of the study area.

If water and sediment discharge were limited, alluviation occurred mostly within the channel, the main channel became very narrow (1950 and 1956 photographs, Pl. I, C and D), and progradation was restricted to a narrow zone at the channel mouth. When discharge was high, at times when annual rainfall was above normal, the main channel was scoured and most of the sediment accumulated beyond the channel mouth as a fan.

Observations of constructional phases on the active lobe, and correlation of rainfall data with depositional events, show that short intervals of exceptionally heavy rainfall generally coincide with periods of greater than average annual rainfall. These observations, changes in shape of the fan as shown on aerial photographs, and rainfall and hurricane data, suggest that at least four, and perhaps seven, major depositional events (table 1) accounted for

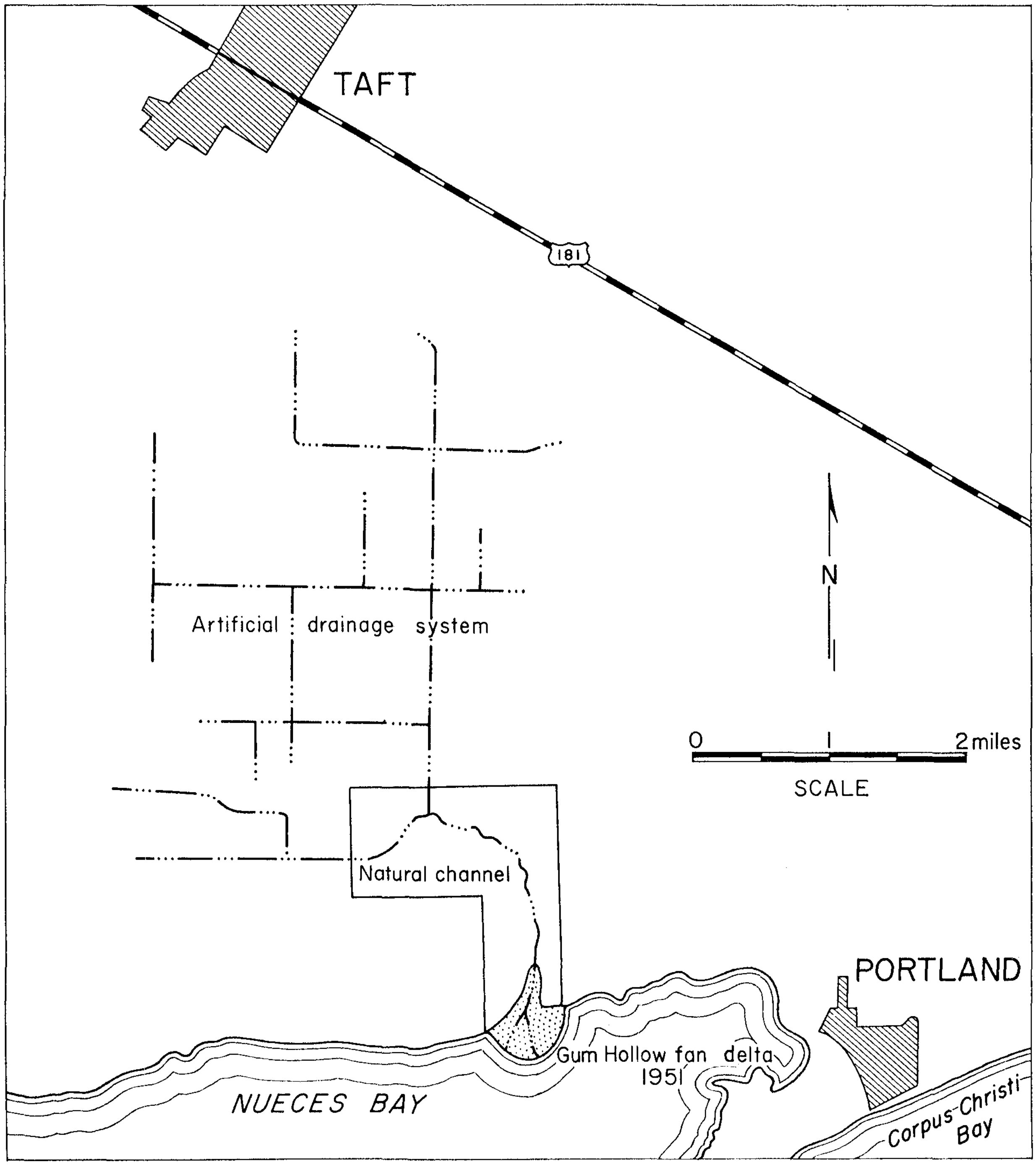


FIG. 2. Drainage system of Gum Hollow fan delta.

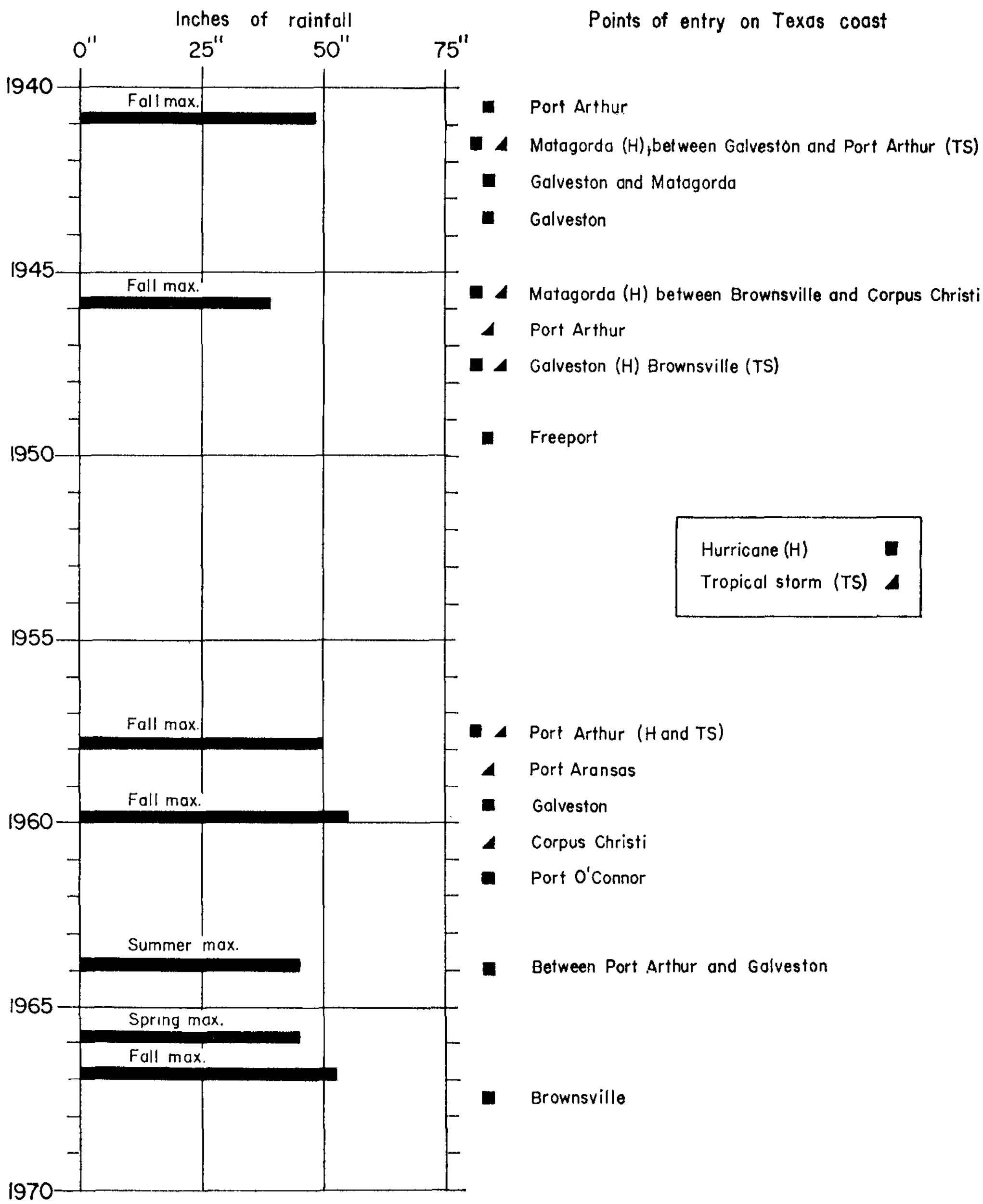
construction of the middle and western lobes from the time of fan initiation through 1961. Hayes (1965, 1967) reported that 42 tropical cyclones struck the Texas coast between 1900–1963. Fifty-two percent of the cyclones struck the coast in August and September. Table 1 shows the four years having total rainfall in excess of 39 inches; all had a fall maximum that was probably related to a hurricane or tropical storm.

Two tropical storms (1958 and 1960) passed through the Corpus Christi area. Aerial photographs indicate that the middle lobe was prograded in 1958, and that discharge was probably carried by the western channel in 1960. No significant change occurred in the fan shape between 1958 and 1963. The left bank of the middle channel was crevassed in 1958, and the crevasse splay is shown as a salient feature along the east margin of the fan. Overbank sedi-

TABLE 1. *Years with greater than average annual rainfall (Taft area) and occurrences of tropical storms and hurricanes (along the Texas Gulf Coast) for the period 1940 through 1967.*

Annual rainfall in excess of 39 inches is, for the most part, directly related to the occurrence of tropical storms or hurricanes. In general, those years (1940, 1946, 1958, 1960, and 1967) with excessive rainfall had a fall maximum that coincides with the hurricane season.

The years with the highest rainfall were 1958, 1960, and 1967. In 1958 and 1960 two tropical storms had their points of entry on the Texas coast in the Corpus Christi area.



mentation, indicated by climbing ripple laminae, accompanied the 1958 depositional event. The middle lobe became inactive after 1958, although the crevasse channel may have carried some of the 1960 flood discharge. The middle channel was subsequently filled by windblown sand, sheet wash, and mud derived from Nueces Bay.

About a year after the passage of Hurricane Carla (1961) an earthen dam was constructed across the Gum Hollow channel near the fan apex (Pl. III), and flow was diverted away from the middle and western lobes by a man-made channel. Sediment and water discharge were diverted to a position about 800 feet east of the older fan apex. Following channel diversion the western channel began to be filled by the same processes that had filled the middle channel, and distal segments of inactive lobes were eroded by wind tides. Since 1958 the distal part of the middle lobe has retreated about 500 feet.

The subaerial part of the active lobe came into existence in the spring of 1966 as a consequence of three periods of heavy rainfall. The spring series of depositional events prograded the subaerial fan about 1,000 feet beyond the mouth of the diversion channel (Pl. II, A). From July 1966 through September 1967 no appreciable increase or decrease of the fan surface area occurred. It was partly inundated when Hurricane Inez (October 1966) caused a rise in water level in Nueces Bay, new longitudinal bars were developed in the main channel in the early part of 1967, the channel was deepened when northers caused a lowering of water level in the bay, and the distal fan was cut back somewhat by wind tides, but there were no drastic changes in area of the subaerial fan.

Vertical accretion ranging from 1 to 3 feet occurred when the fan was inundated by about 5 feet of water as a consequence of the Hurricane Beulah storm-surge flood (September 1967). Heavy rainfall, in excess of 20 inches, and change in base level created conditions favorable for deposition of an areally restricted, relatively thick fan on top of the 1966 fan (Pl. II,B). Chang (1967) produced this type of feature in a large, laboratory-model basin by changing reservoir base level (increased water depth). After deposition of the Beulah fan and lowering of water level in Nueces Bay a new scour channel was developed; this channel had a trend almost at right angles to the trend of the 1966 main channel.

Hurricane Candy developed off the coast of Mexico in June 1968 and triggered heavy rainfall in the Taft-Portland area. Flooding in Gum Hollow drainage area removed most of the Beulah sediment. The Beulah sediment plus that brought down by the fluvial system constructed a new fan about 2 to 3 feet below the remnant Beulah fan (Pl. II,C). The latest fan was constructed by braided streams; the present fan plain displays the typical brush-defended longitudinal bars and flanking shallow channels that characterize braided-stream deposits. As the flood subsided and water level lowered, a new scour channel developed. This channel occupies the approximate position of the 1966 main channel.

CHARACTERISTICS OF GUM HOLLOW FAN DELTA

General features of Gum Hollow fan delta are shown on a plane-table map made in July and August, in 1966 (Pl. III). It is a broad fan-shaped, sparsely vegetated, sand body with three channels in various stages of development or destruction; these mark the axes of three principal areas of deposition.

Subaerial environments recognizable on the fan (Pl. III) are the fan plain, distal fan, and main channels; most of the sediment in these environments was deposited by braided streams. The prodelta depositional area lies just bayward of the distal fan; sediment was deposited in this area from traction and suspension load. Some of the environments are expressed as physiographic features; others are more subtly expressed as gradual downfan changes in sedimentary structures and textures.

Deposition of sediment on Gum Hollow fan delta is divided into an accretionary and a modification phase that are analogous to constructional and destructional phases of delta development (Scruton, 1960).

The formative processes operating on the fan delta are mostly physical. Biological processes are relatively unimportant on the subaerial fan. Within the bay, in the area peripheral to the fan, biological activity is expressed by the degree of sediment homogenization. Biologically formed debris is insignificant in volume near the Gum Hollow fan delta.

ASTRONOMICAL TIDES

Astronomical tides produce little change in water level in Nueces Bay and do not exert much influence on distribution of fan delta sediment. The diurnal tidal range is not precisely known due to superimposed wind effects but appears to range from 0.3 to 0.5 foot.

Water level in Nueces Bay plays an important role in deposition on Gum Hollow fan delta. When water level is low sediment is distributed laterally over a considerable area; when high, lateral distribution is restricted and vertical accretion pronounced. There are two factors that affect water level: normal wind régime and hurricanes.

WIND RÉGIME

Water level depends primarily on wind direction. Winds are mostly southeasterly, especially in the spring and summer. Water is driven ahead of these southeast winds, raising the water level along the north shore of Nueces Bay.

During the winter months "northers" lower water level along the north shore of Nueces Bay and raise water level along the southern shoreline. Northers result from the penetration of polar air masses into the Gulf of Mexico region, usually between November and March. As many as 15 or 20 northers reach the coastal area each year, and according to Hayes (1965) from one to six of these may be severe storms with wind velocities in the 25–50 knot range. In addition to lowering water level on the north side of the bay, northers are sometimes accompanied by heavy rains that cause progradation of the fan delta, as discussed under Effect of Light Rainfall and Northers (p. 12).

Prevailing and predominant winds are shown on figure 3, B. These are terms used by Lohse (1952, 1955) and Hayes (1965). Prevailing winds are the directions of winds that blow most of the time during each month indicated but are not the winds that do the net geologic work as they do not represent the greatest expenditure of energy (Lohse, 1955). Predominant winds represent the direction in which surface winds expend the greatest amount of energy month by month. Winds are mostly southeasterly, especially in the spring and summer.

Currents within Nueces Bay are generated primarily by the wind. These currents are effective in destroying distal parts of the fan delta and redistributing sediment. Redistribution of sediment by wind on the fan delta surface affects a relatively small area and is not very important as depositional or erosional agents. The most important role of the wind régime is the creation of wind tides that either raise or lower water level in the fan delta area. This fluctuation of water level exposes different areas of the fan delta to destructive influence of wind-generated currents.

In summary, the fan undergoes destruction or construction depending upon wind direction. Lohse (1952, 1955), Hayes (1965), and Andrews (1967) have discussed the importance of the wind régime on sedimentation on barrier islands and in the shallow neritic zone along the Texas Gulf Coast.

HURRICANES

The destructive and depositional role of tropical storms and hurricanes for selected sections of the Texas Gulf Coast has been documented by Price (1956), Hayes (1965, 1967), Andrews (1967), and Scott, Hoover, and MeGowen (in press). Hurricanes cause a rapid change in water level in Nueces Bay, but if the hurricane is not accompanied by heavy rainfall little trace of its passage is likely to be preserved in deposits of the fan delta.

RAINFALL AND FLOODS

Annual average rainfall decreases along the Texas coastal area from about 55 inches at Beaumont to about 26 inches at Brownsville. Rainfall data reported by Hayes (1965) show the annual average rainfall in the Corpus Christi area to be about 25.5 inches, based on a 40-year record. The Taft area, based on a 39-year record, has an annual average rainfall of 32.9 inches (table 2).

Figure 3,A graphically shows rainfall distribution from 1929 through 1967. Two rainfall maxima, one in May and the other in September, are quite distinct. Both Johnston (1955) and Hayes (1965) indicated rainfall maxima in the Corpus Christi area in May and September with the

TABLE 2. *Rainfall distribution for Taft area from 1929 to 1967.*

MONTH	MONTHLY DISTRIBUTION (39-YR. AV., INCHES)
January	2.56
February	1.93
March	1.46
April	2.59
May	4.23
June	2.70
July	2.47
August	3.04
September	5.05
October	2.93
November	1.77
December	2.38

latter having a somewhat higher average. Higher rainfall average for September is related to the hurricane season.

Periods of construction on the fan delta occur any time of the year when a single rain of a few hours duration in the source area is greater than 2 inches. A slow, regional rain does not cause appreciable sediment to be added to the fan. Local, heavy rainfall is the type that is responsible for construction of Gum Hollow fan delta. Rainfall from May through October occurs principally as scattered thundershowers (Johnston, 1955).

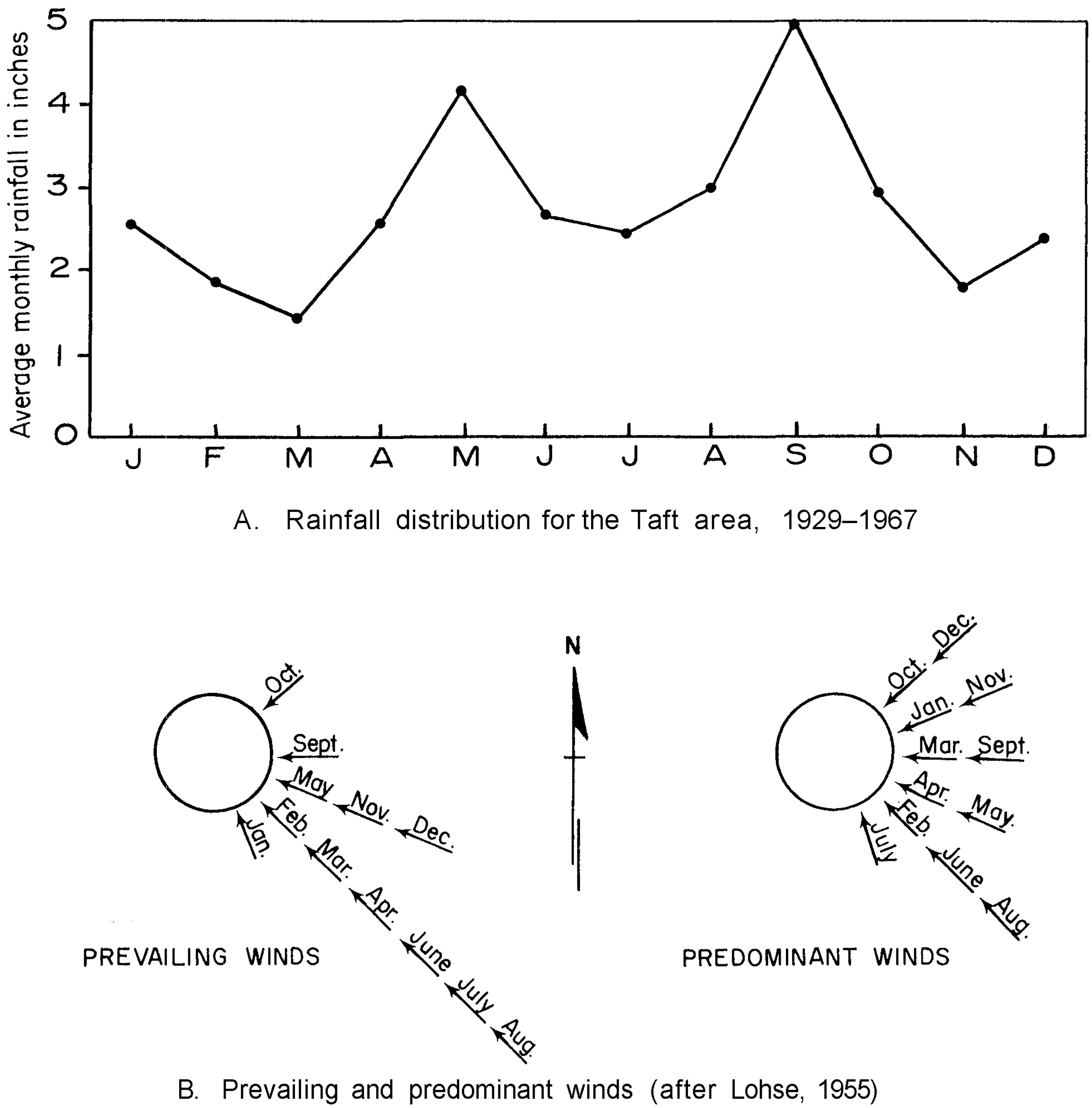


FIG. 3. Wind direction and rainfall distribution.

FAN CONSTRUCTION: MECHANICS

Mechanics of development of Gum Hollow fan delta involve sedimentary processes, rainfall distribution, water level in Nueces Bay, wind régime, drainage area characteristics, and sediment type available to the fluvial system. All these factors operating together are considered as the gross mechanism that produced the fan-shaped depositional feature.

Gum Hollow fan delta is one of the most dynamic areas of sedimentation on the mainland side of the Texas bays. Because the drainage area is small, rain must fall directly upon it in order for the fan to be depositionally active, and this activity lasts a few hours to possibly a day or so. There is little time lag between rainfall and runoff at present as the drainage system lies within an area of cultivation. Flooding is now more severe than pre-1930 when the area was densely vegetated. The volume of sediment deposited at a given time and the type of flow are controlled directly by amount of rain that falls on the drainage area. Flow conditions are recorded in the geometry of the fan, by smaller features such as bars, and by various stratification types.

Flow conditions during progradation of the active lobe were not observed because floods are of short duration and because of inaccessibility of the area during Hurricane Beulah. Bed forms were observed shortly after three major depositional events: (1) spring of 1966, (2) Hurricane Beulah in September 1967, and (3) Hurricane Candy in June 1968. Flow conditions during construction of the 1966 fan, minor floods, and the Beulah fan have been interpreted to be analogous to flow on alluvial fans (Blissenbach, 1954).

SEDIMENT SOURCE

Sediment deposited on the fan is derived from the floor and banks of artificial drainage channels cut into deposits of the Pleistocene Atascosa-Nueces delta, described by Price (1933), and from the adjacent farmland. The area adjacent to the natural drainage system of Gum Hollow Creek is not an important sediment source because of dense vegetation cover.

Shortly after construction of the drainage system, and before salt water (oil-field brine) was disposed through it, channel bars were stabilized by vegetation. Resistant, vegetated bars deflected flow within the channel and caused the thalweg to meander and undercut channel banks. Meandering widened the channel to such an extent that spoil banks paralleling the channel course slumped into the channel. The channel course was subsequently straightened and since brine has been discharged through the system there has been little tendency to meander. Early growth stages of the fan delta were rapid because of the tremendous volume of sediment made available by undercutting the spoil banks.

SEDIMENT DISPERSAL

Sediment dispersal on Gum Hollow fan delta, under direct influence of fluvial processes, is controlled to a large degree by conditions in the bay, amount of rainfall, wind direction and intensity, and stage of main channel development.

Grain size of the source sediment ranges from clay to granule gravel. Sediment which accumulated on the fan under direct influence of fluvial processes is chiefly fine sand. Some pebble and cobble gravel accumulated near the apex of the fan; these particles consist of mud clasts and caliche from banks of a channel cut through the Pleistocene sediment, and shell debris (mostly *Crassostrea virginica*) derived from Indian middens atop the erosional escarpment.

Water level in Nueces Bay affects sediment dispersal by temporarily changing base level. When deposition coincides with a period of lowered water level the fan progrades, and if the fan is inundated by a few feet of water during deposition it is aggraded.

DEVELOPMENT OF ACTIVE LOBE

Rapid growth of the eastern lobe of Gum Hollow fan delta occurred in spring of 1966. Progradation of 600 to 1,000 feet, resulting in about 17 percent increase in width of the fan (fig. 4), occurred between April 25 and June 18. Prevailing winds for April through June were from the southeast quadrant, and water level in the bay was probably above normal. Total rainfall for April through June was 21.8 inches; however, only three days of this period had sufficient rainfall to make the fan depositionally active. Total rainfall for these three days (April 25, May 5, and June 18) was 12 inches.

UNCONFINED FLOW—LATERAL ACCRETION

Blissenbach (1954, p. 178) classified depositing agents on alluvial fans into three types designated sheetfloods, streamfloods, and streams. *Sheetfloods*

> . . . occur when an exceedingly large amount of water and detritus emerges from a mountain canyon. The flow, acting like a viscous medium, tends to spread out in the form of a sheet covering the alluvial fan or parts of it.

He stated that a peculiarity of sheetfloods is "their shortness in distance as well as in time of their flows." *Streamfloods* are confined to definite channels on alluvial fans and form where a large amount of water and detritus emerges from a mountain canyon. They "may also form because channels on alluvial fans are too deep to allow a sheetflood to develop." Streamflood deposits differ from sheetflood deposits by being linear in plan rather than blanket-shaped.

Streams

. . . are formed if both the amount of water and the quantity of detritus are less than the requirements for sheetfloods or streamfloods. A steady, rather than abundant supply and recharge of water from the mountains must be maintained.

Flow conditions responsible for development of the 1966 fan were similar to flow on alluvial fans designated as streamfloods and streams by Blissenbach (1954). On Gum Hollow fan delta, water and sediment, during flood crest, flowed radially away from the cut through the Pleistocene

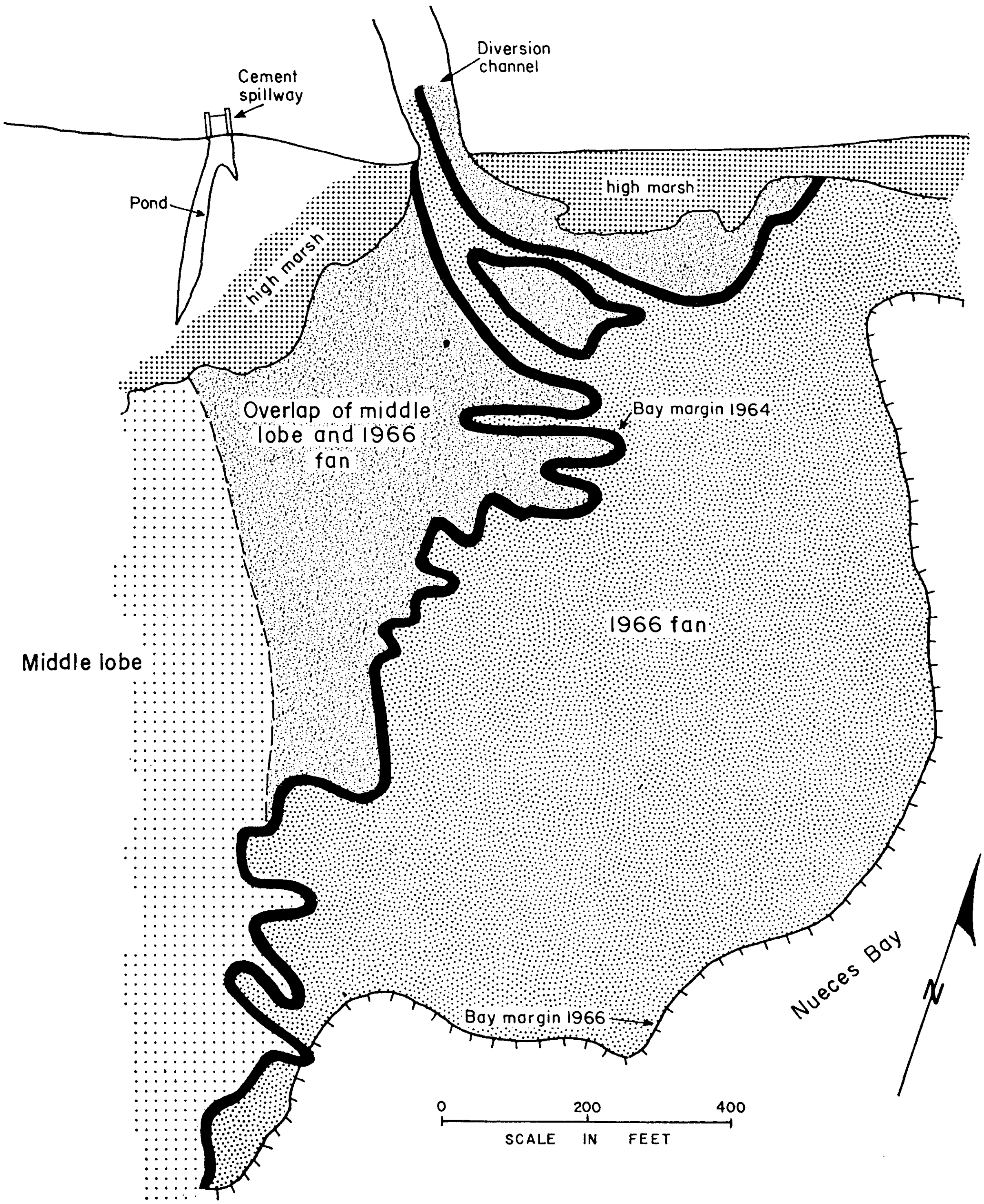


FIG. 4. Overlap of middle and active lobes. Plane-table map of the 1964 fan by Scott, Hayes, and Andrews (1964) and map of the 1966 fan by Scott, Kilian, and McGowen (Pl. III, pocket).

deposits. At this time there was no main channel system and flow was relatively unconfined. The surface of the radiating fan was one of continually shifting, shallow, braided streams and low-relief longitudinal bars (Pl. II,A). Near the apex of the fan scour removed part of the high marsh and an apron of oyster shell, caliche, and mud-cobble gravel was deposited. Farther downfan brush and other debris were dropped as competence of the flood decreased. Debris piles served to retard flow, and sand-size material accumulated downcurrent from these shields in the form of longitudinal bars. Scour was initiated at the upcurrent end of the sediment traps and continued downcurrent along the sides of longitudinal bars. As flow continued deposition downfan occurred as numerous overlapping longitudinal bars. Debris piles served as nuclei of longitudinal bars in a manner analogous to coarse-grained terrigenous sediment that initiated deposition of longitudinal bars in the braided streams studied by Leopold and Wolman (1957), Ore (1963), and Leopold, Wolman, and Miller (1964).

During the flood crest, sediment accumulated as a fan-shaped body. The fan shape is the product of the braided fluvial system. With a single channel or a distributary system, sediment accumulation is concentrated about the channel mouth, but with braided streams sediment distribution is essentially uniform over a large area because of unconfined flow and continually shifting streams.

As the flood subsided a single channel system was cut into previously deposited braided stream deposits. Downcutting was caused by reduced load as the flood subsided. With development of a main channel the channel mouth (initially at the cut through the Pleistocene sediment) was displaced in a bayward direction, and with the following floods the fan-shaped, braided-stream deposits radiated outward from the new channel mouth position. Terraces were cut into fan plain sediment during waning stages of the last flood (fig. 5).

CONFINED FLOW

When the flood subsided a channel was scoured down the axis of the fan. Flow through this single channel is interpreted as being analogous to flow on alluvial fans designated *streams* by Blissenbach (1954). Following the initial flood, and after development of a channel through initial fan deposits, longitudinal bars developed within the channel. As flow through this main channel system decreased, sediment was transported only in lows between longitudinal bars, and bed forms during falling flood stage were cuspate and linguoid ripples. Downchannel termini of some of these ripple fields were steep faces that were 2 to 3 inches high.

EFFECT OF LIGHT RAINFALL AND NORTHERS

A 1-inch rain in the Gum Hollow drainage area produced increased discharge in the 1966 main channel. Average surface velocity ranged from about 0,95 to 1.65 ft./sec., depth of flow was greatest near the apex (maximum of about 1.5 feet) and generally decreased downchannel (0.6 foot at profile F), and slope of the water surface was greatest in the upper reach of the channel (0.00233 between profiles A and C) and decreased downchannel (0.0004 between profiles C and F). Flow conditions during discharge (September 17, 1966) are shown graphically on figure 6.

Suspension load was relatively high at this time, but movement of fine sand as bed load could not be detected. The water was turbid and bed forms could not be observed, nor could transport along the channel floor be detected by feeling the bottom with the hand. Based on data obtained from flume experiments, surface velocities of 1 to 2 ft./sec. should be capable of moving fine sand as ripples if flow depth was only a foot or so (John C. Harms, personal communication, 1968); however, transport rate would be fairly low.

There are two possible explanations for the apparent lack of transport of fine sand as bed load: (1) sediment transport was so low that it was not detected, or (2) the high concentration of suspension load decreased the fall velocity of fine sand to such a degree that sand as well as silt and clay passed through the channel as suspension load. Simons, Richardson, and Haushild (1963) discussed the effect of suspension load on fall velocity of medium sand and on bed forms of the lower- and upper-flow régimes, and their ideas are the basis for suggesting that fine sand was transported as part of the suspension load during discharge produced by light rainfall in September 1966. Flow beyond the channel mouth was hypopycnal (Bates, 1953); the turbid flood water overrode the denser (saltier) bay water. The flood current was deflected toward the southwest by southeast wind (fig. 7). A considerable amount of mud was deposited between the channel mouth and grid point M/6, but deposition within the channel was only a thin mud drape.

Modification processes were dominant on the active lobe between June 1966 and September 1967. Deposition through fluvial processes added no significant amounts of sediment to the fan. There was some change in configuration and position of bars within the active channel as a result of slight rainfall in the drainage area between January 3 and 13, 1967. Following the January rain, water level in the bay was lowered, the channel floor was scoured, sand migrated downchannel as fields of linguoid and cuspate ripples and was deposited in the maze of small braided streams beyond the 1966 channel mouth.

In summary, the September 1966 rainfall occurred when cultivated fields in source area were mostly bare of vegetation, and after heavy rainfall in late spring had removed much of the fine sand normally stored in drainage channels. Sediment load under these conditions is predominantly clay and silt transported as suspension load. Flow beyond the channel mouth is hypopycnal, and wind direction determines the area where suspension load ultimately accumulates. No sediment is added to the fan plain under these

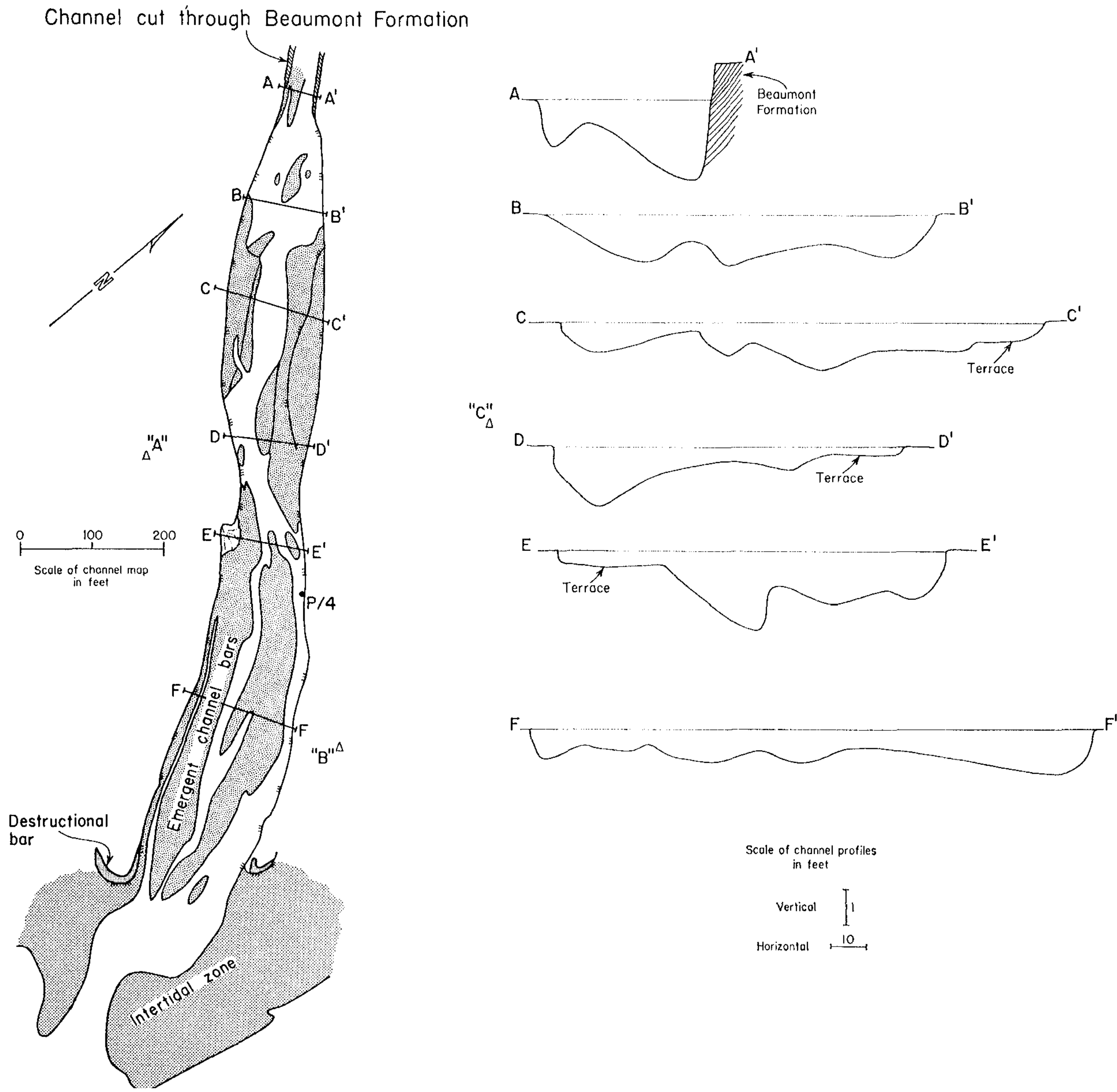


FIG. 5. Profiles of 1966 main channel.

conditions; deposition, if wind direction is favorable, is in low energy, subtidal, interlobe areas. Sea level within the bay was near normal when these observations were made. Sediment transport during winter months is predominantly by traction load; sand accumulates in a relatively narrow sheet up to 400 feet beyond the channel mouth. Deposition is indicated to have been as a sheet-like body with thin, narrow levees superimposed on the sheet and small lunate bars at about the distal end of the sheet. It appears that subaqueous levees and channel mouth bars develop when water level is below normal, and sediment supply and water volume are such that the main channel is not the site of maximum sediment accumulation.

UNCONFINED FLOW—VERTICAL ACCRETION

Conditions favorable for vertical accretion (aggradation) are an increase in water depth in Nueces Bay such that the entire fan is inundated by a few feet of water, and heavy rainfall in the source area. Deposition of about 270,000 cubic yards of sand resulted from heavy rainfall, in excess of 20 inches, triggered by Hurricane Beulah in September 1967 (Scott, Hoover, and McGowen, in press).

Storm surges of Hurricane Beulah caused a significant rise in water level in Nueces Bay; maximum water depth was about 5 feet above normal. Heavy rainfall in the drainage area coincided with the increased water depth.

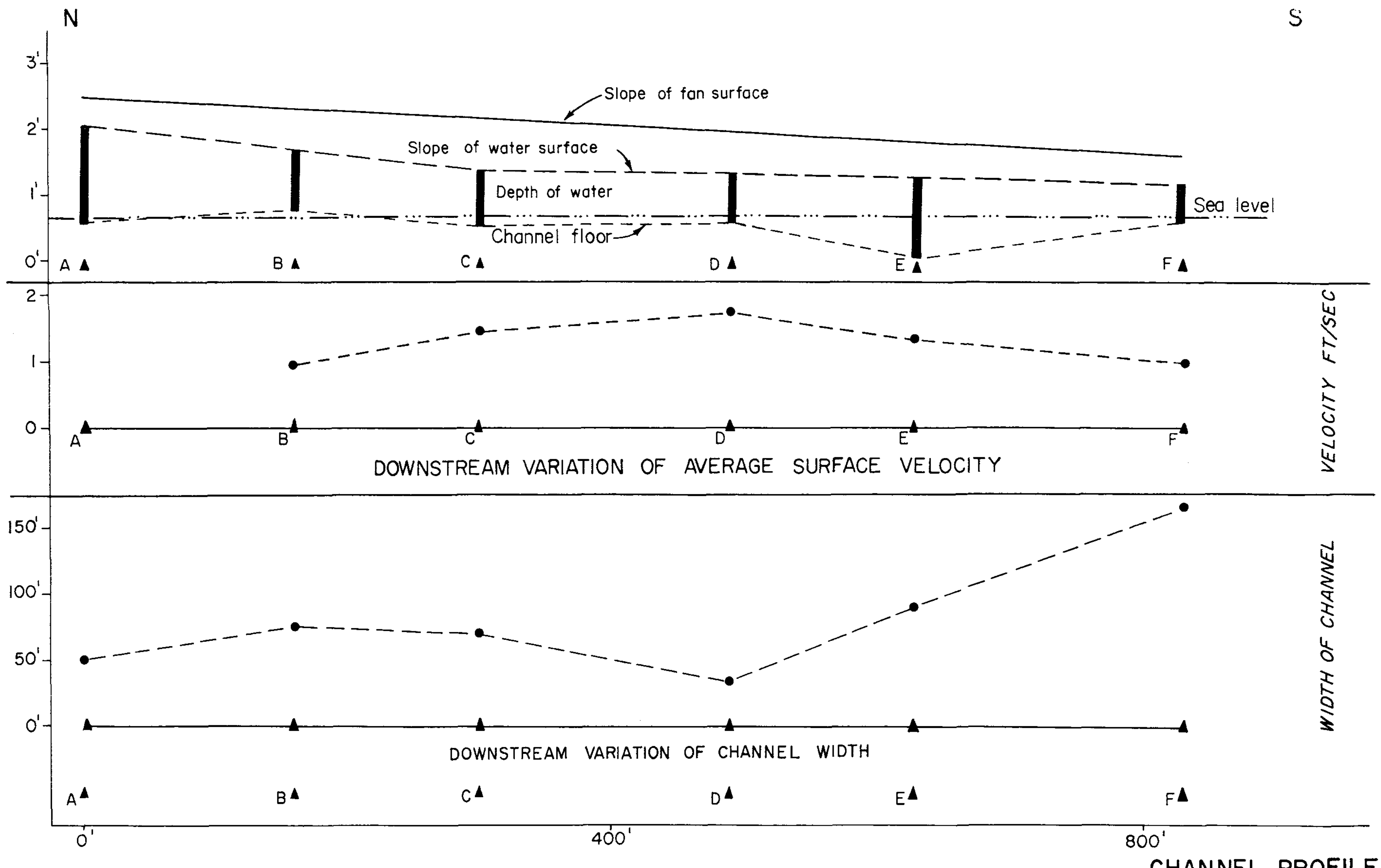


FIG. 6. Channel characteristics (September 17, 1966) during flow produced by a 1-inch rain.

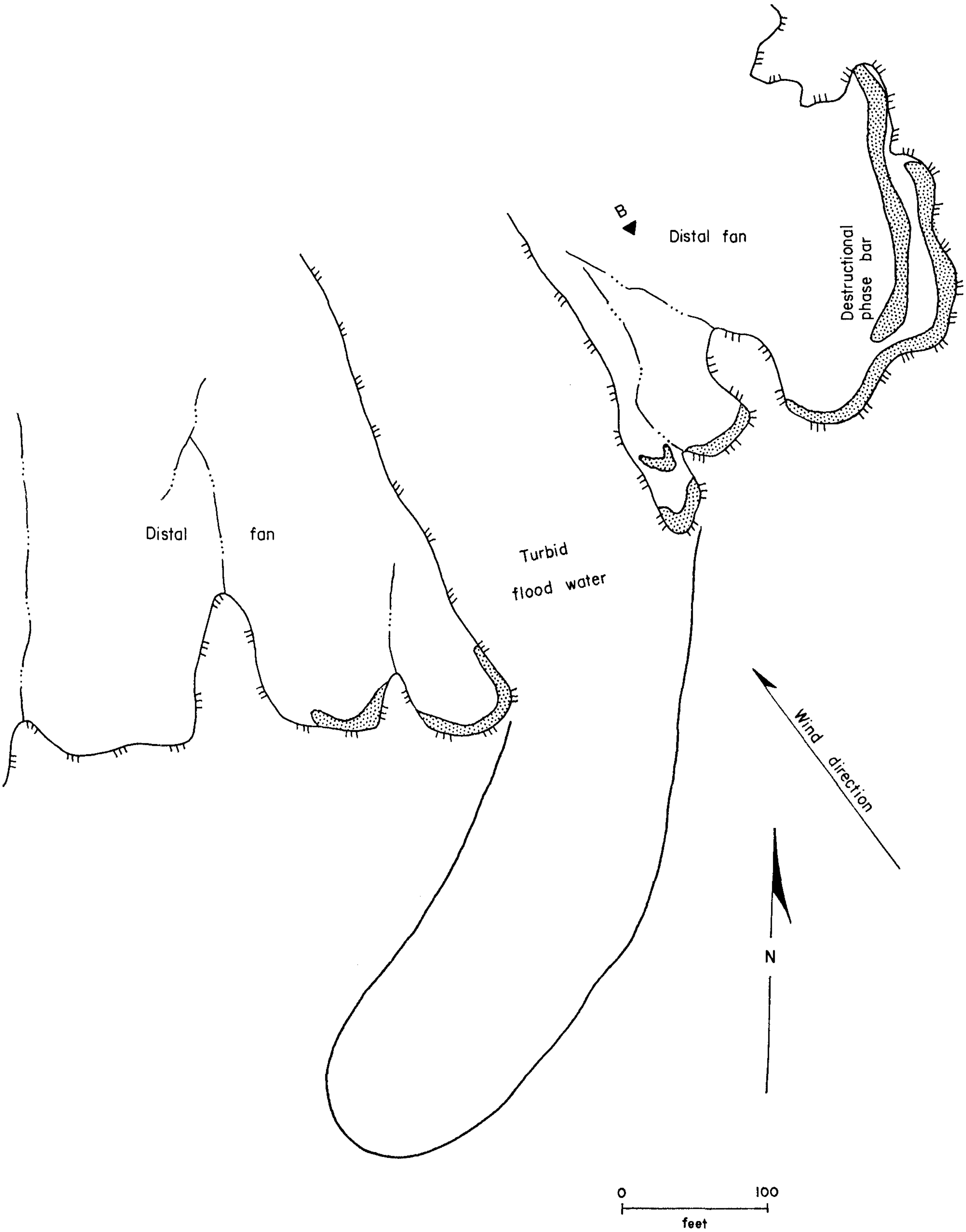


FIG. 7. Deflection of suspension load by southeast wind (September 17, 1966). See Plate III (in pocket) for location of mouth of 1966 main channel.

Aerial photographs of Gum Hollow fan delta (Pl. II,B) taken October 5, 1967 show most of the fan to be inundated.

Flow conditions during deposition of initial Beulah fan sediment are postulated to be analogous to sheetfloods on alluvial fans (Blissenbach, 1954) when extremely large amounts of water and sediment emerge from a mountain canyon. Initial deposition of the Beulah fan occurred under hypopycnal flow conditions (Bates, 1953); at this time the entire fan surface was inundated by as much as 3 feet of water. No major channel system was present, and sediment was dispersed radially away from the cut through the Pleistocene sediment. Early phases of deposition of the Beulah sediment progressed under upper-flow régime conditions (Simons and Richardson, 1961) and possibly when water depth was increasing. Parallel laminae, observed in trenches dug along an east-west section of the fan (fig. 8), suggest plane bed forms and upper flow (*see* Pl. 1 of Harms and Fahnestock, 1965). Along distal ends of western parts of the fan there are climbing ripple laminae in the basal part of the Beulah deposits; these ripples are lower-flow régime bed forms (Simons and Richardson, 1961) that indicate sand feeding (McKee, 1965). Rising water level is suggested by preservation of both foreset cross-strata and their upcurrent plane bed equivalents. During the early stages of deposition and rising water level most of the large pieces of plant debris, mostly limbs, were transported beyond the fan, but as depth of water decreased, tree limbs and other debris were deposited upon the fan. The last phases of deposition differed from earlier ones; flow remained unrestricted but shallow channels developed, suggesting conditions analogous to streamfloods on alluvial fans.

Only the last phase of deposition left an imprint on the fan surface (fig. 9,A). Surficial features are deep scours upcurrent from and lateral to brush piles, longitudinal bars downcurrent from brush piles, and shallow channels flanking the bars. Projections along the western periphery of the fan developed as water level continued to drop. Sand was scoured from low areas adjacent to longitudinal bars and deposited beyond the fan periphery as tongues of avalanching sand. The stream that deposited these tongues changed direction rapidly across the surface of these minor fans as shown by changes in dip direction of foreset cross-strata (fig. 9,B).

Chang (1967) conducted a laboratory study on hydraulics of rivers and deltas and reported that by raising base level or increasing water depth in the reservoir a subdelta developed on top of a previously developed delta. Areal growth of the subdelta was rapid because of the slight increase in water depth. These water-level conditions are similar to those that existed during deposition of the Beulah fan.

Figure 10 diagrammatically summarizes the development of the active fan and shows the sea-level position at time of deposition. Normal sea-level conditions coexisted with streamflood that deposited the 1966 fan (fig. 10,A). During the winter 1966–1967, northers caused a lowering of sea

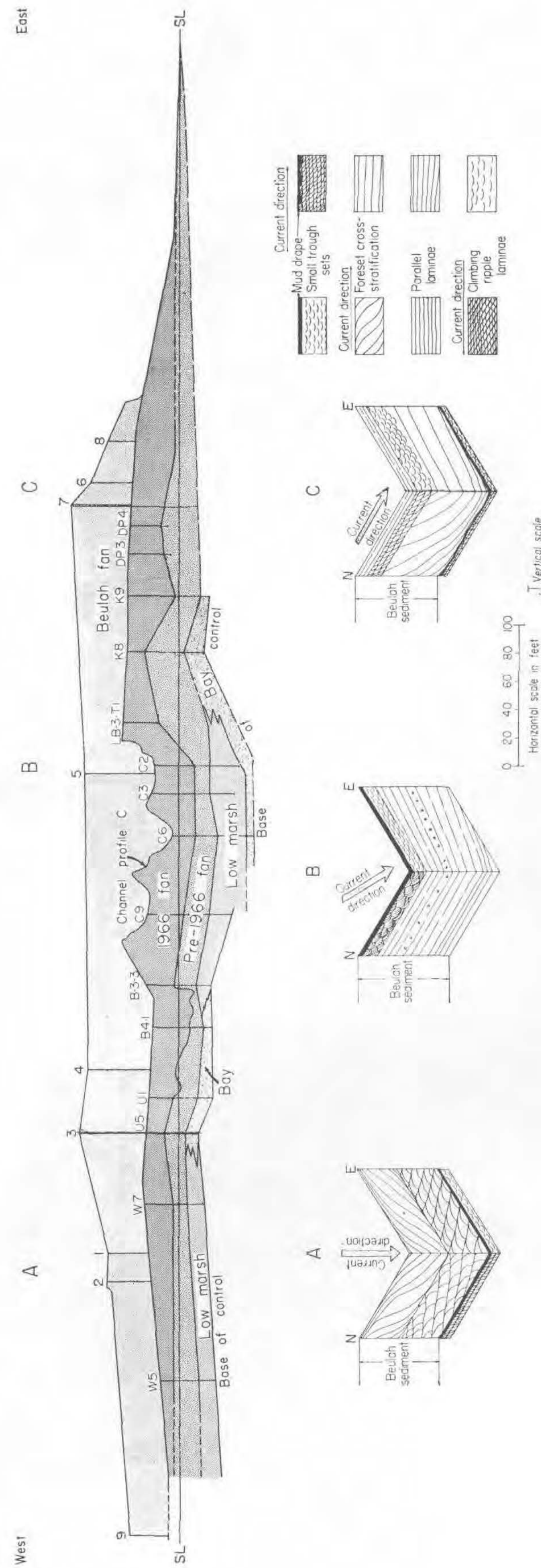


FIG. 8. East-west cross section, Beulah fan and older deposits. Blocks below cross section show stratification changes across the Beulah fan. Line of section is shown on Plate II, B.

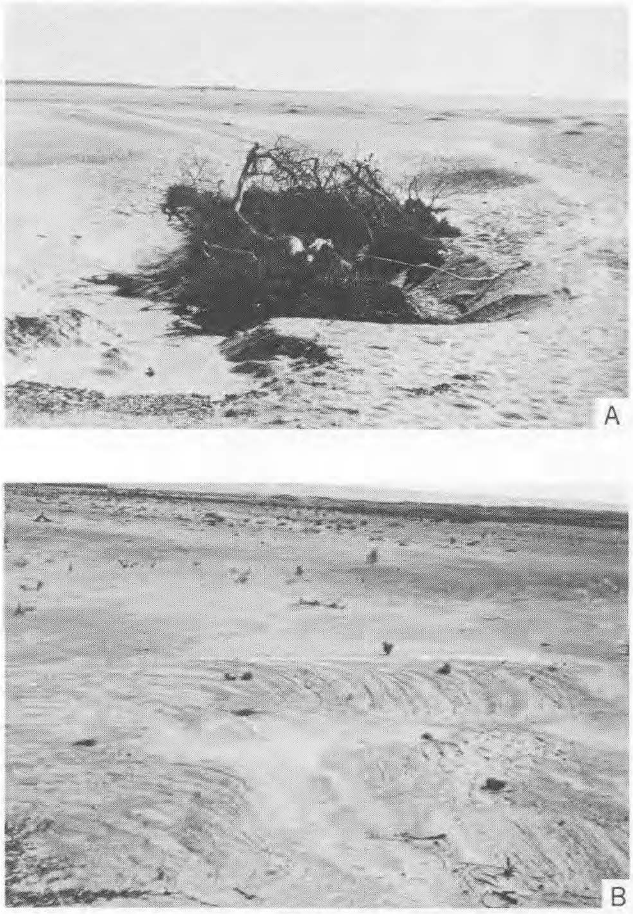


FIG. 9. Surficial features of the Beulah fan. A, Brush pile and associated scour. Depth of scour about 2 feet. B, Foreset cross-strata along west margin of Beulah fan.

level (fig. 10,B) that was accompanied by rainfall in the 1- to 2-inch range. Stream flow developed as a consequence of lowering of sea level. Sediment was deposited seaward of most of the 1966 fan. Sea-level position during Hurricane Beulah is shown in figure 10,C. Flow conditions were presumably unconfined and analogous to sheetfloods during early stage; flow became streamflood during the later stage of deposition.

PRE-1966 FAN

The previous discussion on mechanics of fan construction was restricted to the active fan. The growth sequence of the older fan is documented by a series of aerial photographs, and mechanics of fan construction are interpretive, not observational.

As the area of the fan increases, progradation rates are assumed to decrease, and there must be a limit to the size the fan can attain under the present size of the drainage area, rainfall régime, and intensity of beach processes. If this assumption is valid the shape of the fan will change as sites of deposition shift from place to place, but area will remain more or less constant.

A series of aerial photographs beginning in 1939 and continuing through 1963 indicate that early stages of fan development were characterized by continually shifting braided streams (Pl. I,B and C); in plan many small fans constituted a more or less equidimensional complex fan. As the fan surface area increased, the smoothly lobate form was altered as segments of the fan became narrower and extended greater distances into the bay. This change in form of the fan is related to: change in stream gradient, development of levees near the fan apex, storage of a large volume of sediment within the channel with most of the sediment and water discharge confined within the channel, and relatively insignificant lateral accretion caused by infrequent crevasses.

Vertical accretion of the fan was followed by entrenching of streams flowing across the fan and the ultimate development of a single braided channel. Rapid vertical accretion has been cited as the product of hurricane aftermath (Scott, Hoover, and McGowen, in press). A somewhat slower, and areally more restricted, vertical accretion of the fan resulted from overbank sedimentation. Thickest sediment accumulation under each of these conditions is near the fan apex, and channels flowing through these areas were stable for relatively long periods of time. The middle and western lobes formed concurrently; first one then the other lobe received most of the discharge through the main channel systems (Pl. I, B–F). Channel systems were abandoned and then reoccupied during these processes. The possible reasons for recurrence of streams in sites of older channels are: (1) Vegetation was best developed adjacent to channel sites and banks were relatively resistant to erosion; (2) abandoned channels were incompletely filled and were, therefore, topographically the lowest areas of the fan apex; and (3) channel-fill sediment was easier to erode than vegetated, muddy, levee deposits. Downfan, beyond the apex, channel positions were less stable as the channel floor, water level in the bay, and the fan surface were at approximately the same elevation; flow through the channel was relatively unconfined.

Channels lengthened as the fan area increased, and this caused accelerated rates of sediment accumulation in the fluvial channel. Sediment deposition within the fluvial channel raised the channel floor in order to maintain a slope sufficient for flow. By increasing surface area, progradation decreased as beach processes were adequate to redistribute much of the sediment, and because a significant volume of sediment, that would be carried to the distal fan under braided stream conditions, was stored within the fluvial channel. After a single channel was developed much of the sediment was deposited directly in front of the channel mouth (*see* Pl. I,E and F).

Progradation of the fan after development of a single channel was mostly at the channel mouth, and lateral growth of the fan was by crevassing or development of a new channel following a tropical storm or hurricane. One channel diversion on the presently active lobe occurred after deposition of the Beulah fan. A similar channel

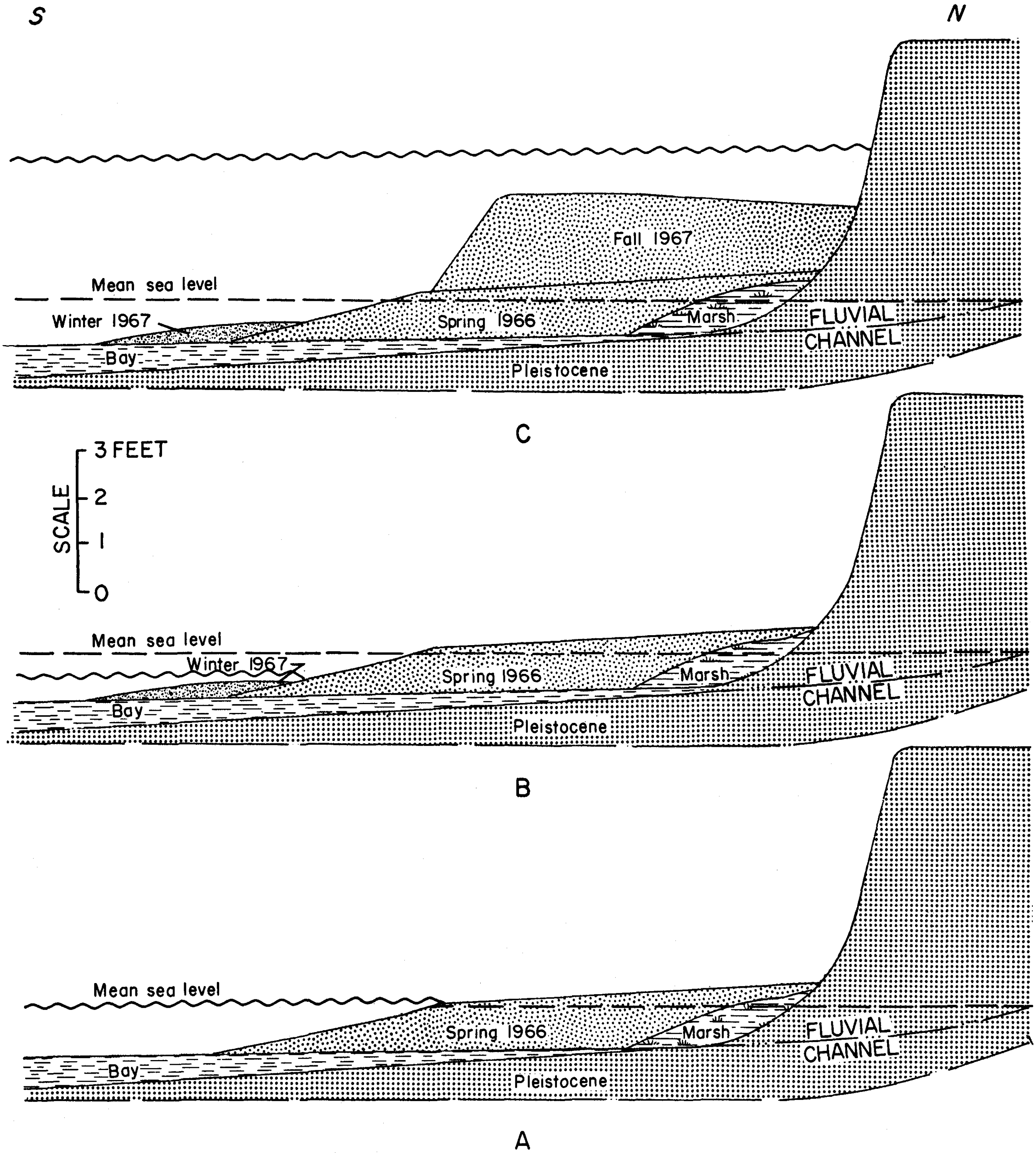


FIG. 10. Effect of sea level on deposition of Gum Hollow fan delta. Progradation under normal (A) and lowered (B) sea level conditions. Aggradation (C) when sea level is above normal.

diversion is shown on the middle lobe; this diversion occurred in 1958 and was expressed on the ground as a relict channel until it was filled by mud during Hurricane Beulah. Diversion of the middle lobe channel probably followed deposition similar to the Beulah fan.

PRIMARY SEDIMENTARY STRUCTURES

To establish a relation between stratification and flow conditions requires that hydraulic variables, such as slope, velocity, water depth, and discharge, and bed forms be observed and measured during flow. Observations such as these were not made on Gum Hollow fan delta. The reasons for this lack of data are that deposition occurs on the fan during hurricanes when it is physically impossible to make observations, and during periods of local thunderstorm activity when flooding ceases in a period of a few hours. It was possible during the term of this study to observe only one flood.

Observations made on September 17, 1966 document immediate flooding on the fan. On this date about 1 inch of rain fell in the Taft area about 10:00 A.M. By 12:50 P.M. flood water had reached the fan delta and by about 2:30 P.M. flooding had ceased.

Therefore, processes operating on the fan were interpreted mostly from primary sedimentary structures. Genesis of particular depositional features on the fan is explained in the light of published data on experimental work and observations on natural fluvial systems. Primary sedimentary structures are related to fluvial, aeolian, and beach processes. Fluvial processes are the constructive agents in fan development and their deposits prograde the fan. Beach processes erode distal fan deposits of the inactive fan delta at a rate of about 40 to 50 feet per year; these processes were observed during the study. Aeolian processes are effective in redistributing some of the sand-size material that is deposited on the distal fan by beach processes.

Gum Hollow fan delta, between April 1966 and September 1967, could be divided into a prograding and a destructive segment. Processes operative on the destructive segment are wind tides and wind-generated currents, aeolian processes, and erosion and deposition by sheet wash caused by rain falling directly onto the fan surface (fig. 11). These same processes operate on the active fan segment but less effectively.

Most of the exposed sediment of Gum Hollow fan delta, prior to Hurricane Beulah, was deposited by unconfined braided streams. Observational and experimental studies on braided streams in the last decade have contributed to the knowledge of sedimentary processes, geometry of depositional features, and types of stratification that make up these deposits. All of these studies were made on streams that had gravel and coarse sand bed loads. Because of the fine sand size of the Gum Hollow sediment, primary sedimentary structures in these deposits probably arc not exactly like those in coarse-grained deposits of braided streams. Flow conditions are similar for braided streams such as those studied by Leopold and Wolman (1957), Doeglas (1962), Leopold, Wolman, and Miller (1964), and Ore (1963, 1965), for alluvial fans (Blissenbach, 1954; Bull, 1963), and for Gum Hollow fan delta.

CHARACTERISTICS OF BRAIDED STREAM DEPOSITS

As defined by Leopold, Wolman, and Miller (1964) a channel that "is divided into several channels, which successively meet and redivide" is a braided channel. Hydrology of braided streams has been discussed by Leopold and Wolman (1957), Chien (1961), Doeglas (1962), Fahnestock (1963), Ore (1963), and Leopold, Wolman, and Miller (1964); the reader is referred to these papers for details on such features as channel gradient and discharge. Leopold and Wolman (1957) stated that channel division is associated with increased width of water surface and slope and decreased depth. Braided streams are characterized by large bed load to discharge ratio.

Several theories for the cause of braiding in channels have been proposed, such as the erodability of bank material (Mackin, 1956), overloading of the fluvial system (Chien, 1961), and inability to transport certain size material (Leopold and Wolman, 1957; Leopold, Wolman, and Miller, 1964; and Ore, 1963, 1965). Of primary concern here is the process, or processes, of development of bars that cause braiding, and the stratification types associated with these bars. As Gum Hollow fan delta had no main channel system during development of the fan plain, and as the channels that formed after construction of the fan plain are related to lowering of water level in Nueces Bay, erodability of bank material had no effect on development of the maze of shallow channels and longitudinal bars.

Flume and field studies by Leopold and Wolman (1957) and later by Ore (1963) indicate that bar development is initiated when some local change within the stream causes it to deposit some of its coarser bed-load material; in a particular area within the channel it was incompetent to transport certain grain sizes. Sediment accumulation was localized where the coarser material was deposited. The upcurrent end of the nucleus of coarse material was stable in position and subsequent deposition was mostly downcurrent from the nucleus. Ultimately an elongate gravel or sand body was formed with its long dimension parallel to stream flow.

Stratification types in braided stream deposits have been described by Doeglas (1962) for parts of the Durance and Ardiche Rivers and by Ore (1963, 1964, 1965) for parts of the South Platte and Platte Rivers. A correlation between types of primary sedimentary structures and elongation of bars relative to current direction was established by Ore (1963, 1964). Bars that are elongate parallel to the direction of flow are termed longitudinal bars. Stratification of longitudinal bars near the upcurrent end is horizontal; foreset cross-stratification develops at the downcurrent ends and less commonly along the sides of these bars. Transverse bars are elongate perpendicular to current direction. These bars may develop in channels that cut transversely across longitudinal bars, in channels lateral to longitudinal bars, or during extended periods of high discharge. Transverse bars are wedge shape in profile and thicken in a downchannel direction. Internally they are composed of foreset cross-stratification. Small trough sets are commonly found in upper sediments and represent a particular depositional interval succeeding a foreset sequence. Trough-fill cross-stratification is not common in braided stream deposits studied by Ore, but Doeglas (1962) reported that festoons (trough-fill cross-stratifica-

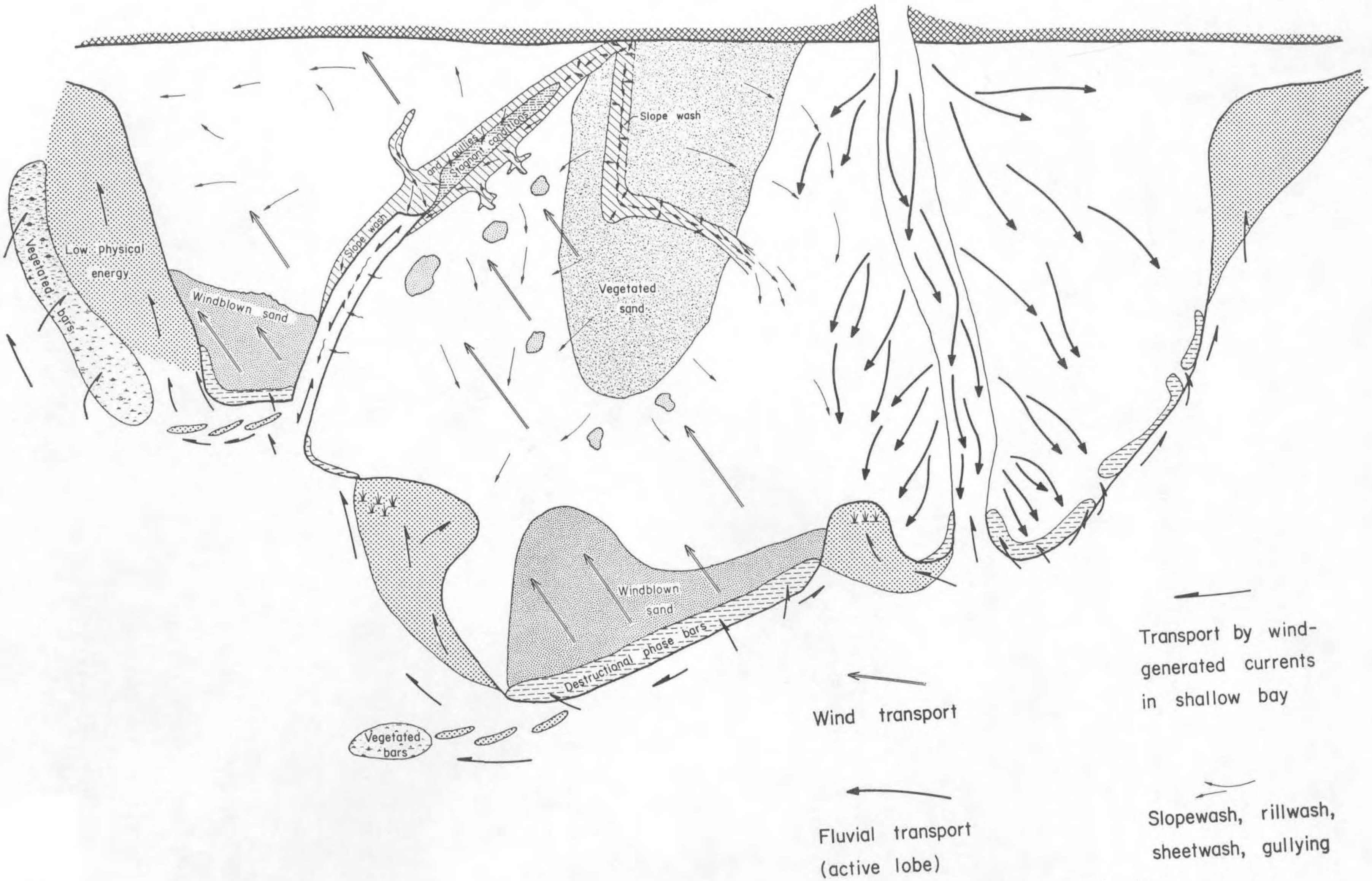


FIG. 11. Generalized current systems operative on active and stagnant fan segments and on the adjacent shallow bay.

tion) were the dominant structures in the streams tributary to the Rhone River. Ore (1965) stated that as the proportion of transverse bars increases over longitudinal bars the abundance of trough-fill cross-stratification increases.

FLOW CONDITIONS ON ALLUVIAL FANS

Processes operating in braided channels are assumed to be similar to those operating on the surface of an alluvial fan during deposition. Bull (1963) believed that deposition on the fans in western Fresno County, California, "is caused by the decrease in depth and velocity of flow that results from the increase in width as the flow spreads out on the fan."

Flow conditions on alluvial fans were designated as sheetfloods, streamfloods, and streams by Blissenbach (1954). Bull did not use this classification but grouped fan sediment into three types: mudflow deposits, water-laid sediments, and intermediate deposits. Only the water-laid sediments have characteristics analogous to those of Gum Hollow fan delta.

Bull reports two types of water-laid sediments on alluvial fans. Most of this type of sediment consists of sheets of sand and silt deposited by a network of braided streams. These streams continually fill up with sediment and shift laterally to a new position. Maximum water depth in this type of flow is said to be on the order of 0.5 foot. Characteristically, water-laid sediment is in the form of a sheet-like sand deposit transversed by shallow braided channels. Channels are generally less than a foot deep and are separated by low bars. Water-laid deposits in the main stream channels are generally coarser and not as well sorted as sheet-like water-laid deposits. These two types of water-laid deposits are analogous to fan plain and channel-fill sediment of Gum Hollow fan delta.

DEPOSITIONAL ENVIRONMENTS

Environments of Gum Hollow fan delta were delineated by sedimentary processes and physiographic features resulting from those processes. The sedimentary processes have been grouped under aceretionary and modification processes. Some of the accretionary environments directly relate to the presently active fan. Data on modification environments are derived mostly from observations made on the inactive middle and western lobes.

ACCRETIONARY PHASE

The accretionary phase is analogous to the constructive phase of delta building as defined by Scruton (1960). Accretion as used here includes both aggradation and progradation. During the accretionary phase fluvial processes are dominant, and depositional areas of the subaerial fan that reflect varying degrees of fluvial intensities are the main channel, fan plain, and distal fan.

CHANNELS OF THE 1966 FAN (EASTERN LOBE)

Channels in this discussion are restricted to those of the 1966 fan; the fluvial channel northward from the escarpment was not a part of this study.

While the field investigation for this study was in progress a new lobe termed the 1966 fan was constructed to the east of the older fan segments. After field work was completed, two major depositional events occurred that changed the channel system completely. One event was related to Hurricane Beulah (September 1967) and the other to Hurricane Candy (June 1968). Data were not collected from channel systems related to these events, and channel characteristics in this section are entirely those of the 1966 system.

The channel was slightly sinuous and increased irregularly in width seaward from about 55 feet at the fan apex to 150 feet at the channel mouth. Overall trend of the channel was about S. 22° E.; this is the direction along the right channel bank. Changes in channel depth and width are demonstrated by a series of channel profiles (fig. 5). Generally, the channel decreases in depth toward the bay.

The channel is braided from the fan apex to the channel mouth. Bars occur both adjacent to channel banks and as longitudinal bars present at various positions within the channel. Longitudinal bars tend to increase in length downchannel. Bars are downcurrent from oyster shell gravel and/or brush piles; this association is always found together. The bars with oyster shell nuclei are present only near the fan apex, and these are generally smaller than brush defended bars.

Crescent-shaped scour troughs are generally present at the upcurrent ends of bars with brush nuclei. These features have scour depths that range from a few inches to about 1.5 feet; in plan they are 1 to 15 feet wide and range from 5 to 80 feet long. The limbs of troughs point downchannel with one limb commonly being longer than the other. The deepest part of scour troughs is immediately upcurrent from brush piles. Similar but smaller features called "current crescents" were described by Peabody (1947) from recent mud flats of San Francisco Peninsula, California, and Triassic Moenkopi Formation. Current crescents formed as scours around such objects as pebbles and plant debris. Size range of current crescents in recent mud flat deposits was about 10 to 20 cm in width and 20 to 60 cm in length.

Not all scour troughs, in the channel, are crescent shaped; some are essentially straight, occupy lows between longitudinal bars, and result from scour associated with northers. Northers lower water level in Nueces Bay, base level is temporarily lowered, and the channel floor is scoured as flow velocity is increased somewhat under these conditions. These troughs vary in width from a few inches to about 5 feet, and in length from about 1 to 25 feet. They are unrelated to the depositional events that develop longitudinal bars and crescent-shaped troughs.

ABANDONED CHANNELS

Four areas on Gum Hollow delta show abandoned channels in various stages of fill (Pl. III); these are the western channel, middle channel, a crevasse channel through the left bank of the middle channel, and small channel south of the cement spillway. The southern part of the middle lobe channel has been completely filled. A crevasse channel through the left bank of the middle lobe channel, the western lobe channel, and the small channels south of the cement spillway were incompletely filled prior to deposition related to Hurricane Beulah. Observations reported here were made before Hurricane Beulah, September 1967.

The inactive channel of the western lobe is presently divided into two segments by a small fan built across the channel in the area between grid points E/3 and F/2 (Pl. III). The north part is a pond that is alternately wet and dry, and the south part is a wind-tidal creek or small fluvial channel depending upon rainfall and wind conditions. Low marsh vegetation grows within both sections of the abandoned channel. In the seaward section *Salicornia bigelovii* (dwarf saltwort) is the only plant present, and it generally forms a vegetation line on each side of the channel. A denser growth of saltwort is present in the ponded section of the channel, and near the fan apex *Distichlis spicata* (saltgrass) is the dominant plant. Filamentous algal mats are common to both segments of the channel.

Sediment fill of the abandoned channel is derived from channel banks and fan plain and is transported to the channel by sheet wash over the fan plain or through small gullies. Suspension load is transported from Nueces Bay into the abandoned channel by wind tides. Little of the suspension material is permanently stored in the lower part of the southern channel segment; it is removed when runoff floods the channel. Linguoid ripples are the dominant bed form in the southern channel segment; these ripples are flanked laterally by a mud veneer. Thick mud accumulated in the pond; extensive desiccation cracks develop in these muds during extended dry periods.

The small gullies and fans associated with the abandoned western lobe channel are especially well developed north of grid point F/3 (Pl. III). These features are not spectacular when viewed on the ground and they are not too impressive in an areal sense when viewed on the plane-table map. Their importance lies in their distinctive internal characteristics and the numerous recurrences of these types of features in trenches cut into the middle channel fill.

Sediment deposited at mouths of gullies is essentially the same in all areas. The sediment is quartz and clay pellet sand with some granule and pebble-size spherical and disc-shaped clay and mud clasts. Granules and pebbles are generally confined to headward sections of gullies and sand-size mud or clay clasts near toes of the small fans. Current ripples (predominantly linguoid or cuspate) floor the gullies and axial part of small fans; laterally away from fan axes, shallow sheet wash prevails and the surface is a smooth sloping plane. Coalescing fans have smooth surfaces that slope toward the abandoned channel floor.

Another pond area, south of the cement spillway (near grid point M/1), has the same low marsh species that are associated with the abandoned channel of the western lobe. Sediment filling the ponds is derived from the fan plain and is predominantly mud with very local concentration of sand. Algal mats form in these ponds and deep desiccation cracks develop when ponds dry up. These ponds are probably related to Hurricane Carla (1961); short bifurcating channels were scoured during the storm-surge ebb when water spilled bayward through the spillway.

A crevasse channel (L/3, Pl. III) was cut through the left bank of the middle channel and subsequently abandoned when the flow was diverted to the western channel. Prior to Hurricane Beulah this crevasse channel had been filled completely in the vicinity of grid point M/4, but in the area of grid points K/3 and L/3 the channel shape and trend were preserved. High marsh vegetation was established along the bed and banks of parts of the channel, and the channel trend between grid points L/3 and M/4 was recognizable only through the presence of a rather dense growth of glasswort and associated species. Slope wash from crevasse banks was a major source of channel fill.

FAN PLAIN

The subaerial part of the fan delta that normally is not inundated by wind tides is the fan plain. Features that define the fan plain limits arc: the erosional escarpment to the north, the most inland effects of wind tides, and the banks of main channel systems. The surface of the 1966 fan was sparsely vegetated; this is in strong contrast to deltas characterized by distributary systems that are covered by a dense growth of marsh and/or swamp vegetation. Sparse vegetation on the 1966 fan plain includes *Suaeda* (seepweed), *Salicornia bigelovii* (dwarf saltwort), *Opuntia* (prickly pear), and *Sorghastrum halepense* (Johnson grass). Seepweed and saltwort are common halophytes on the older fan.

The fan plain is a relatively featureless surface that dips gently toward Nueces Bay. On the surface the fan plain closely resembles alluvial fans developed in desert regions; the surface slope of the fan is low, however, in comparison to alluvial fans. Slope of the 1966 fan surface measured from apex to distal fan, along left channel bank, was on the order of 0.9 foot drop in 800 feet (0.00112 or approximately 0.07°), and measured from apex eastward, along profile GHK (Pl. IV) to distal fan, is about 1.7 feet drop in 800 feet (0.00212 or approximately 0.12°).

Low relief longitudinal bars, shallow channels, and crescent-shaped scour troughs characterize the 1966 fan plain surface. Axes of bars have a more or less radial pattern with respect to the fan apex. As longitudinal bars decrease in height and spread laterally, channels flanking the bars lose their identity; channels become shallower downcurrent and grade imperceptibly into flat areas of the fan plain. Channel floors are commonly covered with linguoid ripples. The fan plain was constructed primarily by overlapping longitudinal bars. These bars are about 6 to 7 inches thick near the fan apex and about 6 inches thick about 120 feet south of instrument station "A"; relief on these bars shortly after deposition ranged from about 9 inches from bottom of crescent-shaped scours to bar crest, to about 2 inches near distal end of bars.

Bars on the fan plain like those in the 1966 channel were, developed downcurrent from brush piles or other debris too large to be transported across the fan surface in the extremely shallow water. Unlike bars in the 1966 channel, those on the fan plain do not have oyster shell nuclei.

DISTAL FAN

The distal fan is low lying (near sea level) and is generally featureless (accretionary phase); it lies just seaward of distal ends of longitudinal bars of the fan plain and extends to the erosional escarpment that marks the seaward edge of the subaerial fan. The fan plain is not sharply separable from the distal fan by physiographic features; the distal fan is a transitional zone between completely submerged fan sediment and the emergent fan plain. Sediment deposited on the distal fan is contributed from the channels during floods and from the bay when that part of the fan is inundated by wind tides.

Reworking by wind-generated waves is most extensive along the fan segments that project farthest into Nueces Bay. Areas undergoing greatest erosion are depicted on the plane-table map (Pl. III) by the presence of destructional phase bars. Landward of these bars is the site of deposition of mud, plant debris, dead fish, etc.

Wind tides transport sediment landward across the distal fan. Mud dominates the sediment type and mud units thicken bayward. Commonly associated with mud deposits, particularly in areas of destructional phase bar development, are incomplete wave ripples that have either straight or sinuous crests. Desiccation cracks and drag marks are characteristic of the distal fan. Drag marks are produced by debris (mostly wood) pushed across the distal fan by wind tides; scours produced in this manner simply reflect the wind path as it moved northwest across the fan surface. Filamentous algae stabilize surface sediment of the distal fan; algal mats are best developed along the lower, more muddy areas of the distal fan.

MODIFICATION PHASE

Sediment input in fan deltas occurs in a few days of each year; during the remaining part of the year modification through beach processes, sheet wash, and wind activity is operative on the active fan. Inactive fan segments are subjected to modification processes the year round. While one area of the fan is being eroded the debris is transported and deposited in some other area. Deposition of this material on the fan surface and intertidal area is considered as part of the modification phase.

Included in the modification environment category are marshes, destructional bars, intertidal zone, and aeolian mounds. In all these areas, previously deposited accretionary sediment is modified by either physical or biological processes.

MARSHES

Marshes occur on the upper parts of Gum Hollow fan delta at the base of the erosional escarpment and along the distal fan in abandoned channels and muddy interlobe areas. Active marshes are best developed on inactive distal fan segments. Prior to fan development marshes were continuous adjacent to the erosional escarpment. This area was partly buried by fan deposits and the marsh became stranded (Pl. III). The marsh environment has been in effect displaced in a bayward direction to the distal fan.

Marshes along inactive fan segments modify distal fan deposits by root mottling. Both high and low marshes are increasing in area on the inactive fan. *Spartina alterniflora* is the characteristic species of the low marsh. This plant occupies a zone along the bay margin from water depths of 6 or 8 inches inland to areas that are barely inundated. The low marsh is gradational with the high marsh. *Solicornia perennis* (glasswort), *Salicornia bigelovii* (dwarf saltwort), *Dislichlis spicata* (saltgrass), *Monanthocloe littoralis* (dwarfstand saltgrass), *Borrichia frutescens* (seaoxeye), *Batis maritima* (maritime saltwort), and *Suaeda* sp. (seepweed) are species common to the high marsh. High marsh plants have their most dense growth in the area between grid points D/5 and G/6.

DESTRUCTIONAL PHASE BARS

Reworking of distal fan sediment by beach processes begins immediately after deposition by fluvial processes. Sand-size terrigenous material is drifted parallel to the distal fan by longshore currents or is deposited upon the subaerial distal fan by breaking waves. It is the debris deposited on the subaerial distal fan that is termed destructional phase bar. Similar features are called beach ridges, berms, and swash bars.

There are three principal areas of bar development, one on each of the three lobes of the fan. Best development is on the inactive lobes and the most extensive bar development is associated with the middle lobe (Pl. III). This compound bar has a lateral extent of about 1,050 feet and varies in width from less than 10 feet to a maximum of 70 feet. Thickness of these bars ranges from about 2 to 12 inches. Bars along the western lobe form a discontinuous series that is disrupted by the incompletely filled channel. Sand accumulation to the left of the channel mouth is very thin (about 1 to 2 inches). In this area clay or mud chips (predominantly platy pebbles) comprise a significant part of the seaward part of the bar. To the right of the channel, bars are well developed and have a maximum width of about 50 feet. Plate III shows an en echelon pattern on both the subaerial and intertidal bars. Poor bar development is shown in the distal fan of the active (eastern) lobe (Pl. III). At the time these bars were mapped beach processes had been operative for a short time. Maximum width of the bars associated with the active lobe was about 12 feet.

In cross section, all bars are wedge shaped, thickest on the seaward side, and have a gentle landward slope of about 1° to 1.5°. The seaward faces of bars have been modified by swash and backwash in the surf zone; immediately after construction they slope seaward at about 7° to 8.5°.

The bars along the older middle and western lobes are multiple features. Formation of bars occurs only during periods of extended strong southeast winds. When bars are not inundated, seaward parts are undercut by waves, and exposed upper surfaces undergo alteration by aeolian processes that produce a thin sand sheet extending downwind from the bars. Plant debris, driftwood, and pulmonate gastropod shells commonly form a debris line just below the bar crest on the seaward side. Molluscan shell material derived from the bay is rare in bar sediment. *Cyrtopleura* and *Mulinia* shells were found on the surface of bars on the middle lobe but only *Mulinia* on the eastern and western lobes. Carapaces of blue crabs and fiddler crabs, bird feathers, and fish scales and bones are common to all destructional phase bars.

INTERTIDAL ZONE

Sediment seaward of the mud scarp (Pl. III) is dominated most of the year by beach processes. Surficial sediment in this area was originally like that of the distal fan above the mud scarp; subsequent reworking has deposited a thin veneer of fine wave-rippled and parallel-laminated sand across underlying mud. When this part of the fan is exposed during parts of winter months the mud becomes desiccated. Desiccation extends through the sand veneer and is expressed as hairline, straight fractures that are oxidized to yellowish brown. Frequent exposure and inundation locally produced hydrated, iron-oxide cement in these fractures.

There are two interlobe areas of the distal fan that are generally inundated and are essentially areas of deposition. One area lies between the active and the middle lobes, the other lies between the middle and western lobes. These areas are in a shadow downwind from the active lobe and the middle lobe. Sediment here is characterized by a high mud content in contrast to areas of the fan that receive the full impact of wind-generated waves. Sediment source and mode of transportation are different for each interlobe area. Sand and mud deposited west of the middle lobe are derived from the middle lobe and transported by wind-generated currents to the northwest. Sand and mud that accumulate between the active and middle lobes are derived in part by reworking previously deposited distal fan sediment, and in part from suspension load delivered to the bay by streams. Figure 7 shows clay and silt-laden flood water (September 17, 1966) from active fan being deflected into interlobe area under influence of southeast wind.

The emergent distal fan, particularly on the inactive parts of the fan, decreases in area through physical redistribution of sediment by wind tides and through compactional subsidence. Physical reworking of older deposits is exhibited in such features as destructional phase bars, exhumed juvenile angel-wing clams, and development of an erosional escarpment. Evidence for inundation by compactional subsidence is the presence of dwarf glasswort roots and stalks, and iron-oxide-cemented desiccation cracks under several inches of water about 100 feet seaward of the mud scarp.

AEOLIAN MOUNDS

Depositional features produced by winds, and commonly stabilized by plants, are designated aeolian mounds. Sediment comprising aeolian mounds was reworked from distal fan and higher parts of the fan plain. Mounds vary in size from about 3 feet in diameter and about 2 inches in relief to elongate features 20 × 60 feet with about 1 foot of relief. Elongate mounds show no consistent pattern of elongation; trend of mounds ranges from east-west to north-south.

Maximum development of mounds is on older (higher) fan segments. Two areas of rather dense aeolian sedimentation roughly parallel channels of the middle and western lobes. Along the axis of the middle lobe, mounds merge with and are surficially indistinguishable from natural levee sediment. Mounds associated with the western lobe are restricted to an area southeast of the left channel bank.

Most aeolian sediment is quartz sand derived from older fan deposits, though not all mounds consist of quartz sand. There is a barren mud area between the right bank of the western channel and a small alluvial fan at the base of the erosional escarpment (Pl. III). This mud area is a stranded low marsh. During summer months the surface mud is thoroughly desiccated; strong southeast winds transport sand-size clay or mud chips northward to the toe of the small alluvial fan where it accumulates as low relief dunes. Small, clay-pellet dunes on Gum Hollow fan delta are formed by the same processes reported by Price and Kornicker (1961) for clay dunes of the Gulf Coast area.

DIRECTIONAL FEATURES

Features of Gum Hollow fan delta that are valid as overall current system indicators are the tri-lobate plan, trends of channels and crevasse system, and the shallow channels and longitudinal bars of the fan plain.

Figure **12,A** and B, shows the flow pattern across the surface of the 1966 fan and the Beulah fan. Braided channels and longitudinal bars of the 1966 fan (fig. 12,A) outline the current system operating when that fan segment was laid down. The Beulah fan formed under different conditions than the 1966 fan, and the features on this fan that reflect direction of flow are the relatively steep avalanche faces at the fan edge and scour features associated with brush piles. Surficial features such as shown by the 1966 fan and Beulah fan are immediately altered by aeolian processes, rain, wind tides, etc. To define adequately the current system of a genetic sand body such as Gum Hollow fan delta requires recognition of various environments within the fan delta, the larger depositional units (e.g., longitudinal bars, transverse bars, and scour troughs) that characterize each environment, and relationship between these larger features and their internal structure.

Most of the presently exposed area of Gum Hollow fan delta was constructed under braided stream conditions. Flow in braided streams on Gum Hollow was relatively unconfined and stream courses continuously shifted position across the fan surface. This superimposes such depositional features as longitudinal bars, scour troughs, and transverse bars. Each of these features if formed contemporaneously in the same area and in the same stream will, when examined internally, display different directional trends.

Observations made on sedimentary structures, various types of bars and scour features, channel systems, and general flow directions for specific areas on Gum Hollow fan delta indicate that only the larger depositional and erosional features are reliable indicators of flow direction. Although most of the sediment deposited on Gum Hollow fan delta, amenable to study by trenching, was deposited under the direct influence of fluvial processes, a suite of sedimentary structures characterizes a particular fluvial facies. In each facies internal features deviate from general current direction under which they were produced; some show less deviation than others (e.g., directional trends within the middle channel more closely reflect the channel trend than structures on the fan plain reflect current directions). Sediment of Gum Hollow fan delta was deposited by a braided-stream sheetflood complex where directional features, general slope, and transport direction are not very closely related.

To illustrate the importance of recognizing environments to avoid grouping genetically unrelated primary sedimentary structures, the writer has chosen to discuss features of the fan plain, main channel systems, crevasse channels, and distal fan-destructional phase bar areas of Gum Hollow fan delta.

FAN PLAIN

In the sections on Directional Features and Sediment Characteristics, extensive reference will be made to trench sections in the Appendix. Trench sections are located on Plate IV. These trench sections show the gross textural type and details of primary sedimentary structures for each sedimentation unit that could be delineated. Dip angles are indicated on each unit from which a reading was taken.

All trench localities on the active lobe (Pl. IV) are on the fan plain, and trenches between the middle and western lobe channels are also on the fan plain. Externally, a single longitudinal bar gives the impression of being structurally simple. Internally, bars are characterized by a dominance of low-angle parallel laminae. These laminae are almost horizontal near the crests of bars; along bar flanks laminae dip toward the adjacent shallow channels. Angle of inclination of parallel laminae ranges from 0° to about 9°, but inclination more commonly lies in the 0° to 4° range. Thickness of a bar ranges from a few inches to about 1 foot; lengths of laminae range from about 15 feet to beyond trench control (unless terminated by erosion). Ore (1963, 1964, 1965) designated parallel laminae of longitudinal bars "horizontal stratification." Commonly, these structures grade laterally across the bar and distally (in the direction of elongation) into foreset cross-stratification (Ore, 1963, 1964, 1965; Jopling, 1963, 1965). Foreset cross-stratification, for the most part, are characterized by sigmoidal laminae that decrease in inclination toward the toe; toes are tangential to the underlying deposits and grade downcurrent into parallel laminae or regressive ripples. Angle of inclination of foreset cross-stratification, associated with longitudinal bars, ranges from about 5° to 14°. Transverse bars are not dominant depositional units on the fan plain, but they are common. These features are elongate perpendicular to current direction; internal characteristics are foreset cross-stratification and ripple cross-laminae.

Three trenches (L-Bl-T1, L-B2-T1, and L-B3-T1, in the Appendix and on Pl. V) illustrate the variability in directional trends of fan plain sedimentary structures. Most of the sediment observed in these trenches accumulated prior to development of a permanent channel system, and trench sections demonstrate vertical and lateral succession of structure types. Uppermost units in the two trenches nearest the fan apex (L-Bl-T1 and L-B2-T1) were deposited as overbank sediment after the main channel system developed (*see* Appendix and Pl. V).

Elongate scour features, associated with longitudinal bars, are common on the fan plain. Trends of bars and scour features were mapped using 1967 photographs (fig. 12) and are interpreted to represent general flow directions at the time of their formation. The U series of trenches (in Appendix; *see* Pls. IV and V for trench localities) illustrates the trend direction of the scour trough and longitudinal bar. This trough was crescent shaped and the east limb was the longest. The trough was asymmetrically filled. Dominant trend of directional features, plotted on a rose diagram (fig. 13), is south 60° to 90° west; the trend of the trough and longitudinal bar is almost south. Trench 1 of this series shows a closer relationship to the trend of the trough and bar than do structures in other trenches. Dip directions of trough-fill cross-strata vary from parallel to approximately right angles to the general current direction. The dominant direction shown on the rose diagram has little significance in interpreting the overall current direction.

Directional features have been plotted on rose diagrams (Pl. V) for fan plain deposits lying between the middle and west channels and for the active fan (*see* trench sections in the Appendix for structure types). If these diagrams are interpreted in the common way, a general flow direction to the southwest is indicated for both fan segments.

CHANNEL FILL

Directional feature data were obtained from both active and filled channels. Flow during deposition of sediment within these relatively stable channels was confined; a braided pattern existed within active channels unless flow was in the sheetflood stage.

Most of the directional features of channel-fill deposits presented here are from the filled, middle channel (Pl. V). Longitudinal bars exposed near the fan apex in the active channel were also studied (Pl. IV). These bars have parallel laminae that dip upcurrent and foreset cross-stratification that dip 60° to 90° to general current direction. Observations were made on bars in the active channel in an attempt to relate directional features to bar trend and surface slope.

Pace-and-brunton maps, surface slope, and directional features of longitudinal bars are shown in figure 14. Rose diagrams (fig. 14A) of the bar along the right bank indicate that the dominant slope direction is approximately at right angles to the bar trend and that the dominant dip direction of sedimentary structures deviates from 34° to 64° from the bar trend. Deviation between bar trend and dominant surface slope direction of the bar along the left bank varies from 66° to 126° (fig. 14,B), and the dominant trend is 144° to 174° to general flow direction. For

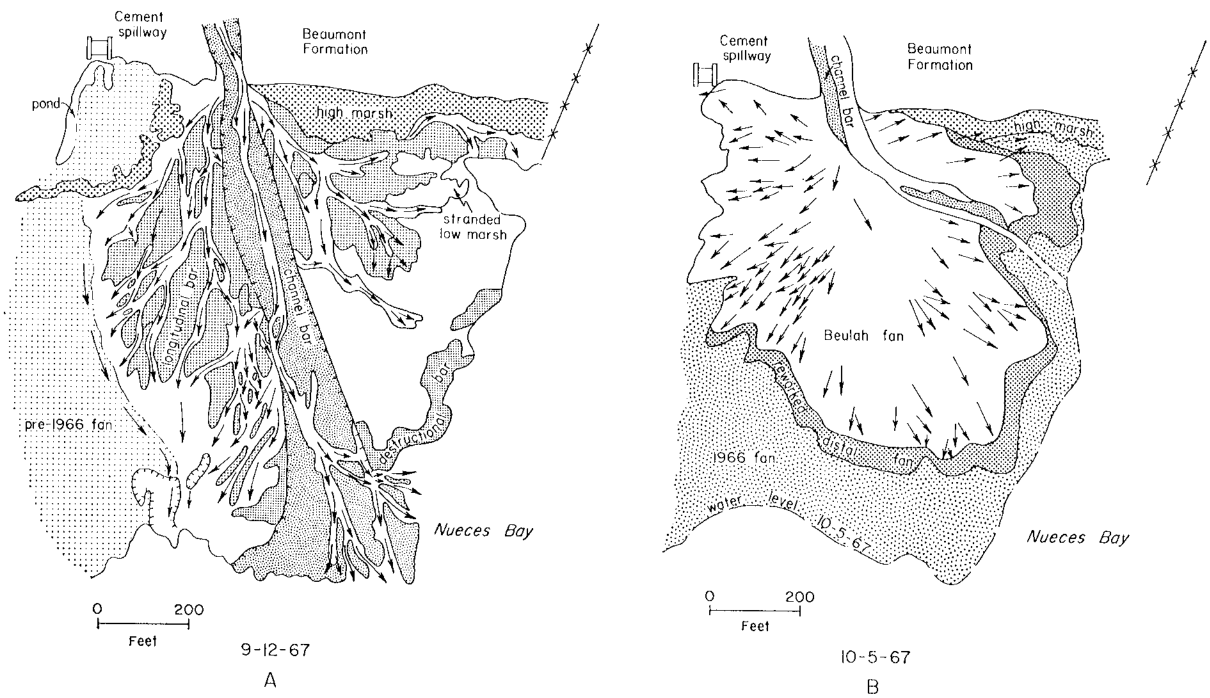


FIG. 12. Gross directional features for the 1966 fan (A) and the Beulah fan (B).

These figures were compiled from aerial photographs (at a scale of 1:200) flown in September 1967 (A) prior to Hurricane Beulah and in October 1967 (B) shortly after the passage of the storm. Trends of longitudinal bars and braided streams (A) and scours (created by turbulence in the areas of brush piles) and dip direction of steep foresets (B) at the fan margin are better indicators of the overall current system than directional trends shown by primary sedimentary structures.

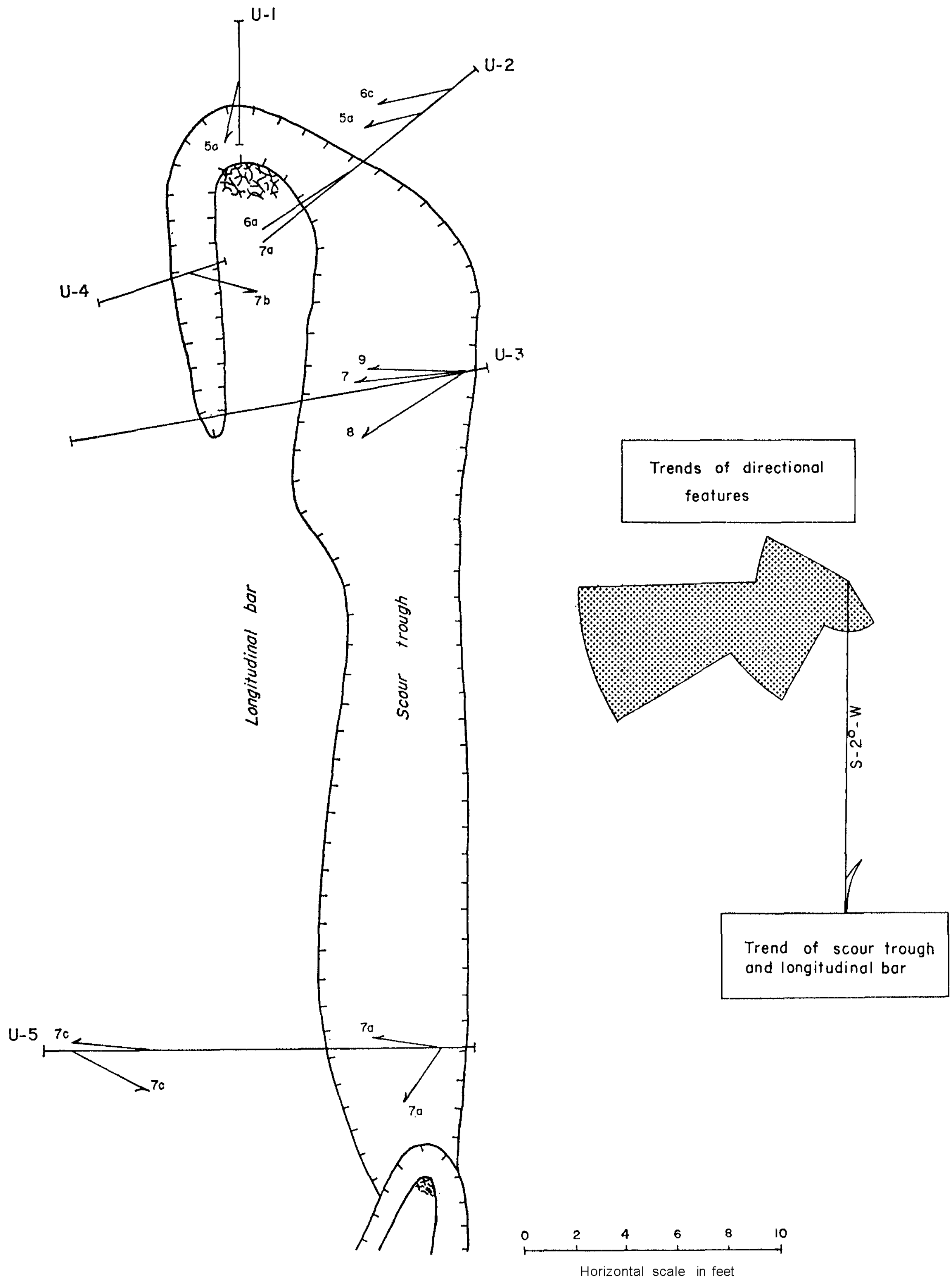


FIG. 13. Pace-and-brunton map and directional features for U-trench series.

Data for rose diagram from trenches 1 through 4; nine directional readings were taken from trough-fill cross-strata and parallel laminae. The rose diagram clearly shows the asymmetry of trough fill. Trenches are shown as straight lines across the scour trough and bar. Single barbed arrows indicate the dip direction of the unit from which the reading was taken. See trench sections (Appendix) for details of each trench.

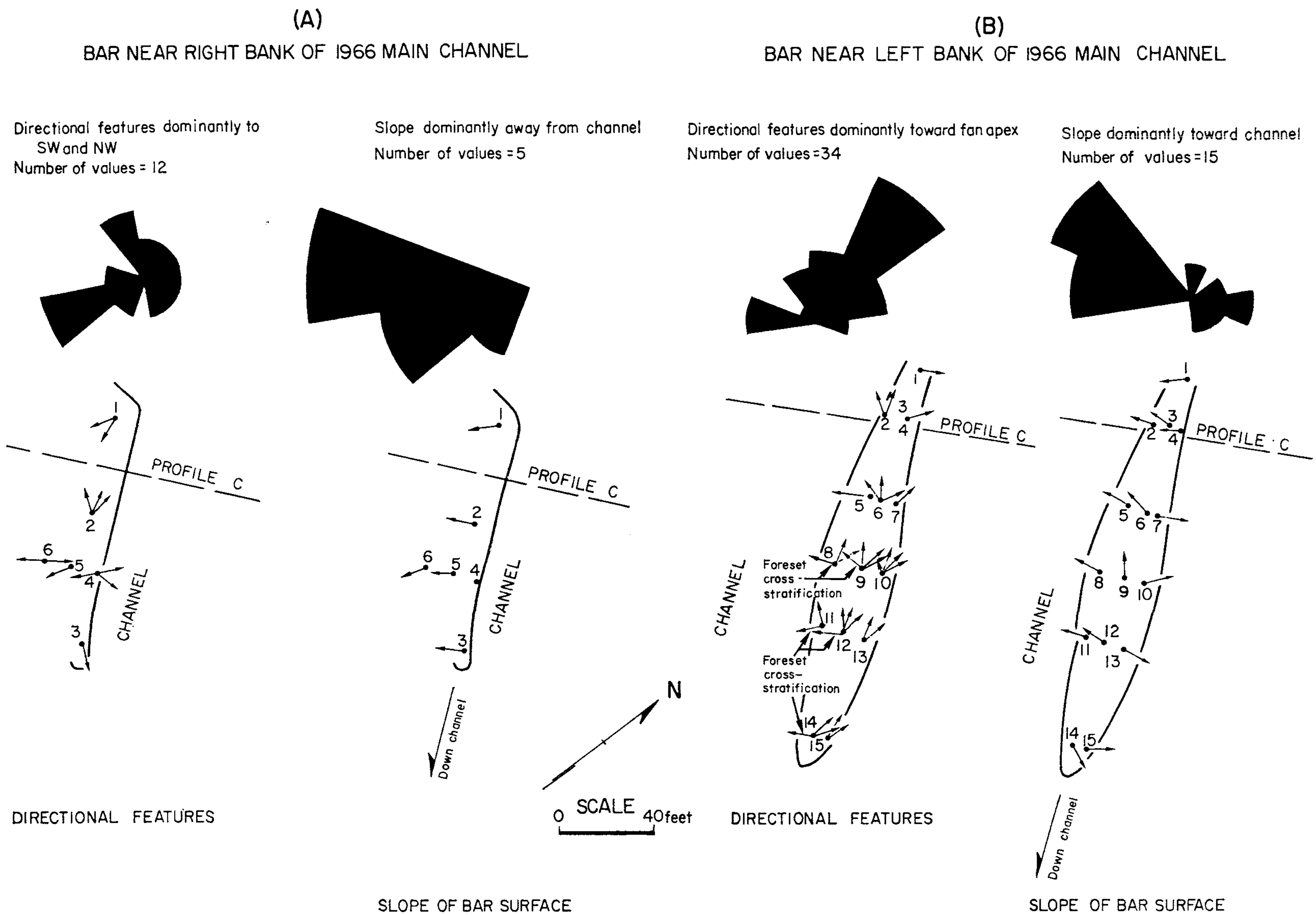


FIG. 14. Bar trend, surface slope, and directional features of longitudinal bars of the active channel.

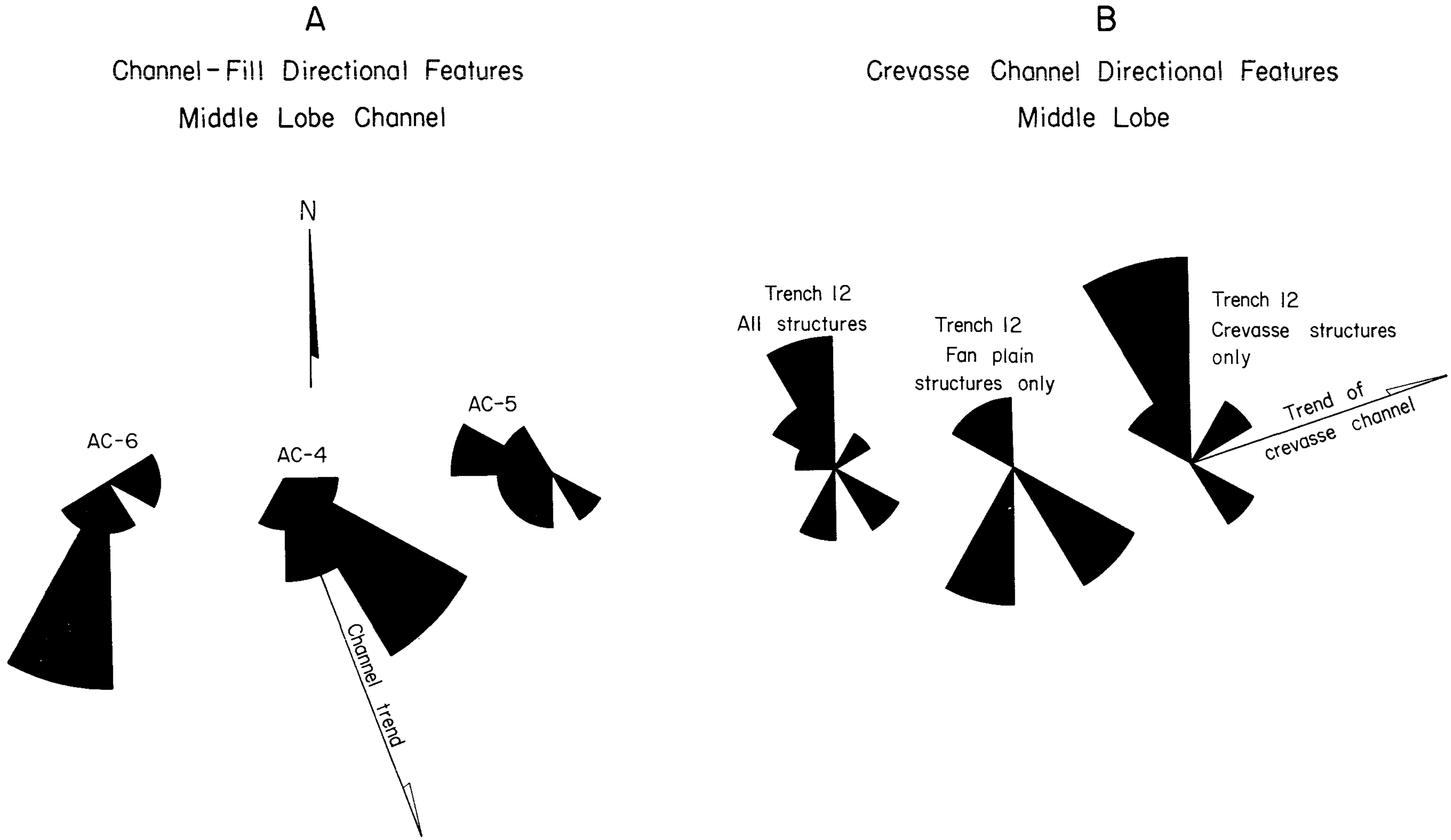


FIG. 15. Rose diagrams of main channel and crevasse channel deposits.

A. Directional features are shown for trenches AC-6, -4, and -5 of the middle lobe (*see* Pl. IV for trench localities). AC-6 is a trench near the right channel bank, AC-4 is near the center of the channel, and AC-5 is near the left channel bank. Directional readings were made on parallel laminae (longitudinal bars), trough-fill cross-stratification (crescent-shaped scours associated with brush piles), and climbing ripple laminae (residual channel fill). The number of values for each trench was eight.

B. The number of values in trench 12 was ten. All of these were used in constructing the first rose diagram; of these, five were from features related to the fan plain and five were from crevasse-fill features. Directional readings were made on parallel laminae (longitudinal bar, sheet sand, and slope wash), wavy laminae (bimodal direction, product of standing wave bed form?), and trough-fill cross-stratification (gully-fill).

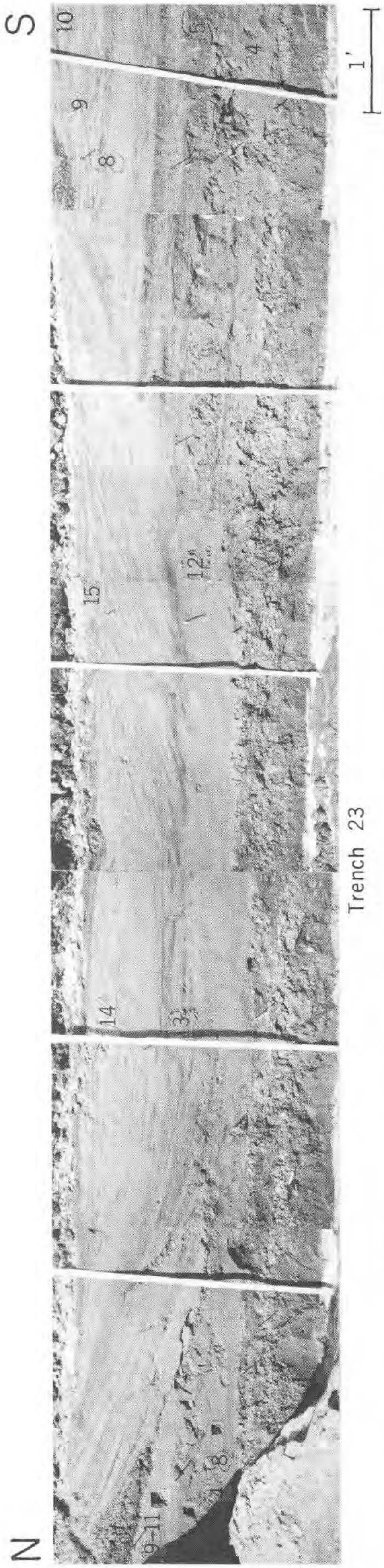


FIG. 16. Mosaic of crevasse channel. Symmetrically filled crevasse channel (units 12–14); slopewash (15); overbank sediment (south end of trench); main channel fill (south end of trench 4–8, north end of trench 4–11); and marsh (1–3).

the same bar, deviation between surface slope and dominant trend of directional features varies from about 60° to 120°. When foreset cross-stratification alone are considered (fig. 14,B), the dominant trend of directional features deviates about 60° to 90° from the general flow direction.

Directional features of longitudinal bars must be used with caution as an indicator of current direction. Parallel laminae that dip upcurrent (dips range from 1° to 8°) simply reflect a downcurrent increase in bar height. The higher angle, foreset cross-stratification developed when local currents flowed transversely across the longitudinal bar; foreset dip directions are approximately perpendicular to general flow direction within the main channel. The trend of the bar best approximates overall current direction at time of deposition.

General trend of the middle channel, from the earthen dam through the AC trench series, is about S. 20° E. A rose diagram (Pl. V) constructed from azimuth readings of all structures in the AC trench series shows dominant trends of directional features to be in the southwest quadrant. Rose diagrams (fig. 15A) of individual trench sections (AC-6, -4, and -5, in Appendix) show spreads in directional features. Most of the sediment in the AC series accumulated in the main channel of the middle lobe. Generally, directional features of channel-fill sediment have a more restricted spread than those of the fan plain. The difference in degree of spread of directional features reflects the nature of flow conditions.

CREVASSE CHANNEL

Only one crevasse channel could be recognized on the fan surface (Pl. III; grid points K/3, L/3, and M/4), and directional features observed in it are assumed to be characteristic of crevasses associated with Gum Hollow-type fan deltas. The crevasse channel was almost completely filled with sediment when the observations were made; it trends almost at right angles to the middle channel (Pl. V). Near the point where the levee was breached the crevasse channel was symmetrically filled (fig. 16), and flow direction paralleled the channel trend. Downchannel (trench 12) directional features were recorded for both fan plain and crevasse depositional units. Both a rose diagram of all structures recorded for trench 12 and trends of individual depositional units are bimodal (Pl. V).

The spread in fan plain directional features is in the range of those plotted for L-B3-T1 (Pl. V). Trend of the crevasse channel is about N. 70° E, and the dominant trend of directional features for crevasse-fill deposits is approximately at right angles to the channel (fig. 15, B). Parallel laminae, interpreted as longitudinal bars, are the most common stratification type. In trench 12 only the bar flanks were observed; these displayed a higher dip transverse to current direction than in the downchannel direction.

DISTAL FAN AND DESTRUCTIONAL PHASE BARS

Maximum development of destructional phase bars during the course of the field work was along the distal middle lobe. Measurements of directional features were made only in trenches cut through this group of bars. These bars were constructed from reworked fan plain and distal fan sediment.

Stratification types of destructional phase bars are foreset cross-stratification and various types of ripple cross-laminae. These structures generally trend toward the mainland and display a spread in migration direction of the ripples and foreset cross-stratification of about 180° (Pl. V). Trend of the bar was about N. 37° E., almost perpendicular to the dominant wind direction (about S. 45° E.). Directional features show transport inland ranging from 30° to 90°, relative to bar axis.

Wind-generated waves erode the distal fan and construct destructional bars. The direction perpendicular to elongation represents the general direction of wave approach. These bars develop only on those parts of the fan that front the dominant winds. Internal structures of bars indicate only a general downwind transport of sediment. Their application to predicting elongation trends in similar ancient sediments may or may not be valid depending upon dominant wind direction relative to shoreline orientation (fig. 11).

SEDIMENT CHARACTERISTICS

A generalized map of the current systems that affect sedimentation of Gum Hollow fan delta shows that fluvial processes are dominant on the active lobe and on certain parts of the inactive fan, particularly in segments of abandoned channels (fig. 11). Environments dominated by fluvial processes are the main channel systems, fan plain, and the upper part of the distal fan. On the inactive fan segment aeolian processes, wind tides, and sheet wash and gullying are the dominant processes.

Interpretation of flow conditions responsible for development of particular sedimentary structures observed on Gum Hollow fan delta is based on laboratory experiments in recirculating flumes and field studies of flow and sediment transport by Simons and Richardson (1961, 1962), Simons, Richardson, and Nordin (1965), Ore (1963, 1964, 1965), Jopling (1961, 1963, 1965), and Harms and Fahnestock (1965).

Simons and Richardson (1961), on the basis of field observations and laboratory studies of alluvial channels, divided forms of bed roughness into two flow régimes—upper and lower with a transition zone between them. Bed forms in the lower-flow régime are ripples and dunes, and in the upper-flow régime plane bed, standing waves, and antidunes are the bed forms. Bed forms in the transition zone are variable and range from typical lower- to upper-flow régime types. The lower-flow régime is characterized by relatively large resistance to flow with a small volume of sediment transport. In the upper-flow régime resistance to flow is relatively small and the volume of sediment in transport is large. Table 3 lists the characteristics of lower- and upper-flow régimes. Terms applied to stratification types in Gum Hollow deposits are given below:

Small trough sets	downstream inclined laminae
Foreset cross-stratification	downstream inclined laminae (6° to 20°)
Trough-fill cross-stratification	downstream inclined laminae (0° to 20°)
Parallel laminae	direction of inclination varies from upstream to downstream (horizontal to about 9°)

Main channels, fan plain, and distal fan constitute the subaerial fan. Superposed upon these fan segments are gullies, slope wash, and destructional phase bars. Prior to Hurricane Beulah the main channels of the western, middle, and active lobes were the most conspicuous features on the subaerial fan. These three channels show the sequence of channel evolution and fill.

CHANNELS

Sediment characteristics of the various Gum Hollow fan delta facies are presented on Plate VI (pocket). Channel-fill sediment is predominantly yellowish-brown, clean, fine sand. Second most common textural type is less well-sorted sand which ranges from coarse clay pellet sand, pebble-bearing fine sand, to muddy fine sand. The next most common textural type is medium to dark gray mud. Although some gravel-size material occurs in the channel fill, it is volumetrically unimportant.

Organic components are relatively insignificant in channel-fill sediment. Halophytes are established in ponded channels. *Uca* (fiddler crab) and insect burrows and a few pulmonate gastropod shells occur in pond deposits. Primary sedimentary structures are rarely obliterated by biologic activity; however, some channel-fill sediment has been distorted by cow tracks.

ACTIVE CHANNEL

Depositional features in the 1966 channel were longitudinal bars, crescent-shaped scour troughs at upcurrent ends of longitudinal bars, relatively straight scour troughs between longitudinal bars, and linguoid ripples that occur on tops of longitudinal bars or in deeper parts of the channel (fig. 17).

During the brief existence of this main channel, linguoid and sinusoidal ripples were the only bed forms observed. Wind direction and intensity appeared to be the factor that determined geometry of ripples. The form of ripples changed from linguoid to sinusoidal when the wind was strong and persistent from the southeast. Water depth in areas where sand was transported as linguoid ripples by fluvial processes was on the order of 2 to 4 inches; persistent south or southeast wind caused a rise in depth on the order of 2 to 3 inches. Surface velocity in the area of profile C (*see* Pl. IV), where change in ripple form was observed, was about 1.2 ft./sec. (33 cm./sec.). Surface velocity data were not collected when the wind was strong from the south or southeast. Flume experiments by Harms (1966) indicate that

> Ripples formed by lowest energy unidirectional flow have relatively continuous but sinuous crests, uniform height and spacing, well oriented avalanche faces, and asymmetric, angular profiles. As flow energy increases, crests become shorter and more curved and height and spacing more variable.

The change in ripple form in the Gum Hollow channel from linguoid to sinusoidal probably resulted from a decrease in velocity as water depth increased.

Some sediment in the active channel was transported in the form of linguoid or sinusoidal crested ripples by oil field brine discharge. Movement of sand-size material was slow under these conditions. The supply of the bed-load material was within the channel and was simply the redistribution of channel floor sediment. Redistribution of sand was restricted to the upper 700 feet of the channel

FIGURE 17.

(between the erosional escarpment and grid point P/4). The downchannel end of the ripple fields was an irregular front roughly perpendicular to flow direction.

Sedimentary structures produced by these lower-flow conditions are small trough sets that commonly occur as cosets that suggest sand feeding (McKee, 1965). Ripple migration was slow; the front of one ripple field migrated about 3 feet in one week, then it ceased to migrate and was ultimately stabilized by filamentous algae. Two types of cosets are present in cores taken along channel profiles B, C, and E. One type has erosional surfaces bounding each set, and in core sections only ripple foresets are preserved. Each of these sets is interpreted as a distinct depositional event involving limited bed-load transport with no sediment deposited from suspension. The other coset type may or may not have erosional bounding surfaces, with little or no scour between adjacent sets. This type of small trough sets develops when accumulation on the lee side of ripples is greater than erosion on the stoss side and may or may not be accompanied by deposition of material from suspension (Allen, 1963; Walker, 1963; McKee, 1965). Net sediment accumulation is indicated by this structure type, which has been termed ripple drift with deposition from above (Sorby, 1908), climbing ripples (Coleman, Gagliano, and Webb, 1964; Coleman and Gagliano, 1965), climbing ripple laminae (McKee, 1965), ripple-drift cross-lamination (Walker, 1963), and asymmetrical ripple marks (Allen, 1963).

Development of climbing ripples was not observed in the main channel of the 1966 fan during the course of this investigation. Observations were made during development of the first type of ripple cross-laminae and surface velocity was recorded between the channel profiles. Sediment samples of linguoid ripples were taken (February 19, 1967). Table 4 shows average surface velocity for the various channel segments and grain size parameters for each sample. Velocity was essentially constant between profiles B and F. The higher surface velocity between profiles A and B resulted from the flow being confined to a single small channel whereas beyond profile B the flow was carried by several small streams (*see* table 4 for maximum water depth at each channel profile; fig. 5 shows locality of channel profiles).

Sediment samples of linguoid ripple bed forms were sieved at ¼ ϕ intervals and grain-size parameters were determined by the graphic method of Folk and Ward (1957); samples were taken only from the surface and, therefore, represent just a few laminae. All samples have a mean in the fine sand range and are moderately well to well sorted. Size and sorting are largely inherited from the source sediment but also reflect transport processes (i.e., gravel is restricted mainly to fan apex; ripple transport of 0.6-mm rock or shell is unlikely).

Skewness of linguoid ripple sediment from the 1966 channel is varied. Near the cut through the escarpment the sediment is coarse skewed; all other samples except the one near profile D are near symmetrical. All samples, except profile F, are leptokurtic. Coarse skewness in the linguoid ripple samples is the result of addition of clay or mud clasts, caliche fragments, shell debris, and sandstone fragments to well-sorted fine sand.

Other stratification types associated with the 1966 main channel are parallel laminae and foreset cross-stratification. Because of the relatively low relief of longitudinal bars, which are characterized by these stratification types, only two of these bars were trenched (*see* fig. 14 for trench localities). Parallel laminae are the dominant structures and foreset cross-strata are a subordinate stratification type.

Vertical and lateral succession of stratification types is shown for the bars along the right and left channel banks (figs. 18 and 19). These structures are commonly terminated laterally by erosion as with each succeeding flood new channels are scoured and longitudinal bars develop in new areas within the channel. Figure 20 shows a longitudinal bar, just north of channel profile C, that has been scoured along its left flank. The 1966 channel was not active for a period of time sufficiently long for drastic changes to occur; however, such changes can be demonstrated in trenches cut into the filled middle lobe channel.

Sequences of stratification types in the bar along the left channel bank are simple, and although several units are numbered on the cross section two depositional events probably account for all the sediment accumulation. The first event includes the lower parallel laminated unit through the mud or clay drape. These units represent upper-flow régime for the longitudinal bar, decreasing flow conditions for the small trough sets, and finally stagnation for deposition of the mud layer; ripple form was preserved beneath the mud layer. Radiographs (at actual scale) of these stratification types are shown in figure 21, Sample 9/1a is oriented parallel to the bar trend (downchannel is to the right) and was taken from the lower part of the bar. Farther downchannel (sample 14/lb) parallel laminae are well defined by heavy mineral laminae; this sample

FIG. 17. Depositional features of active channels.

A. Brush-defended longitudinal bar and associated, crescent-shaped scour trough. Main channel system is shown in the background. Washed out ripples occur along the bar crest. View southeast.

B. A small longitudinal bar, with an oyster-shell nucleus, and a scour trough (shown by dotted line) developed in the main channel as a consequence of lowering of water level in Nueces Bay during a wet norther; rainfall (January 13, 1967) of about 2 inches accompanied the norther. Machete (2 feet long) is on the upcurrent end of the bar. View southeast.

C. Linguoid ripples in the 1966 main channel. Depth of water about 3 inches. View northwest, upchannel.

TABLE 3. *Lower- and upper-flow régime characteristics* (modified from Harms and Fahnestock (1965).

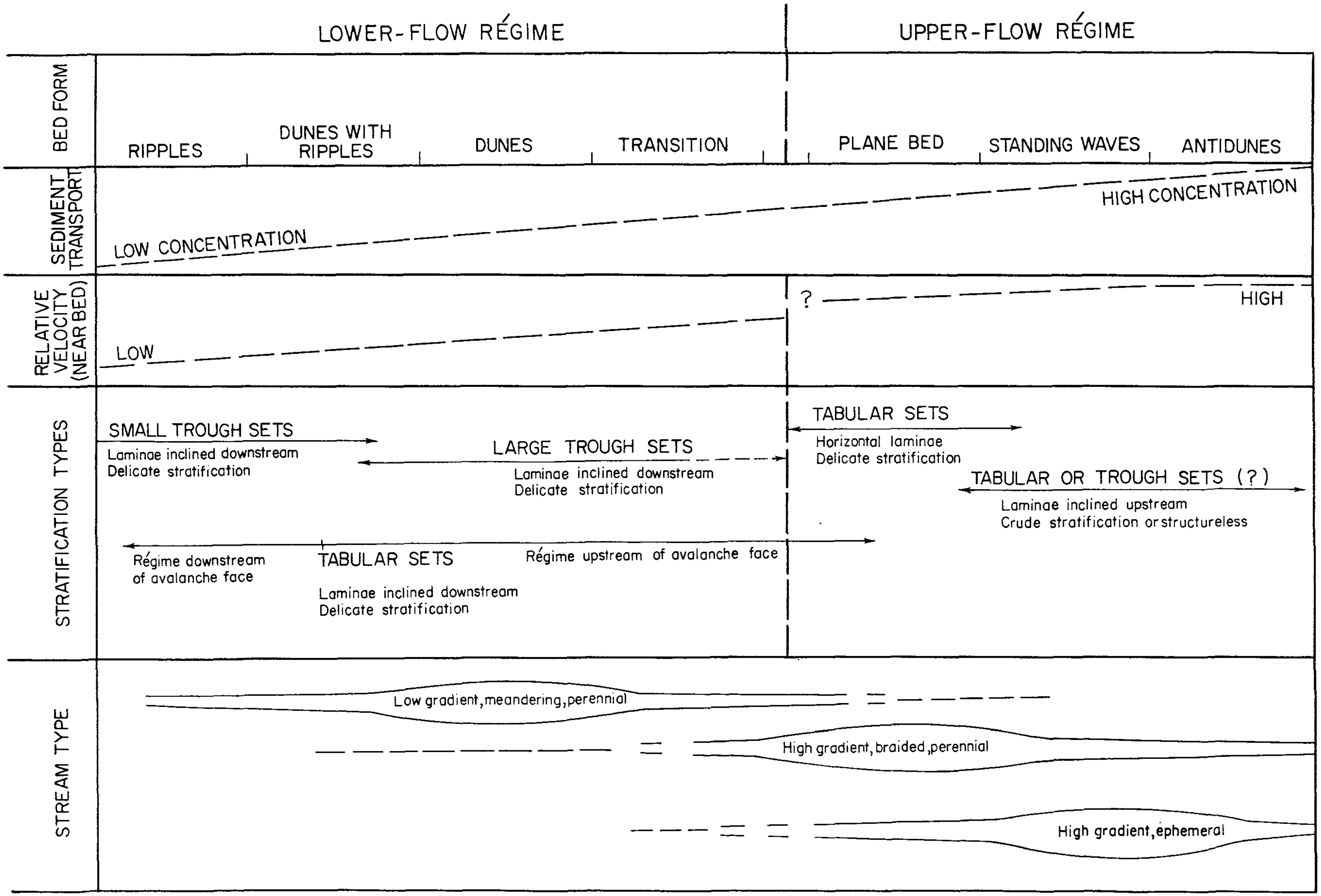


TABLE 4. *Grain size parameters and downchannel variation in surface velocity.*

A. Grain Size Parameters - Linguoid Ripple Bed Form

Sample	A	B	C	D	E	F	Average
Mean ∅ (M_z)	2.3 ∅ (0.2 mm) Fine sand	2.63 ∅ (0.16 mm) Fine sand	2.59 ∅ (0.16 mm) Fine sand	2.64 ∅ (0.16 mm) Fine sand	2.81 ∅ (0.14 mm) Fine sand	2.67 ∅ (0.16 mm) Fine sand	2.6 ∅ (0.16 mm) Fine sand
Sorting ∅ (σ_I)	0.46 Well sorted	0.53 Moderately well sorted	0.56 Moderately well sorted	0.61 Moderately well sorted	0.43 Well sorted	0.35 Well sorted	0.49 Well sorted
Skewness (SK_I)	-0.14 Coarse skewed	-0.13 Coarse skewed	+0.02 Near symmetrical	+0.13 Fine skewed	0.00 Symmetrical	+0.08 Near symmetrical	-0.01 Near symmetrical
Kurtosis (K_G)	1.21 Leptokurtic	0.46 Leptokurtic	1.19 Leptokurtic	1.25 Leptokurtic	1.19 Leptokurtic	1.07 Mesokurtic	1.23 Leptokurtic

B. Downchannel Variation in Average Surface Velocity

Channel Segment	A - B	B - C	C - D	D - E	E - F
Water Depth	A = 1.2', B = 0.4'	B = 0.4', C = 0.5'	C = 0.5', D = 0.7'	D = 0.7', E = 0.45'	E = 0.45', F = 0.65'
Surface Velocity (Feet per second)	2.64	1.36	1.37	1.25	1.37

Data collected 2-19-67.

Wind slight from east-southeast, but no significant waves upchannel from the channel mouth.

Water level in Nueces Bay normal.

Samples collected at channel profiles A, B, C, D, E, and F.
Surface velocity recorded between channel profiles A-B, B-C, etc.

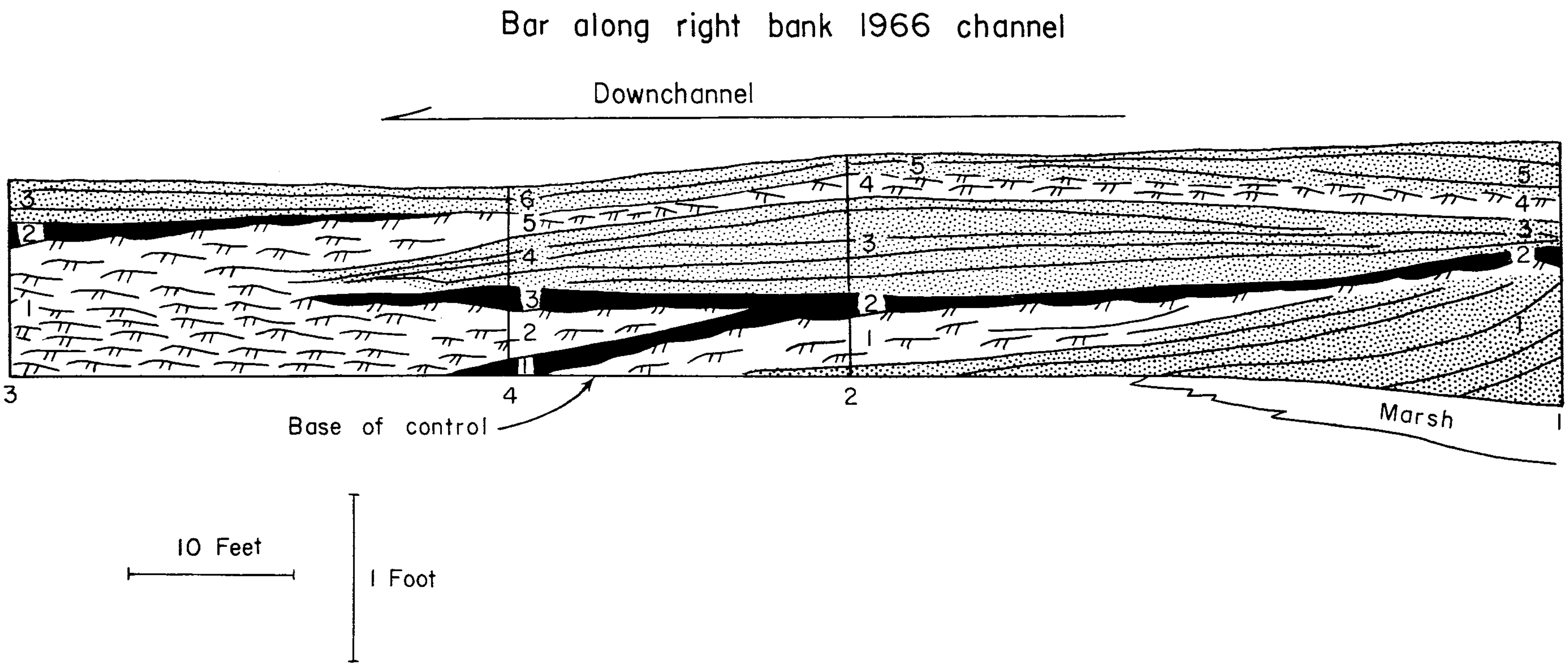


FIG. 18. Vertical and lateral succession of stratification types of the longitudinal bar along the right channel bank of the 1966 main channel. Unit 3 of trenches 1 and 2 and unit 4 of trench 4 are parallel laminated fine sand that comprises a longitudinal bar. Sediment deposited in shallow braided streams and in scour troughs underlie the longitudinal bar: trough-fill is shown in unit 1, trench 1; small trough sets in unit 1, trench 2; unit 2, trench 4; and unit 1, trench 3, are representative of ripple-bed forms in the shallow braided streams. Mud drapes are shown in black. The depositional feature shown by unit 5 of trenches 1 and 2, unit 6 of trench 4, and unit 3 of trench 3 was interpreted as either a thin longitudinal bar or sand sheet.

represents a section perpendicular to the bar trend and is transitional with small trough sets. The small trough set part of the longitudinal bar is shown in radiograph 15/1b; troughs are accentuated by heavy minerals.

The longitudinal cross section (fig. 19) of the bar along the left bank of the 1966 channel does not truly depict the trend of the lower longitudinal bar. This is a tangential section, as shown by a series of east-west cross sections through the bar (fig. 22). An isopach map (fig. 23,A) is a close approximation of the trend of the lower bar; this map suggests that the small trough sets unit flanking the longitudinal bar represents deposition in shallow braided streams.

All sediment above the mud drape unit (fig. 19) is considered as a single depositional event. The isopach map (fig. 23, B) indicates that this unit more closely approximates the trend of the compound bar. Flow direction during accumulation of this unit deviated from the trend of the underlying longitudinal bar by about 110°. The upper unit is a transverse bar that accreted into a former channel. Stratification types of the transverse bar appear to be controlled by relief on the underlying longitudinal bar, and changes from undulatory laminae, or parallel laminae, was not controlled by changes in discharge but by increasing water depth beyond the crest of the underlying longitudinal bar. That part of the transverse bar that is composed of foreset cross-stratification is wedge shaped; this is shown by longitudinal and transverse trench sections and by isopaching the upper depositional unit. Sections through the bar are somewhat analogous to "deltas" produced by Jopling (1963); mechanics of developing topset, foreset, and bottomset beds are described in his paper. Angle of inclination of foreset cross-stratification ranges from about 6° to 20°. The angle increases with thickness of the unit. The foreset cross-strata are slightly concave upward and the lower parts grade imperceptibly into parallel laminae.

The low inclination of foreset cross-strata and their parallel to undulatory laminated upcurrent equivalents indicate relatively high velocity flow conditions. Superposed foreset cross-stratification beds have not been encountered on Gum Hollow fan delta, as flow during flood stage is normally very shallow and these beds can develop only when sediment progrades transversely into shallow channels, crescent-shaped scour depressions, or during hurricanes when water level in Nueces Bay is drastically changed.

Radiographs (fig. 21) of the transverse bar are shown by units 8/3a, 9/3a, 13/3a, 8/4a; 8/3a, 9/3a, and 13/3a are bottomset bed samples taken roughly parallel to current direction. Sample 9/3a shows the effect of backflow at the top of the specimen; this sample was taken near the toe of foreset cross-strata, and the undulatory laminae are believed to be hummocky nondirectional ripples such as those described by Jopling (1961).

Sample 13/3a is from a parallel laminated, slightly undulatory unit near the crest of the underlying longitudinal bar and is near the transition into foreset cross-strata. The sample is approximately perpendicular to transport direction. The darker bands are heavy mineral placers. Sample 8/4a was taken from foreset cross-strata and is oriented perpendicular to flow direction; stratification is poorly defined in this radiograph. Sample 9/5a, the uppermost parallel laminated unit, was taken perpendicular to flow direction. In addition to being parallel laminated there are local scour depressions near the base of the unit; one of these scours is shown in the radiograph. The base of the scour contains a few mud clasts.

Considerable deposition of material in the area of the bar along the right channel bank (fig. 18) was in a shallow channel system that maintained a relatively constant position. This is indicated by a dominance of small trough sets in the lower part of the profile and an increase in small trough sets in the upper part of the profile south of trench 4.

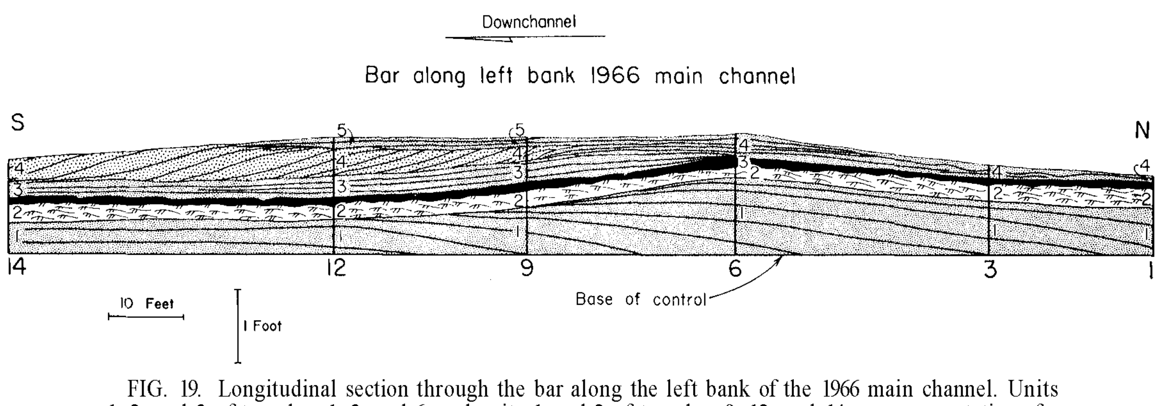


FIG. 19. Longitudinal section through the bar along the left bank of the 1966 main channel. Units 1, 2, and 3 of trenches 1, 3, and 6, and units 1 and 2 of trenches 9, 12, and 14 are representative of a single depositional episode. A lower parallel laminated unit, a middle small trough set, and an upper mud drape comprise a depositional feature termed longitudinal bar. All sediment above the mud drape (parallel laminae, wavy laminae, and foreset cross-stratification) comprises another depositional feature termed transverse bar. Unit 3 of trenches 9, 12, and 14 is in part contemporaneous with the overlying foresets (unit 4 of all trenches) that are locally transitional into parallel laminae of the overlying unit 5 (trenches 9 and 12).

Extensive trenching was not done on this bar, and trends and geometry of the various units are not known. Sediment below the lower two mud drapes represents channel fill of either linguoid or cuspate ripples, and trough-fill cross-bedding. Development of longitudinal bars (parallel laminae) succeeded the lower mud drape. A transverse section (trenches 4, 5, and 6) and the longitudinal section through the bar (fig. 18) suggest the lower bar and surface trend are alike; however, an isopach map (fig. 24,A) of the bar indicates that is not the case. Inclination of laminae shows the bar accreted from west to east. Residual shallow channels, shown by small trough sets (trenches 4 and 6), flanked the bar and ripples covered the bar surface (trenches 1 and 2) as discharge decreased. A mud drape, if deposited as a continuous layer across the ripple bed form, was preserved only in the area of trench 3 (probably the lowest point in the residual channel). A very low relief longitudinal bar, or sand sheet, was the last depositional event. An isopach map of this unit shows it to be the thinnest across the crest of the underlying longitudinal bar (fig. 24, B). Directional features suggest flow in the residual flanking channels was approximately parallel to the channel trend, and flow across the top of the underlying longitudinal bar was predominantly from the eastern channel at an angle roughly perpendicular to the bar trend. Accretion of the upper bar or sheet sand was generally to the southwest. Foreset cross-strata might have been present to the west beyond trench control for this unit.

Data obtained from these two bars indicate a compound nature for bars developed in main channels and that directional features of longitudinal bars do not necessarily correspond to current direction during deposition of these features. After development of longitudinal bars flow can be expected to develop transverse to the trend of the underlying bar, and directional features from these transverse bars closely approximate current direction at time of deposition. Foreset cross-strata appear to develop only if deposition, accompanying transverse flow, occurs in one of the deeper channels flanking the underlying longitudinal bar.

FILLED CHANNELS

Sedimentary structures characteristic of main channels are illustrated by trenches cut into the middle channel. Both the middle and western channels were alternately active and stagnant prior to diversion of the fluvial channel to the east. Upon abandonment steep channel banks were laid down by slope wash. Normally the steeper escarpments were formed along the right channel bank because of the predominant southeast wind. During the inactive period (when flow was dominantly from oil field brine discharge) wind tides served to undercut the channel banks, and during periods of flood, if the channel was not flowing bank full, southeast wind served to deflect woody material toward the right bank where it lodged against the channel bank or bottom, causing relatively deep scour. Brush piles were conspicuous along the surface of both the middle and western channels. Brush and associated scour features were consistently encountered in the AC trench series near the position of the right channel bank (*see* AC trench series in Appendix).

Multiple scour-and-fill features adjacent to channel banks, particularly trenches AC-1 and AC-6, show vertical accretion of the fan and lateral shift in bank position. No persistent direction of lateral shift is indicated. Terracing, trough cross-bedding, slope wash, and marsh development are dominant features adjacent to the right bank. In the upper parts of the AC trench series contorted bedding, produced by cow tracks, is a characteristic feature. Generally, contorted bedding is confined to the topographically higher parts of the fan and adjacent pre-fan high marsh.

Terracing was not recognized in trenches that supposedly were cut into the left channel bank, but trough-fill cross-stratification were common in that area. Asymmetrically filled troughs appear to be the most common type. Some trough-fill cross-stratification were compound with two or more events of deposition and erosion recorded in a single trough (e.g., AC-3, unit 9). This is shown by discordance in structures, change in composition of trough-fill from quartz sand to predominantly clay pellet sand, and commonly a lower symmetrically filled part of a trough is succeeded by small trough sets (e.g., AC-3, unit 9b). Mud-filled troughs were observed where scour features had developed relatively high on the channel bank.

Trough-fill sediment.—In the main channel system of Gum Hollow fan delta there are two scour trough types (fig. 25, A and B). Each trough type is different in plan, and each was formed under a specific set of flow conditions.

FIG. 20. Longitudinal bar in 1966 main channel (view northwest). This is the same bar as shown in figure 17, B; photo taken February 12, 1967, shows that the bar had accreted down channel to profile C (stake in foreground is along profile C). Elongation of the bar resulted from a 2-inch rain (February 6, 1967). The man-made cut through the Beaumont Formation (A) is shown in the background.

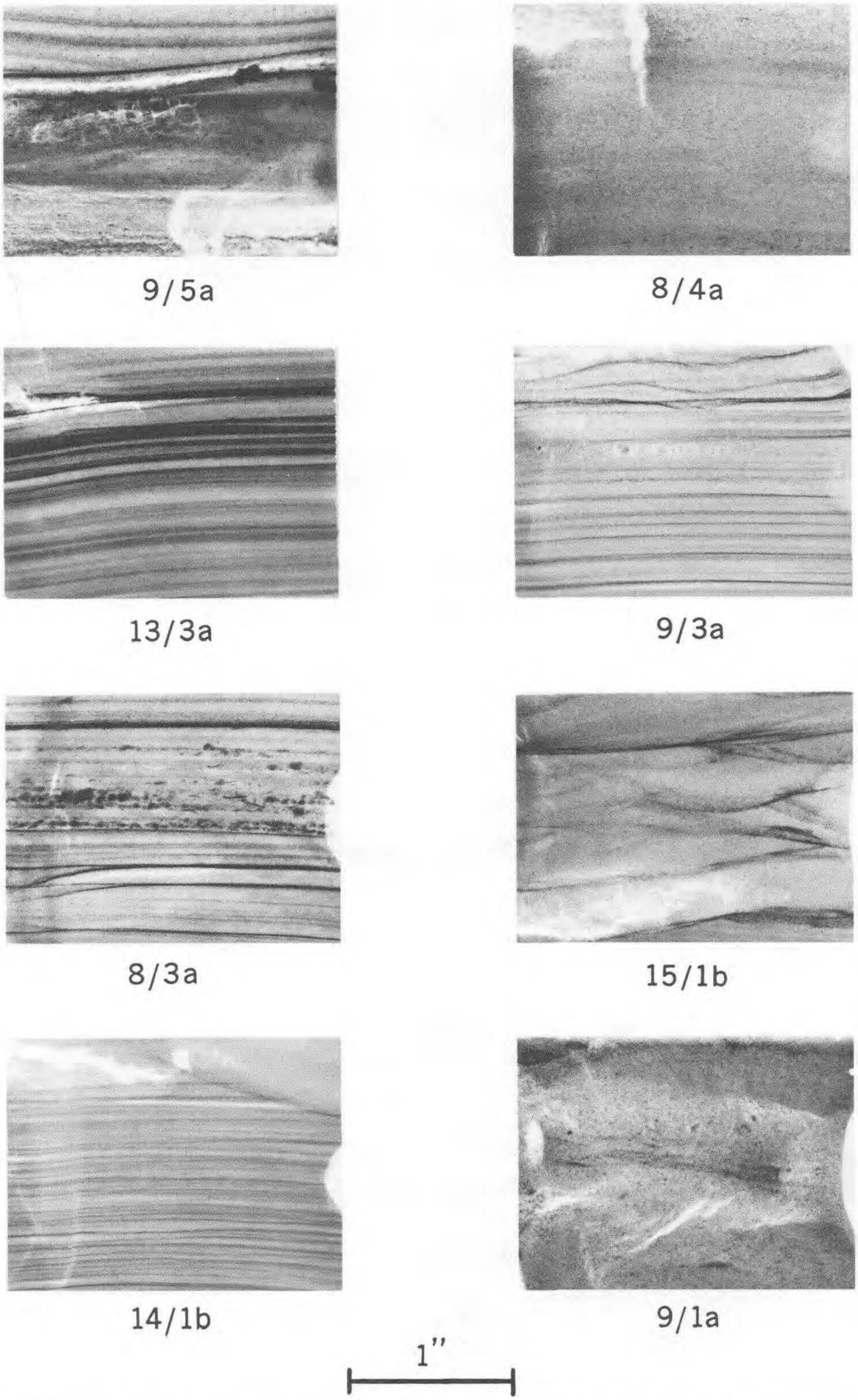


FIG. 21. Radiographs of samples taken from the bar along the left bank of the 1966 main channel. Radiographs are actual size of the sediment slab. The first digit (e.g., in 9/5a) is the trench number; the second digit is the unit number; the letter "a" indicates the sample was taken parallel to the trend of the bar, and "b" indicates the sample was taken perpendicular to the bar trend. Samples were taken by inserting a 20-dram plastic vial (parallel to depositional surface) into the trench face. The samples were impregnated with Elmer's Glue and then slabbed with a rock saw.

Radiographically denser material (calcium carbonate in shells or heavy minerals) is darker on these photographs.

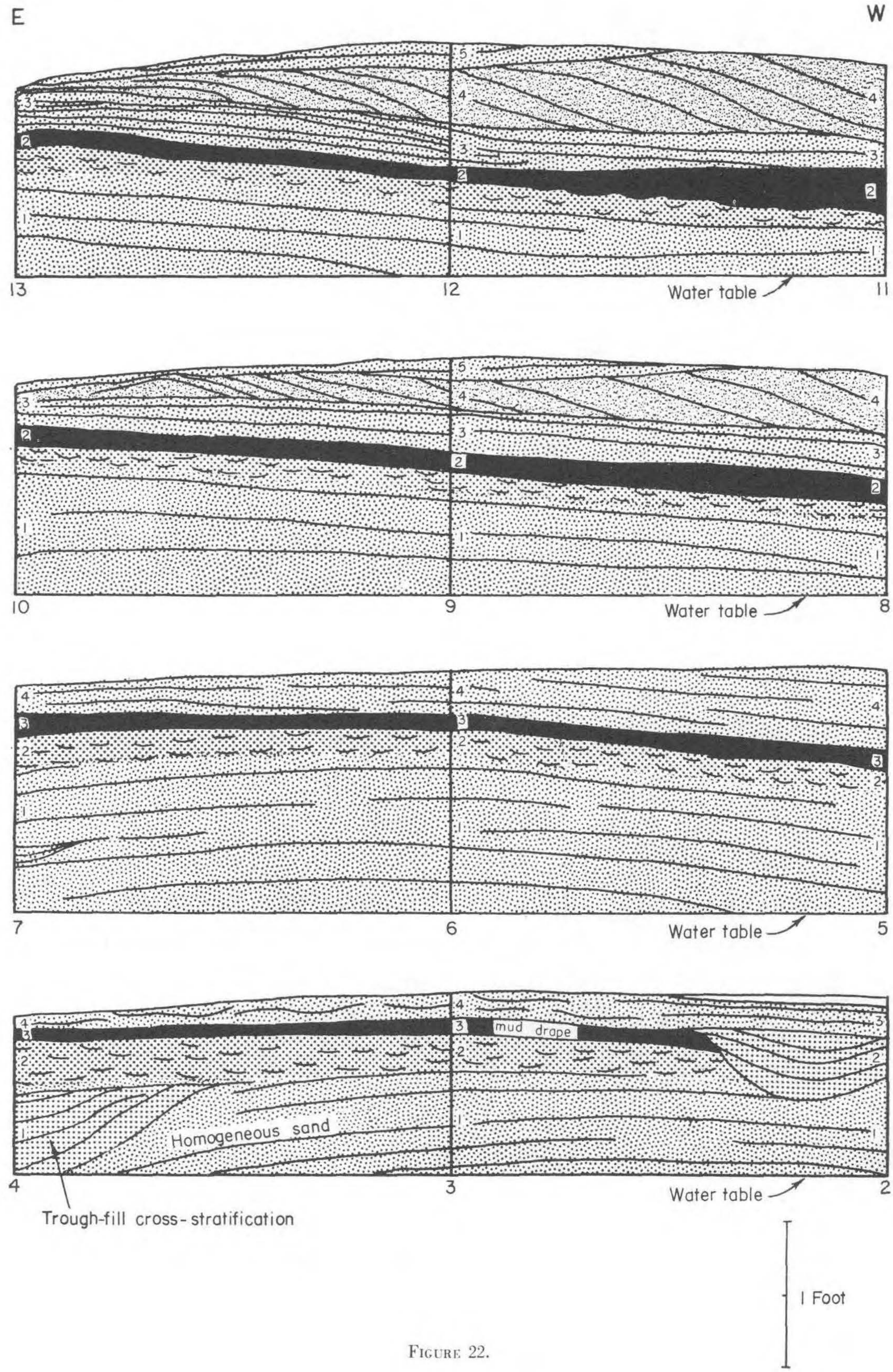

E
W
5
4
3
2
1
13
12
11
Water table
10
9
8
7
6
Homogeneous sand
mud drape
Trough-fill cross-stratification
I Foot

FIGURE 22.

Trough-fill generally consists of sand deposited as foreset cross-strata, small trough sets, parallel laminae, and thin mud drape. Rarely are scour troughs symmetrically filled as in some point-bars (Frazier and Osanik, 1961; Harms, Mackenzie, and McCubbin, 1963) and in specific, straight reaches of the Rio Grande (Harms and Fahnestock, 1965).

Large-scale trough-stratification sequence is shown diagrammatically in figure 25,C. Theories proposed for the formation of this stratification type have been summarized by Harms and Fahnestock (1965). Their work on the Rio Grande indicates that scouring of troughs is associated with dune bed forms.

The two types of troughs developed in main channels of Gum Hollow fan delta are those formed adjacent to debris piles (these are also common features on the fan plain), and the other type is a straight trough, scoured within the lower parts of a channel as a consequence of lowered base level.

The first trough type is filled at its upcurrent end by sand or gravel (gravel-sized mud clasts generally). The angle of inclination of trough-fill cross-stratification varies with the flow régime. Low-angle faces presumably developed when the bed forms upcurrent were plane bed, and became higher angle when discharge decreased and upcurrent bed forms were ripples. Final fill, or partial fill, was mud or clay when flow conditions began to stagnate. Types of fill at the upcurrent end of the trough are shown in figure 25,A (a, b, c). Farther downchannel the scour trough assumes a more symmetrical form transverse to current direction. The most common type of fill in these sections of a trough are foreset cross-strata that migrated transversely to trough elongation (fig. 25, A, d). These deposits represent lateral accretion of a longitudinal bar into a scour depression. Trenches cut into fan plain (U trench series), abandoned middle lobe channel (AC-3, unit 7), and the partially filled west channel (trench NT1, fig. 26) all display structures interpreted as trough-fill by accreting longitudinal bars.

The second trough type (fig. 25, B) varies in plan from roughly elliptical to long sinuous features with sharp upcurrent and downcurrent ends. This trough type varies in length from about a foot to about 25 feet and in width from a few inches to about 10 feet. Depth of scour was generally limited by a floor of cohesive clay in the 1966 main channel, by pre-delta marsh near the apex (0.5 to 1 foot below general fan surface), or farther downchannel by distal fan mud drape (1 foot to 1.4 feet below general fan surface).

Figure 27 is a pace-and-brunton map of scour features developed during a norther in early winter 1967 (the area was in the main channel between profiles B and C). The longitudinal bar developed downchannel from a relatively deep scour (about 0.5 to 1.0 foot deep) and had a nucleus of oyster shell. Bed forms ranged from linguoid to sinusoidal crested ripples. To the east of the bar a scour trough is shown being filled with linguoid ripples (arrows show current directions at the time the map was made). This type of feature was recognized in some of the trenches in the filled middle lobe channel (AC-1, unit 11 in the east-west trench and unit 11a-11d in the north-south trench).

Generally, the second trough type is not filled completely soon after it is scoured. Clay layers suggest periods of very slow flow. The diagrammatic sections (fig. 25, B, a, b) through a single trough show several depositional events. Stratification within the central part of the trough is commonly small trough sets, and troughs may be filled laterally by accreting longitudinal bars.

Longitudinal bars.—Longitudinal bars were recognized in filled channels by the characteristic parallel laminated units. Scale of individual bars is not known but is assumed to be on the order of those in the 1966 main channel. These depositional features are best preserved in the central parts of a channel-fill sequence. With the exception of bars near the fan apex (trench 15), sediment is dominantly quartz and clay pellet sand. Stratification is always accentuated by clay pellets, shell debris, or heavy minerals.

Most longitudinal bars are interpreted as representative of a single depositional episode. For the most part an individual bar does not show the lower-flow régime structures that would be expected from observations made on the active lobe. Several factors affect preservation of these structures (if indeed they formed at the top of a particular longitudinal bar), such as sheet wash, modification of the bar surface by wind generated tides, and erosion of upper parts of bars at the onset of the next flood. The latter is indicated to be the primary cause for small trough sets not being preserved as most longitudinal bars are bounded by erosional surfaces, and there are remnants of small trough sets in the youngest longitudinal bars of the AC trench series.

Instability of flow within main channels is indicated by changes in direction of inclination of laminae of a single bar. Commonly, a bar shows discordance in structure along the crest and rarely shows evidence of erosion along the flanks. This suggests fluctuation in flow conditions—possibly a relative decrease in water depth as the bar accreted upward, a decrease in discharge, or change in flow direction (AC-1-15, AC-3-7, AC-4-6).

FIG. 22. East-west cross sections through the bar along the left bank of the 1966 main channel. The mud drape separates the lower longitudinal bar from the upper transverse bar. With the exception of trough-fill cross-stratification in trenches 2 and 4, stratification types are the same as shown in the longitudinal section (fig. 19) through this bar. Unit 1, trench 4 (interpreted as trough-fill cross-stratification) could have been deposited contemporaneously with low-angle strata of the longitudinal bar; if so then unit 1 probably represents the fill of a shallow braided channel by an eastward-accreting longitudinal bar.

As a main channel system decreases in depth toward the distal fan, longitudinal bars make up a greater part of the channel fill. Presumably longitudinal bars in the channel fill formed only when floods were great enough to spread overbank. Observations made on the active channel suggest that when flow is confined to the main channel both water and sediment discharge are inadequate to develop extensive longitudinal bars.

Terraces and slope wash surfaces.—Terracing is a common feature associated with main channel systems of Gum Hollow fan delta (fig. 28,A). Terraces are developed as a consequence of lowering of water level in Nueces Bay following a brief interval of vertical or lateral accretion by either tropical storms or floods produced by normal rainfall conditions. Terraces produced by either one of these depositional events are alike; they are temporary features because of the almost vertical faces and incoherent sandy sediment.

A smoothly sloping surface, termed slope wash surface, replaces the vertical face below the terrace (fig. 28, C). The rate at which the terrace is destroyed depends upon the frequency of rainfall, position of the terrace along the main channel system, and intensity and duration of southeast winds that generate tides that move upchannel and rework the channel banks.

During the period of field investigation both the western

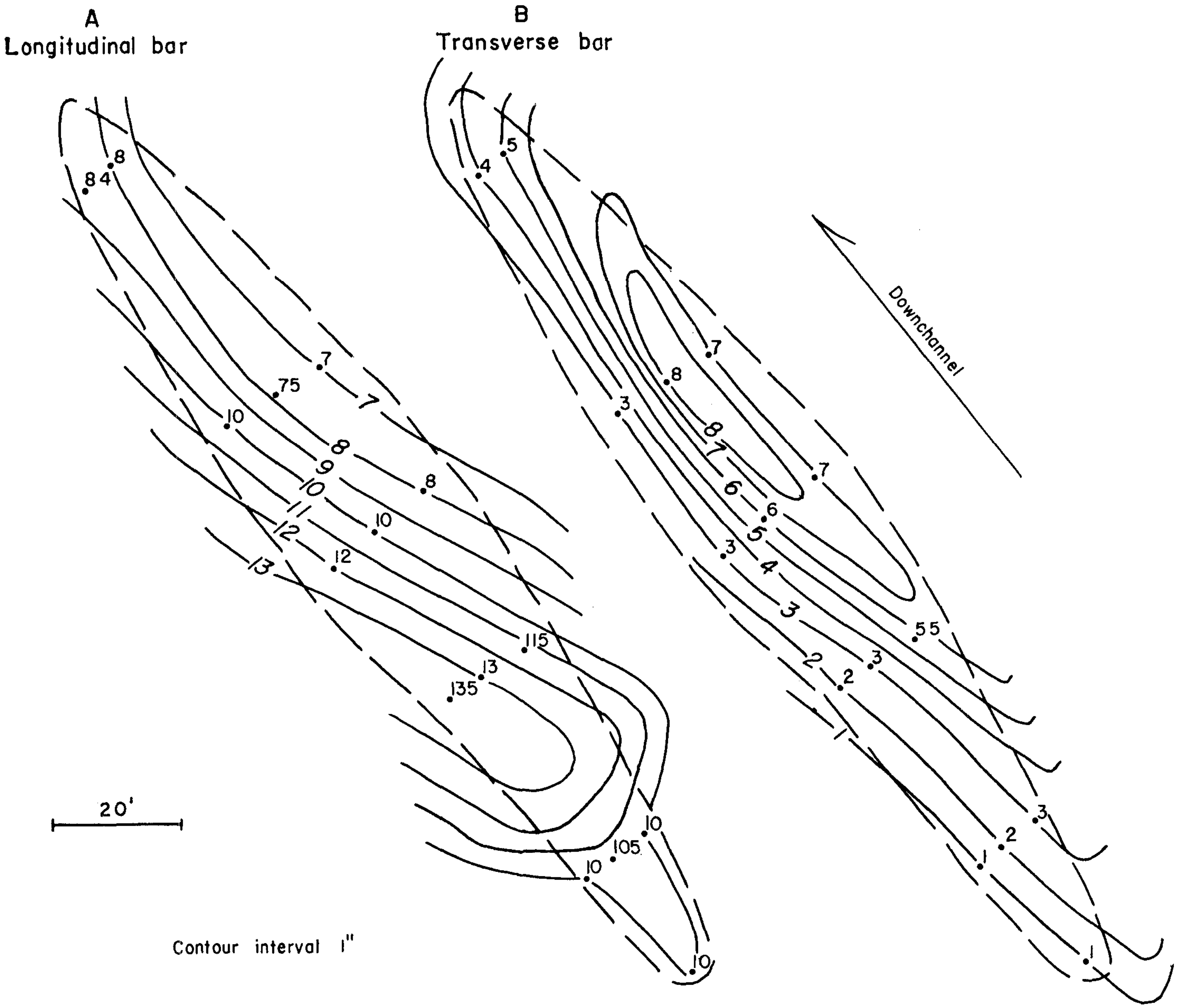


FIG. 23. Isopach map of bar along left channel bank, 1966 main channel.

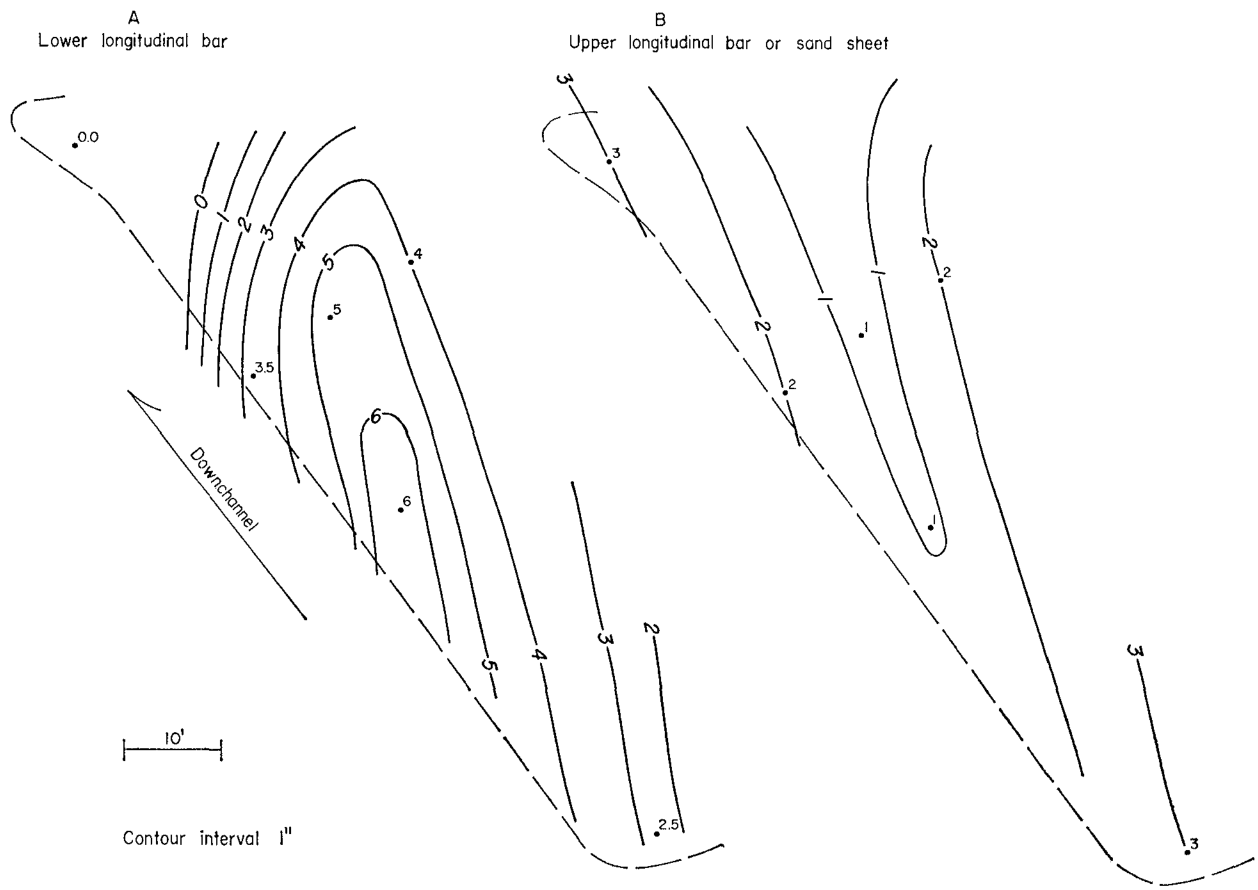


FIG. 24. Isopach map of bar along right channel bank, 1966 main channel.

channel and active channel banks were being laid down by slope wash. The western channel banks were modified almost entirely by gullying and sheet wash, as was the crevasse channel associated with the middle channel. These surfaces sloped toward the abandoned channel centers at angles of 5° to 11°. Within the filled middle channel dip angles of slope wash units were on the order of 1° to 3°. The only significance attached to slope wash units within the filled channel is that they represent deposition adjacent to channel banks and that their recognition aids in distinguishing channel fill from fan plain sediment. Gullying, sheet wash, and wind tides were all active in destroying terraces along the 1966 main channel. The dip on the surface of slope wash units along the active channel averaged about 6°.

Stratification of slope wash deposits is mostly parallel laminae. Bed forms near axes of small fans, developed at distal ends of gullies, are linguoid ripples; this type of structure was not recognized in any of the trenches. Near the lower parts of slope wash units, particularly those of the abandoned middle channel, primary sedimentary structures had been destroyed by evolution of gas-filled voids; sand in this zone was frequently flushed by rain water or flooded by wind tides,

In cross section, slope wash deposits are generally lenticular (L-T-T2, unit 10; AC-1, units 3, 6, lower part of 11 in west part of trench; AC-9, units 5 and 10b). Slope wash deposits, although emplaced by different processes, accumulate under unidirectional flow whether the flow is generated by wind tides or by sheet wash. Flow that produces these features is extremely shallow, from an inch or so to flow in which sand grains are not completely covered.

Grain-size parameters of slope wash deposits indicate it is fine sand, well-sorted, fine-skewed mesokurtic. The fine skewness is a characteristic of both river and dune sands (**Friedman, 1961**).

Ponded sediment.—Periods of channel abandonment are indicated in filled channels by muddy sediment. Characteristically this ponded sediment is thick (4 to 7 inches), either mud or alternating mud and sand layers, and contains plant debris and recognizable roots of halophytes. It is commonly medium to dark gray, clayey silt to muddy, very fine to fine sand. Some apparently homogeneous mud is actually composed of sand-size mud clasts. Pond sediment adjacent to channel banks commonly lies between sand units of slope wash origin. Evidence that much of this sediment was derived from Nueces Bay is the presence of thin mats of *Diplanthcra wrightii* debris.

Internally, pond sediment shows a variety of structures, such as wave-rippled, clayey silt with a thin veneer of clay accentuating the ripple form; homogeneous, muddy, quartz sand or homogeneous, clay-pellet sand; and small trough sets of very fine sand.

Ponded sediment is not preserved throughout the length of the filled, middle channel. The area of best preservation of ponded sediment is some distance downchannel from the apex, in the vicinity of trenches AC-4, 5, and 6 (*see* AC-5, units 3, 6, and 7–8). Preferential preservation of pond sediment appears to be controlled by its occurrence along a particular cross section of a channel and its position with respect to the fan apex. Pond sediment occurs most commonly near the right channel bank. Preservation, after the channel again became active, was aided by a vegetative cover and by resistance of muddy sediment to erosion (AC-1, unit 11; AC-6, unit 7; and AC-9, units 10–11).

Units 3, 6, and 7–8, trench AC-5, are characteristic of

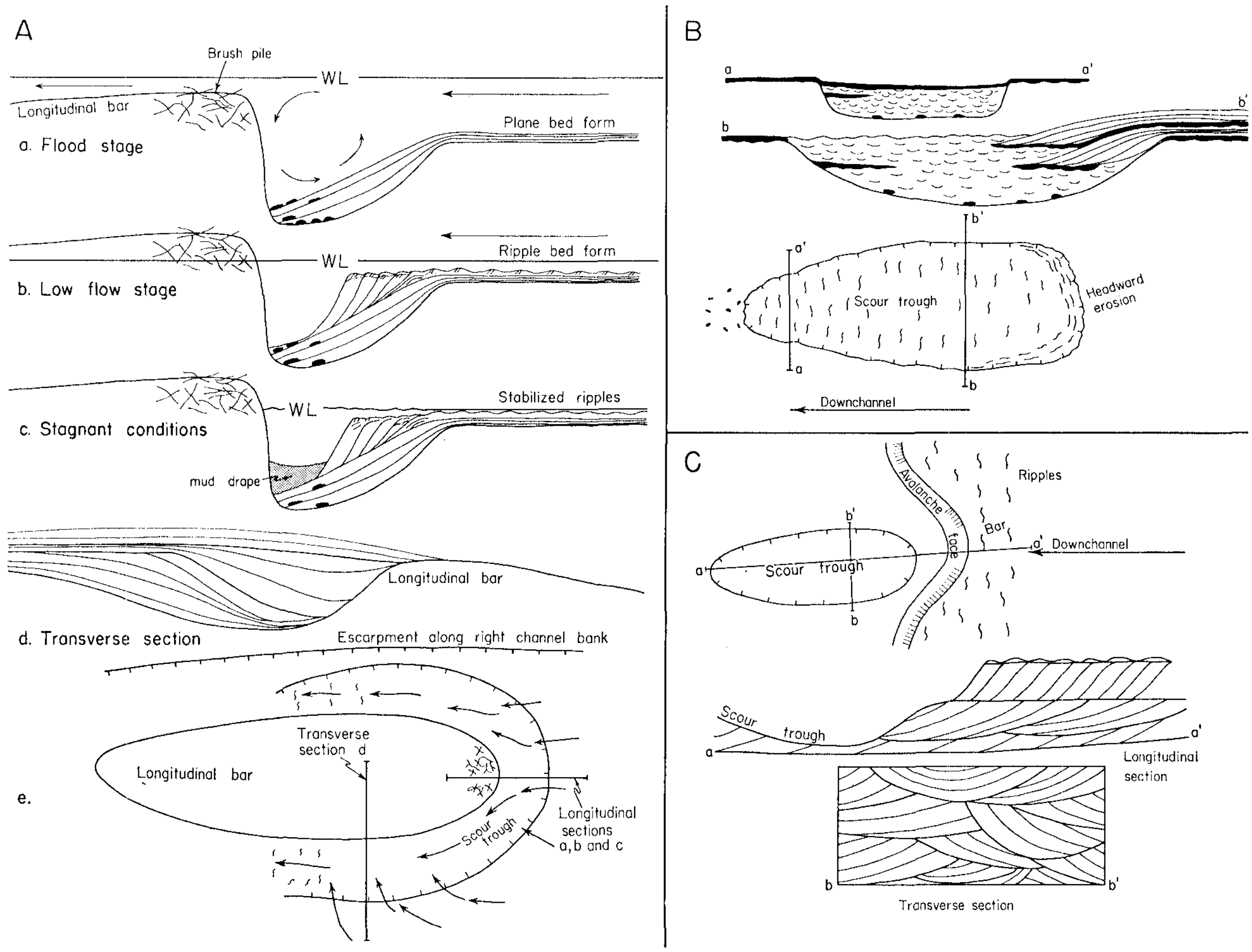


FIG. 25. Types of scour troughs associated with Gum Hollow fan delta.

A. Scour trough and longitudinal bar developed because of turbulence created in the area around a brush pile. Plan view of scour and bar is shown by (e). These crescent-shaped scours range from 10 to 50 feet in length, 2 to 5 feet in width, and 0.5 foot to 1.5 feet in depth. (a) through (c) show the type of fill at the upcurrent end of a longitudinal bar. (d) shows lateral fill of the scour trough by a longitudinal bar accreting to the right; lateral fill by accreting bars ranges in thickness from 0.5 foot to about 1.5 feet.

B. Scour trough produced by lowering of base level within a main channel. The trough is subsequently filled by migrating ripples and/or laterally accreting longitudinal bars. These scours range from about 1 foot to 25 feet in length, 1 foot to 10 feet in width, and about 0.1 to 0.7 foot in depth.

C. Scour troughs and trough-fill stratification types reported for several modern fluvial channels. Filled troughs of the Rio Grande (Harms and Fahnestock, 1965) were 10 to 20 feet long, 2 to 5 feet wide, and 0.3 to 1 foot thick. Filled troughs on a point bar of the Red River (Harms, Mackenzie, and McCubbin, 1963) were from 20 to 100 feet long, 2 to 20 feet wide, and less than 1 foot up to 2.2 feet thick.

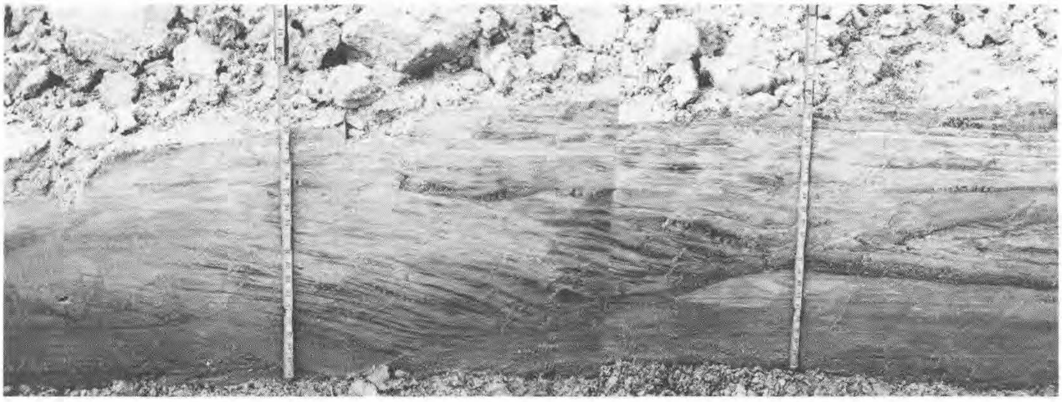


FIG. 26. Trench NT-1 along left bank of west lobe channel (view north). Asymmetrically filled scour trough; transport direction was approximately at right angles to channel trend. Sediment fill consists of well-sorted fine quartz sand and poor to moderately sorted medium to coarse clay pellet sand. Right of photograph is toward left channel bank.

pond sediment near the central part of the channel. The eastern part of unit 3 consists of about 90 percent mud with thin discontinuous silt and sand laminae. Mud layers are apparently homogeneous and are in the range of 0.5 to 1.0 inch thick and contain sand-filled root mottles and injection features comprised of silt and sand. The silt layers contain abundant plant debris up to 2 mm long. Generally, the contact between sand or silt and overlying mud is sharp. To the west in unit 3 mud layers thicken toward the lower part of the channel. This part of the unit consists of parallel laminated, moderately sorted to muddy very fine sand; clean, parallel laminated silt (the silt commonly shows convolutions believed to be gas-heave structures); and dark gray, desiccated, mud laminae that may be overlain by small trough sets of fine, clay pellet and quartz sand. Some mud layers probably represent algal mat accumulation, and most of the sand and silt layers represent incomplete ripples formed by sheet wash. Unit 6 is about the same lithologic and structure type as west part of unit 3, the primary difference being that unit 6 contains about 1 to 2 percent coarse sand to granule-size mud pellets. The original character of the unit 7–8 has been obscured by cow tracks and is a convoluted, muddy fine sand.

Windblown sand commonly fills depressions in the topographically higher areas of the fan that have been disturbed by cow tracks. An example of this type fill is unit 13 of trench AC-1 (Pl. VII, C, and fig. 14). Lithologically, unit 13 is moderate to well sorted, fine sand with about 1 to 2 percent coarse sand to granule-size shell debris and a trace of granule-size clay pellets. Undulatory laminae are accentuated by clay, plant debris, and shell material.

DEVELOPMENT AND COMPLETE FILL OF MAIN CHANNELS

Main channels are erosional features that were cut into fan sediment following a major depositional event. Scouring of a channel is a consequence of decreased flow, a lowering of water level in the bay, and continued low-velocity brine-discharge. Channels are deepened in the winter when northers lower water level along the mainland shore. Slope wash reduces terraces to gently sloping surfaces and increases the channel width.

Subsequent floods build up the channel floor by sediment accumulation as longitudinal and transverse bars and in the deeper parts of channels by ripple bed forms. Abandonment of a channel at various times causes mud deposition and local marsh development.

Reactivation of the channel was accompanied by extensive scour near the fan apex and development of more terraces. Complete channel fill was accomplished by several processes, such as hurricane-aftermath deposition, slope wash, and aeolian processes.

CREVASSE CHANNEL

Crevasse channels may or may not be common features associated with fan deltas. Only one channel was positively identified on Gum Hollow fan delta (Pl. III; grid points K/3, L/3, and M/4).

Fill near the cut through the left channel bank of the main channel distinguishes crevasse channel fill from main channel fill. Near the point where the left channel bank was breached the crevasse channel had a smooth arcuate bottom (fig. 16) and symmetrical fill. Concordance of fill with the shape of channel cross section suggests that much of the channel-fill sediment was carried in suspension; however, dip angle to these beds was not determined and this may be a scoop-shaped, downstream-dipping feature, possibly the last stage of channel fill. Trench 12 shows that initial fill was by bars that formed alternately adjacent to one bank and then the other during the initial flood. Some ripple bed forms developed contemporaneously with bars, and as flow subsided transportation was restricted to the lows (*see* fig. 29 for stratification types). Farther down the crevasse channel (trench 22) depth of scour decreased, and fill was mostly by accreting bars. At least two scour events are indicated in trench 22. Multiple shallow channels probably existed from this point to the area where discharge was no longer confined.

Figure 30,A, diagrammatically presents factors that determined whether the crevasse channel would be symmetrically or asymmetrically filled. Figure 30,A, also shows the position of traction and suspension load in the main channel during the last flood stage. At this time considerable sand-size material was in suspension and most of the suspension load was dropped between sections a and b. Depth of scour at section a was limited by underlying tough, marsh sediment.

Farther down the crevasse channel, and also downslope of the fan surface, depth of scour decreased and bed-load deposition was dominant; apparently the crevasse was not deep enough to confine the flow in the area of trench 22.

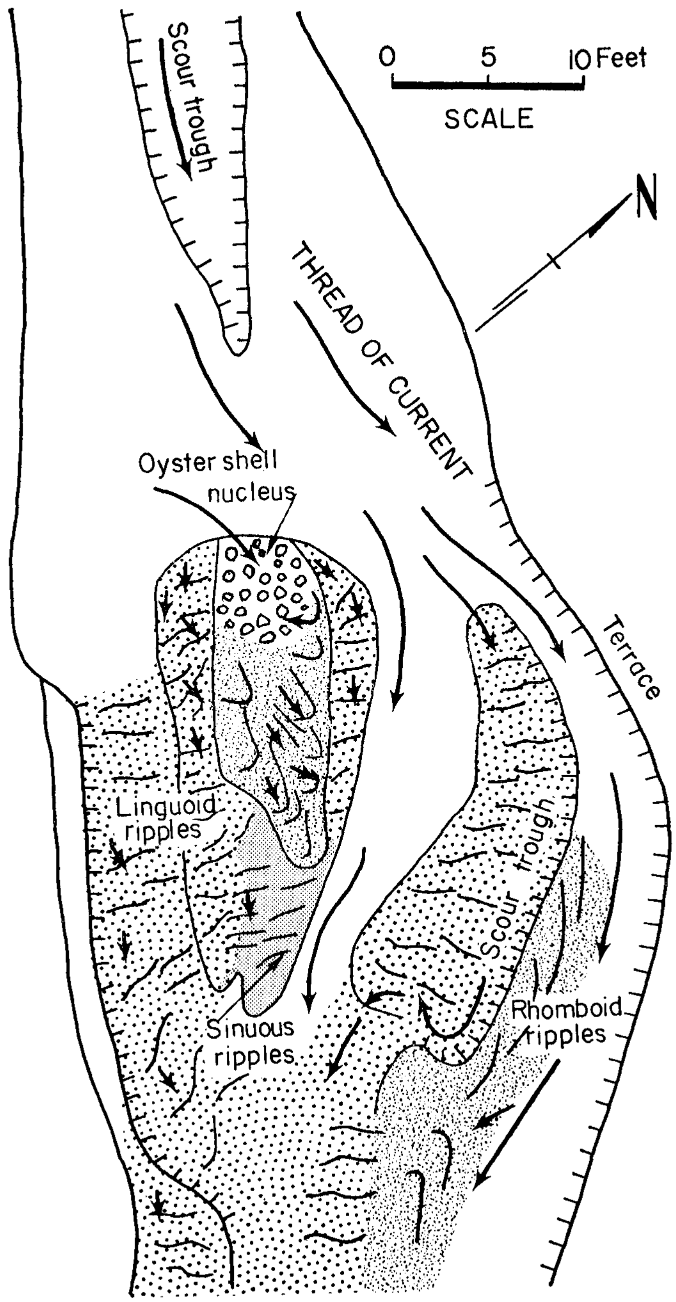


FIG. 27. Pace-and-brunton map of scour troughs and small longitudinal bar. This area lies between channel profiles B and C of the 1966 main channel. Scours and bar developed between January 7, 1967 and January 14, 1967.

FAN PLAIN

About 90 percent of Gum Hollow fan delta surface is fan plain sediment. Sediment characteristics of the fan plain, derived from both surface and subsurface data, are summarized in Plate VI. Texturally clean quartz sand is dominant with clay-pellet sand the second most common type. Mud is next in frequency of occurrence and is commonly present as lenses in scour features or succeeds small trough sets in the shallow, braided channels. Gravel-size material is an insignificant part of fan plain sediment and is mainly confined to oyster shell aprons near the fan apex. Locally within scour troughs gravel-size mud clasts are present. The dominant sediment color is yellowish brown, and various shades of gray are subordinate colors. Most mud and muddy sand are gray. The position of the sandy sediment with respect to the water table generally determines its color. Sand composed of clay pellets is always some shade of gray regardless of whether it is above or below the water table.

Organic components are rare in fan plain deposits. Plant roots are the most commonly occurring, indigenous, organic constituent. Oyster shell derived from Indian middens occurs locally. Filamentous algal mats are present everywhere when surface sediment is wet but occur most frequently along the lower (bayward) parts of the fan and in the residual braided channels. Algal filaments are recognizable in surface pure sand and mud laminae, though malts were not recognized in subsurface sand laminae. Algal-bound sand and mud laminae, for the most part, do not show the typical crinkly or wavy laminae reported for this type structure in carbonate rocks. Desiccation is apparent in most of the algal-bound, muddy sediment both on the surface and in the subsurface. Algal filaments were observed in some of the recently buried muds, but in presumably algal-bound mud covered by a foot or so of sediment, algal structures could not be identified. Other organic components are worm and *Uca* burrows and *Diplanthera wrightii* debris.

Stratification types of fan plain sediment are analogous to those reported in braided streams (Ore, 1963, 1964, 1965) and for certain types of alluvial fan deposits (Blissenbach, 1954; Bull, 1963). Prominent surface features on the Gum Hollow fan plain are longitudinal bars, shallow braided channels, and scour troughs (fig. 31). Immediately after a major depositional event most of the fan plain is covered with linguoid ripples.

Two depositional episodes (spring 1966 and summer 1968) produced similar surface features. An aerial photograph of the 1966 fan was taken about six months after the fan plain was constructed (Pl. II, A), and a photograph of the post-Candy fan (Pl. II, C) was taken a few days after the fan was constructed. These photos show the braided stream—longitudinal bar surface and the younger main channel system.

Data from surface and subsurface sediment indicate that small trough sets are the most frequently occurring stratification type. Small trough sets are not too important volumetrically; they are most commonly preserved along bar crests. Most small trough sets represent a general downfan migration of sand as linguoid ripple bed forms. These ripples developed contemporaneously with longitudinal bars in the slightly deeper flanking channels, or troughs, and are commonly a transitional bed form between parallel laminae and trough-fill cross-stratification that indicate deepening flow (U-4, unit 7). Some scour troughs are partially or completely filled with small trough sets (B3-T3, units 5, 9a, and 10a; E-l, unit 5b). Other areas occupied by this stratification type are crests of longitudinal bars (B3-T1, unit 2b, and B4-T1, unit 4c), downcurrent from transverse bars (L-B1-T1, unit 6; L-B2-T1, units 5b and 5d), and shallow, scour channels (E-l, unit 8).

Parallel laminae are the second most frequently occurring stratification type. This structural type comprises the bulk of longitudinal bars, and one unit comprised entirely of parallel laminae represents one depositional event. The older longitudinal bars are for the most part bounded by erosional surfaces. Like the bars in the main channels, those of the fan plain commonly show changes in accretion direction. During construction of longitudinal bars flow was unconfined, and probably depth of flow (except in the deeper scour channels) was about 6 inches near the fan apex to about 2 inches at the distal ends of the most seaward longitudinal bars. Estimations of depth of flow are based on relief of bars measured from bottoms of channels to tops of bars near the fan apex and relief at toes of the most seaward bars.

Stratification types found in scour troughs at upcurrent ends of longitudinal bars are the same as those found in the main channels. Trough-fill structures are shown in some detail for a single trough on the 1966 fan plain (U trench series). Troughs are filled by foreset cross-stratification, small trough sets, and lenticular mud units that are commonly desiccated. Sand was supplied to scour troughs by migrating ripples moving down shallow, braided channels, or by laterally accreting longitudinal bars. The postulated trough-fill process is the same as for similar features of the main-channel fill. As this type scour feature decreases in depth downfan, fill by small trough sets increases (U3, unit 11; B3-T3, units 9a, 9b, and 10a). The U series trough was incompletely filled at the time of observation. The scour trough represented by units 9a, 9b, and 10a, trench B3-T3, shows at least two depositional events.

Trough-fill cross-stratification developed as described above, as transverse bars that succeeded longitudinal bars (developed in the same manner as described for main channels), as overbank material related to the 1966 main channel, and along flanks or distal ends of laterally accreting longitudinal bars.

Transverse bars appear to have developed downcurrent from both lower- (L-B1-T, unit 3e) and upper-flow régime bed forms (B3-T1, unit 4; B3-T2, unit 5; and B3-T3, unit 7b). Each of these had a residual low created by a previously developed longitudinal bar. Foreset cross-strata

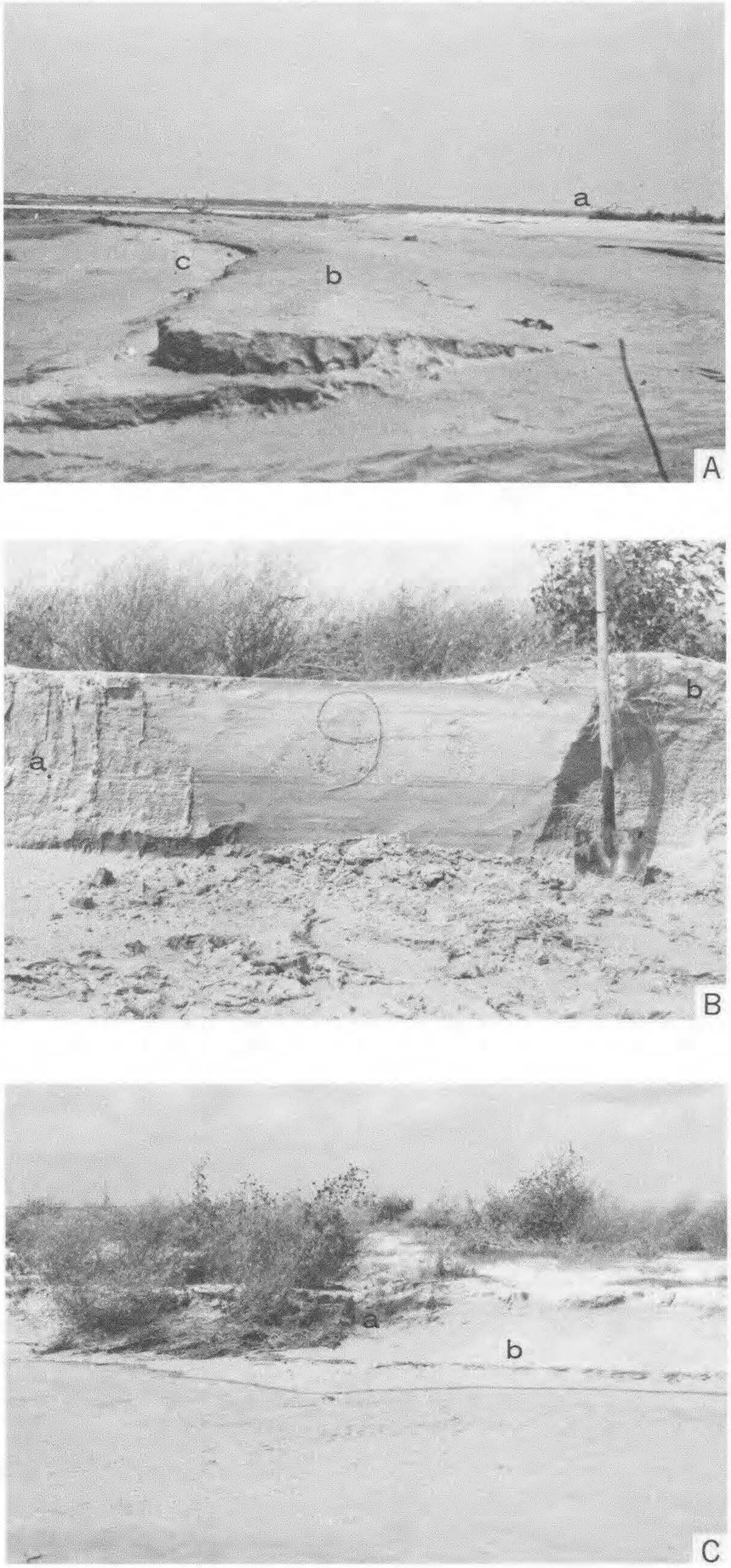


FIGURE 28.

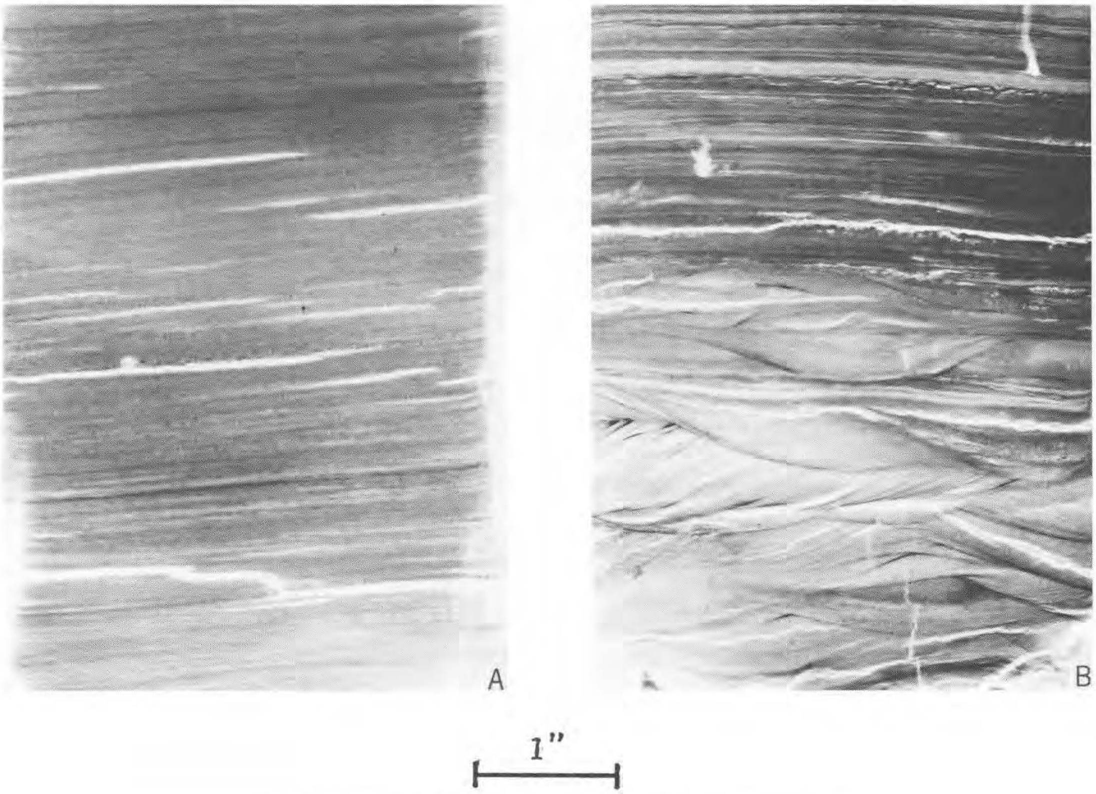


FIG. 29. Radiographs of crevasse-channel sediment (trench 12).

A. Parallel laminae of longitudinal bars in lower crevasse-channel fill comprised of well-sorted, fine quartz sand and moderately sorted, medium clay-pellet sand.

B. Three depositional units are shown in this radiograph: (1) a lower small trough set unit with a thin mud drape at the top; (2) a middle small trough set unit; and (3) an upper parallel laminated, well-sorted, very fine sand and sandy mud/or mud. Small trough sets are characteristic of the filled, residual lows that are adjacent to the right bank. Parallel laminae (the last depositional event) are the product of slope wash.

related to overbank deposition from the 1966 channel have been recognized only adjacent to the left channel bank (L-B1-T1, unit 6, and L-B2-T1, unit 5a); this is in fact a transverse bar. Foreset cross-strata along flanks of accreting longitudinal bars, or at distal ends of these bars, may be more common than indicated by this report.

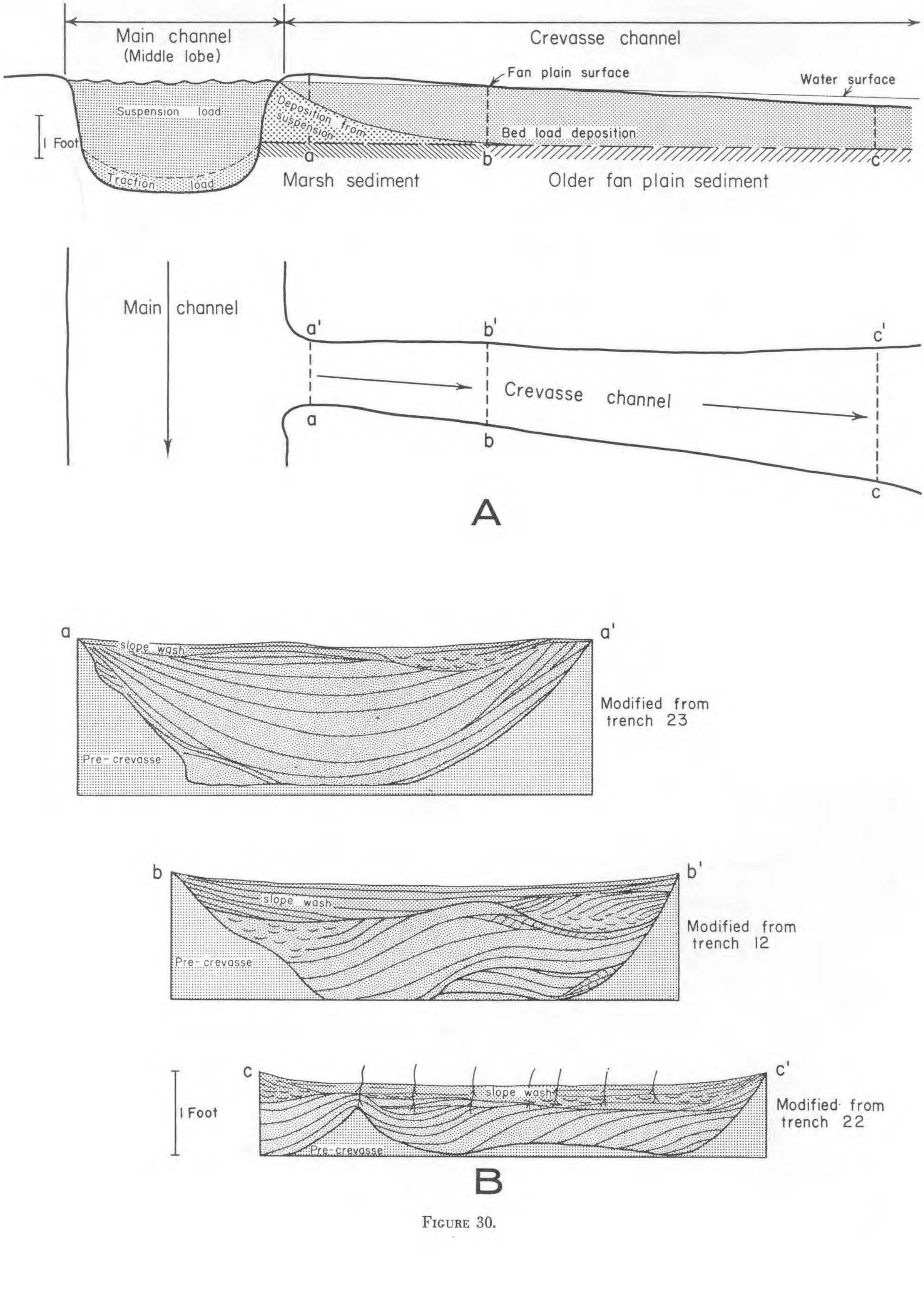
There appears to be a close relationship between climbing ripples and sediment type. Climbing ripple laminae always have high, sand-size clay-pellet content. It is postulated that sand-size clay pellets are hydraulically light and move relatively farther above the bed, whereas quartz sand moves close to the bed as a thin traction load. Ripples of this type formed in various scour troughs and channels (U3, unit 12; DP 3, units 4 and 6; and DP 5, unit 7) and pre-

FIG. 28. Terraces and slope wash associated with main channels of the active lobe.

A. Terraces and main channel (view east). This is the main channel that developed after deposition of the Beulah fan. Two terrace levels (a and b) are shown along the right channel bank. Slope wash (c) modified the lower terrace (b).

B. Vertical escarpment cut into Beulah fan sediment (view southwest). Height of escarpment (a) is about 2.5 feet. Stratification types shown here are a lower parallel laminated unit, a middle foreset cross-stratification unit, and an upper parallel laminated unit that is succeeded by small trough sets and a thin mud drape (flow direction was toward the left of the photo). A small aeolian mound (b) is shown at upper right of the photo.

C. The same escarpment as shown in "B" (view southwest), but farther downfan. A gully (a) and slope wash deposit (b) are shown in this photograph. Two plant debris lines mark former, high, water-level positions.



Main channel
(Middle lobe)
Crevasse channel
Fan plain surface
Water surface
Suspension load
Deposition from suspension
Bed load deposition
1 Foot
Traction load
a
b
c
Marsh sediment
Older fan plain sediment
Main channel
a'
b'
c'
Crevasse channel
a
b
c
A
a
a'
slope wash
Modified from trench 23
Pre-crevasse
b
b'
slope wash
Modified from trench 12
Pre-crevasse
c
c'
1 Foot
slope wash
Modified from trench 22
Pre-crevasse
B

FIGURE 30.

sumably represent rising water level conditions with considerable deposition from suspension (*see* McKee, 1965; Walker, 1963).

Thin mud drape units were generally deposited in ponded areas of the older fan or across both bars and channels of the 1966 depositional surface. These thin mud beds display some degree of desiccation.

DISTAL FAN

The distal fan area lies between normal sea level and the area represented by the most seaward development of longitudinal bars. There is no sharp structural or textural demarcation between distal fan and fan plain, and the main criterion for making the distinction between them, on the surface, is the extent to which the distal part of the subaerial fan is inundated by wind tides.

Sediment characteristics of distal fan facies are summarized on Plate VI. Mud and clean sand are the dominant textural types and have about the same frequency of occurrence. Muddy sand is the next most common sediment type. A relatively high silt content is characteristic of distal fan sediment. Increase in clay and silt content in this zone resulted from a downfan decrease in physical energy related to fluvial processes and by addition of fine-grained sediment from Nueces Bay.

Dominant stratification types are parallel laminated sand and thin mud layers, and the next most common type is homogeneous sand. Homogeneous sand units commonly contain gas-filled voids; the formation of the voids probably destroyed any primary sedimentary structures. Desiccation cracks are particularly well developed in the low areas between the various lobes of the fan. Windblown or wind-tide-transported sand fills some of the cracks. Early cementation of sand by hydrated iron oxide within the cracks is a characteristic feature of distal fan sediment and is well displayed in areas of the inactive fan. Several types of small trough sets are present in distal fan sediment. The most frequently occurring is interpreted as a single set laid down by bayward-migrating linguoid or cuspate ripples. Small trough cosets produced by climbing ripples are present in those areas near the interpreted axis of flow (trench Fl, unit 3), and, like climbing ripples in other areas of the fan, are composed, for the most part, of sand-size clay or mud pellets. Other ripples are developed by wind tides. Their form is quite variable; a sequence from seaward to landward is lunate, straight to sinusoidal crested, or, where water depth was generally less than 1 inch, sand ribbons.

Organic components include filamentous algae, plant debris, and worm burrows; these are indigenous features. Algal mats are the most obvious organic constituent. Other components are transported and include pulmonate gastropod shells, tree limbs, and *Diplanthera wrightii* debris.

DESTRUCTIONAL PHASE BARS

Bars deposited at the seaward edge of the inactive fan by wind tides are temporary features. They form during a short period of time, generally in the late spring and early summer. Sediment is dominantly a yellowish-brown, clean, moderately well-sorted, fine, quartz sand. Contained within the bar are sand-size clay pellets and mud clasts in the pebble-size range. Mud layers develop in ponds formed on the landward side of bars (fig. 32); successively younger bars migrate inland over algal-bound muds.

The dominant stratification types in bars are small trough sets (these generally dip toward the mainland) and parallel laminae. Parallel laminae form on the seaward sides of bars during the lowering of water level in the bay; structures here are analogous to foreshore on beaches. Parallel laminae also develop along bar crests when water level lowers or when vertical accretion of the bar decreases the water depth. As water depth lowers, ripple bed forms are truncated and plane bed forms are produced.

Sediment exposed in trench DPB is characteristic of bars that developed between mid-April and early May 1967. Units 5 through 8 represent the bar sequence, and unit 4 is characteristic of interlaminated algal-bound muds and windblown sand that accumulated on the landward side of an older bar. Bed forms present during and shortly after deposition of this sand body were linguoid, cuspate, and sinusoidal crested ripples. Water depth across the bar crest at the time of maximum inundation was on the order of 2 inches. A shaved horizontal surface indicates that bed forms present at the time unit 5 was deposited were straight to sinusoidal crested ripples, and that units 6 and 7 are the products of either linguoid or cuspate ripple bed forms (fig. 33).

FIG. 30. Diagrammatic section of crevasse channel.

A. Cross section and plan view (diagrammatic) of a main channel and crevasse channel. Water depth and vertical sediment distribution are inferred.

B. Crevasse channel fill (generalized from trenches 23, 12, and 22). The dominant stratification type in trench 23 deposits is trough-fill cross-stratification that conforms to the channel configuration. Stratification of trench 12 is dominantly parallel laminae; residual troughs (lows) adjacent to right and left banks were filled with small trough sets. Stratification of trench 22 is dominantly parallel laminae and trough-fill cross strata. Slope wash (top of each trench section) is characterized by parallel laminae that dip generally toward the center of the channel. Channel-fill sediment is predominantly well-sorted, fine quartz sand and poorly sorted, medium to coarse clay-pellet sand. Clay pebbles and cobbles were present in the basal parts of trenches 12 and 22 but not in trench 23.

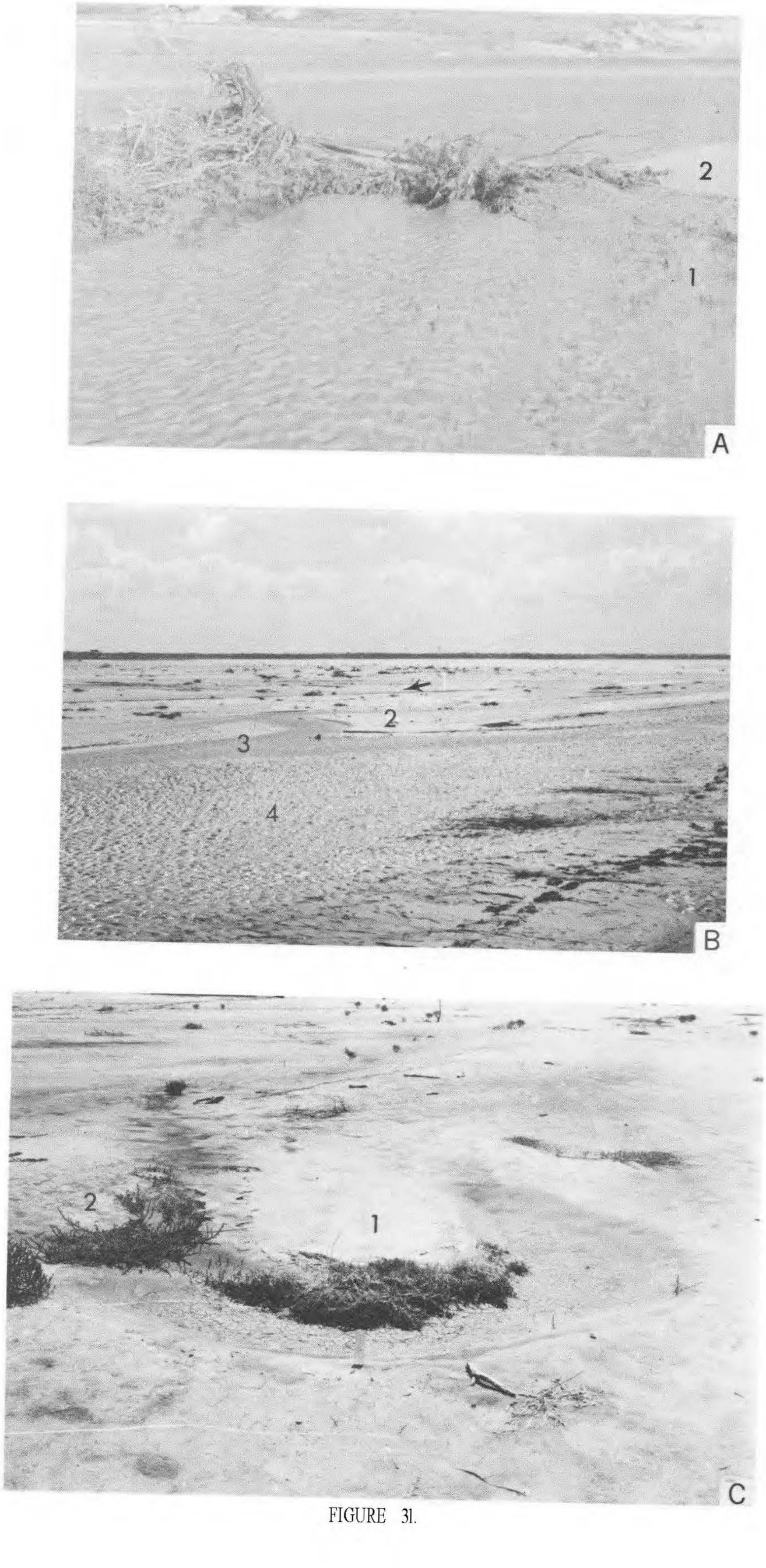


FIGURE 31.

FIG. 32. Destructional phase bar and associated pond. This bar was in the area of trench 8 (east of grid point J/8). View is southwest. Water depth in the pond was about 2 inches. Southeast wind distributes a thin sand sheet across algal-bound mud (*see* trench section DPB).

Foreset cross-strata were observed in trenches through the older middle lobe bars. These were present on the landward sides of bars and had been partially destroyed by wind and sheet wash.

Bars are continually being destroyed and new ones constructed along the seaward edge of inactive fans, and under these conditions preservation of such features in subsurface sediment would not be expected. Some depositional units overlain by the 1966 fan were interpreted as destructional phase bars. The area encompassed by this bar is defined by trenches B4-1, B3-3, B3-4, and U series trenches. Toward the north (trenches B3-3 and B4-1) the bar overlies *Spartina alterniflora* marsh, and in the area of trench B3-T4 it overlies a medium to dark gray, desiccated mud interpreted as distal fan sediment. In the area of the U trench series, bar sediment overlies distal fan muds and is in turn overlain by distal fan mud or low-marsh muddy sand. Finally, the entire mass was buried beneath the 1966 fan sediment.

Because of the instability of destructional phase bars biologic activity is restricted. High-marsh vegetation (*Salicornia bigelovii* and *Batis maritima*) is sparsely distributed along the bars. *S. bigelovii* is present on all parts of the bar; it is first established along margins of ponds behind the bars and its presence on other areas of the bar results from inland migration of destructional phase bars. *B. maritima* (saltwort) was more prolific on the seaward side of bars until the spring of 1967. Commonly associated with saltwort are fiddler crab burrows. Filamentous algae are present across the entire bar surface, but their preferred habitat is the low-lying muddy area just landward of the bar. Other organic components were transported from the bay. These include shells of the pelecypods *Mulinia lateralis* and *Cyrtopleura costata,* pulmonate gastropod shells, and the marine grass *Diplanlhera wrightii.*

AEOLIAN MOUNDS

Wind was not an effective agent of sediment dispersal on the 1966 fan because of saturated condition of the sediment.

FIG. 31. Depositional features of the fan plain.

A. Longitudinal bar with brush-pile nucleus. Pre-fan *Distichlis* marsh (1) is shown at the right of the photograph. Scour channel (2) is shown upcurrent from the brush pile.

B. Shallow, braided stream (3) and longitudinal bar (2); stream (at time photograph was taken) is shown cutting transversely across the bar. Fan surface in the foreground (4) is covered by linguoid ripples, and in the background several brush piles can be seen. The main channel (1) lies to the east of the residual braided stream (3) and associated longitudinal bars (view east).

C. Crescent-shaped scour; view southeast, main channel about 200 feet to east (trench DP2 in background). Trough is almost completely filled, and longitudinal bar downcurrent from the scour has been almost obliterated by rain wash. Bermuda grass is the plant (1) at the upcurrent end of the bar and *Suaeda* (2) is the plant to the left of the scour trough.

A and B are photos of fan sediment and associated features taken in June 1968 (about two weeks after Hurricane Candy triggered an 8-inch rain in the Taft area). C is a photo of a scour trough and longitudinal bar developed in the spring of 1966. The photograph was taken about a year later.

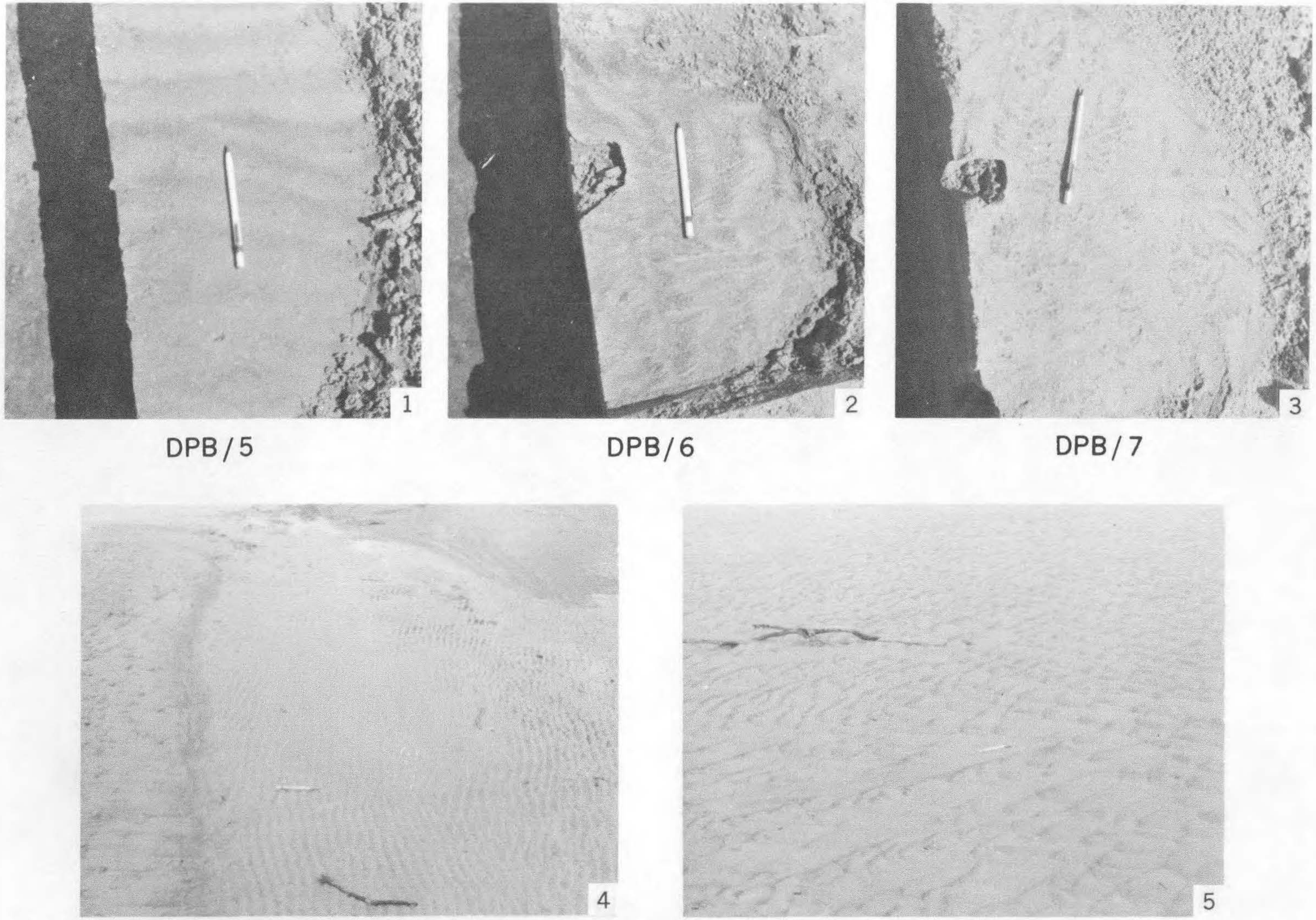


FIG. 33. Stratification types of trench DPB and ripple forms present during development of destructional phase bars.

1. Shaved surface of climbing ripples (unit 5) trench DPB. The pencil points the transport direction. In plan, ripples are straight to sinusoidal crested. Dark bands that outline ripple trend are comprised of clay pellet sand.

2. Photographs 2 and 3 are of climbing ripples (units 6 and 7) trench DPB. These ripples were either cuspate or linguoid at the time of deposition (there is also the possibility that a slightly oblique cut could have yielded these patterns). The pencil points in the direction of sediment transport.

4. Straight to sinusoidal-crested, asymmetrical ripples with the steep face to the right (Nueces Bay to the left of the photograph). Shell debris and clay pellets are present in some troughs. Crest of destructional bar (clay pebbles are near the crest) is at the left of the photograph, and a pond on the landward side of the bar is at top right of the photograph. This ripple type is represented by DPB/5.

5. Altered linguoid or cuspate ripples (as water depth decreased ripple crests were planed off). Nueces Bay is to the left of the photo. These ripples formed at or near the bar crest. DPB/6 and 7 are stratification types formed by this type of ripple.

After deposition of about 2 to 3 feet of sand by Hurricane Beulah, aeolian processes began to play an important role in sediment dispersal. Vertical accretion of 2 to 3 feet raised the fan surface sufficiently above sea level to permit thorough drying of sand.

Almost any kind of obstruction is adequate to initiate sand accumulation. The most common wind shadows are patches of bermuda and Johnson grass. Incipient mounds are ovate in plan, with the broad end in the downwind direction. These small mounds begin to coalesce and form continuous sheets toward the fan apex.

Characteristically aeolian sediment on the older fan segments is a pale yellowish-brown, clean sand. Clay-pellet sand and clayey sand are about equally common. Clay-pellet sand is, for the most part, derived from thoroughly desiccated surficial mud layers of the fan plain and distal fan. Clayey sand results from periodic inundation of mounds by wind tides. Mud or clay derived from the bay is mixed with clean sand by biologic activity.

The dominant sedimentary structures in this facies are thin, wavy beds produced by vegetation and convoluted beds resulting from cow tracks. Some sediment has been homogenized by plant roots. In the more recently deposited, less intensely bioturbated mounds, parallel laminae that conform to the mound surface are preserved. Small trough sets are relatively insignificant stratification types in the mounds. Most of the stratification produced by ripples is attributed to straight or sinusoidal crested ripples formed by wind tides, particularly in the mounds nearest the bay.

Vegetation on the older middle and western lobes is characteristic of high marshes, and on the higher parts of the middle lobe Johnson grass, clover, and other upland plants are present. *Uca* and insect burrows are common.

MARSH

Predelta marsh sediment was encountered in trenches near the fan apex, and commonly this sediment type was just above or below the water table. In trenches cut into the older fan segments, particularly those adjacent to the middle channel, marsh sediment was a medium to dark gray, tough, homogeneous mud to muddy, very fine sand. Texturally muddy sand is dominant and mud is the next most frequently occurring type. Clean sand is also an important textural type particularly on the seaward side of low marshes. Pebble-bearing muddy sand is present but does not comprise a significant part of marsh deposits. Pebbles are formed along distal fan segments (e.g., between the middle and western lobes) and are incorporated into marsh sediment by landward transport into high marshes or transported short distances laterally into low marsh areas.

For the most part, low marsh sediment is coarser grained (mostly sand) than high marsh sediment, and primary sedimentary structures are commonly preserved in this facies. Primary sedimentary structures in low marshes are very thin beds comprised of alternating laminae of mud and muddy sand; wave-rippled muddy to clean fine sand; undulatory laminae of clayey silt to muddy very fine sand; and laminae of mud and plant debris. Low marsh sediment is shot through with roots of *Spartina alterniflora* (fig. 34).

FIG. 34. Radiograph of low marsh sediment. Sample taken from *Spartina alterniflora* marsh lying along the distal fan in the low between the middle and eastern lobes.

1. Homogenized, muddy, very fine sand adjacent to plant roots. Upper left of photo is wave rippled very fine clay pellet sand and quartz silt.
2. Wave rippled, muddy, very fine clay pellet and quartz sand. This unit is extensively root mottled.
3. This unit is composed of a lower parallel laminated mud and very fine sand (a layer of finely comminuted plant debris overlies this unit; a broad white band on the radiograph represents the desiccated plant debris layer); a middle parallel to wavy laminated clayey silt to muddy, very fine sand; and an upper unit composed of alternating clay and silt. This entire unit is shot through with small roots.
4. Poorly defined wave ripples and parallel laminae that converge or wedge out are the stratification types in this unit. Wave ripples consist of slightly granular, muddy to moderately sorted, fine clay pellet and quartz sand. Parallel laminated units consist of alternating laminae of well-sorted, very fine quartz sand and moderately sorted, fine clay pellet and quartz sand. Unit is shot through with *Spartina alterniflora* roots and unidentified small roots and worm burrows.
5. Parallel laminae of well sorted, fine quartz sand and mud and clayey silt. Also present are *Spartina alterniflora* roots and unidentified small roots and worm burrows.

Oyster shell, caliche, and calcareous mud pebble to cobble gravel commonly overlie the predelta marsh. After deposition of the oyster shell apron, marsh was not established again in the area. Near distal ends of the older fan, marsh was developed again in areas where it had been overrun by fan sediment. Density of trenching was not sufficient to establish sequences of marsh destruction and rejuvenation for the entire Gum Hollow fan delta area, but Plates VII and VIII show the marsh-bay-distal fan relationship in the area of the 1966 fan.

ASSOCIATED FACIES

Sedimentary processes and sediment characteristics of the bay did not receive the amount of study given to the subaerial fan. Elliott (1958) studied grain-size distribution and mineralogy of surface sediment in Nueces Bay; his work was not duplicated by this study. Data on bay sediment were derived from cores taken along the 1966 main channel, to the east of the main channel, and along the distal parts of the inactive lobes. Bay and prodelta deposits can generally be distinguished by the intensity of bioturbation and by the degree of preservation of primary sedimentary structures related to unidirectional, fluvial-induced currents. Intensely reworked bay sediment reflects the relatively slow rate of sediment accumulation prior to fan development. Prodelta sediments have retained most of their primary sedimentary characteristics because of relatively rapid sediment accumulation. Some prodelta sediment was reworked by burrowing animals, and in some cores distinction between this and bay sediment is difficult.

PRODELTA FACIES

Sediment deposited in Nueces Bay, under the influence of fluvial processes, is termed prodelta. Prodelta sediment has retained most of the characteristics it had immediately after deposition, although the upper 2 or 3 inches has been reworked by physical marine processes. The reworked sediment has some of the properties (such as bioturbation) characteristic of bay sediment. Sediment characteristics of prodelta facies are summarized on Plate VI, and the relationships among the various facies are shown on Plates VII and VIII. For the most part the contact between bay and prodelta sediment is sharp but nonerosional.

Sediment transport beyond the channel mouth of Gum Hollow was determined to a large degree by the size and duration of a particular flood and time of year that flow in Gum Hollow drainage occurred. Sediment dispersal beyond the channel mouth was mostly by migrating ripples (lower-flow **régime**), and near the channel mouth climbing ripples (with a high clay-pellet content) commonly developed. Migration direction of ripples of the 1966 fan was generally to the south.

Some floods were sufficient to produce upper-flow conditions well out into the bay, as far east as the GHK core series (Pls. IV and VIII, A). Parallel laminated units are generally succeeded by small trough sets, and if the ripple bed form received considerable clay-pellet material from suspension climbing ripples developed. Lithologic and structural types that preceded deposition of parallel laminae vary from thin, homogeneous, mud beds to current or wave-ripple bed forms in sand or silt. The contact between parallel laminae and the underlying unit is for the most part sharply defined and may be either erosional or nonerosional. Near the interpreted distal end of a fan scour-and-fill features commonly preceded deposition of the plane bed forms. Erosional surfaces are locally overlain by thin foreset cross-stratification units that are gradational into overlying parallel laminae.

The mechanism for producing upper-flow régime bed forms in prodelta deposits is postulated to be crevassing off the middle lobe main channel. Simple overbank flow from the main channel would be unconfined from the point where flow diverged from the main channel, and flow would dissipate within a relatively short distance away from the main channel. Overbank flow would not disperse sand-size sediment as far east as the GHK core series. If the flow were confined for a considerable distance away from the main channel, as in a crevasse channel, much of the energy would be dissipated within the bay where upper-flow régime bed forms could result from a crevasse splay.

Mud content of prodelta sediment increases toward the distal fan. Mud occurs as laminae less than one-tenth of an inch thick that alternate with reworked silt or sand layers and as homogeneous mud layers 3 to 4 inches thick. Most of the mud is either medium or dark gray and contains finely comminuted plant debris that in some instances served as reduction centers for the formation of hydrotroilite. Commonly, the thicker mud units show some evidence of dessication. The increased thickening in mud units toward the subaerial fan, and the association of discontinuous sand or silt ripples with the mud, suggests that much, if not most, of the mud was reworked from offshore and transported toward the fan by wind tides.

Considerable reworking of prodelta and distal fan sediment is presently taking place offshore from the inactive fan segments. Bed forms in these areas are predominantly wave and current ripples. Can samples taken just seaward of the distal end of the middle lobe, in water depths of 1 to 2 inches, show predominantly parallel laminae (fig. 35). The sediment is fine sand, well-sorted, near-symmetrical mesokurtic. Processes operative in this zone include: (1) movement of sand as a traction carpet as. inundation begins, (2) development of wave and current ripples as water depth increases, and (3) movement of sand as a traction carpet with planing of ripples as water depth decreases. These are somewhat different from the swash and backwash processes operative on beaches. The process and sediment characteristics of reworked deposits in the intertidal zone of the inactive middle lobe are thought to be analogous to reworked sand bodies within prodelta sediment shown on Plates VII and VIII.

BAY FACIES

Processes operating in the bay were observed from the shoreline to about 400 feet perpendicular to the distal part of the fan, in water depths from an inch or so to about 1½ feet. These observations were made when the wind was strong from the southeast quadrant. Offshore, sand migrated as ripples generally toward the fan delta, and nearshore the configuration of the fan determined transport direction. Off the 1966 lobe the rippled sand bottom was bare, but between 100 and 200 feet offshore from the inactive lobes *Diplanthera wrightii* was sparsely distributed. Near the distal end of the inactive fan segments *Cyrtopleura costata* were locally abundant, particularly in the area just south of grid point I/9 northward to about grid point H/7 and the area lying between the vegetated bars west of the western lobe and the distal fan. *Cyrtopleura* were not observed in any of the bay sediment cores.

Sediment characteristics of bay deposits are summarized on Plate VI; bay, marsh, and prodelta facies relationships are shown on Plates VII and VIII. There is no sharp demarcation between bay and low marsh deposits; boundary between these facies was placed at the first occurrence of *Spartina alterniflora* roots or root traces. A sharp change in lithology and sedimentary structures characterizes the boundary between bay and prodelta sediment.

Bay sediment is characteristically gray, a feature that sets it apart from the subaerial fan and prodelta deposits that are dominantly yellowish brown. Sand is the dominant textural type and ranges from clean to muddy, very fine to fine sand. Mud and sand mixing is the result of bioturbation by mud shrimp, worms, and to a lesser degree by marine grasses. Recognizable primary sedimentary structures are wave ripples and parallel but undulatory laminae. In lower parts of the cores examined, wave ripples were poorly preserved and only mud lenses preserved in ripple troughs served as a criterion for their identification. Near the contact between bay and prodelta deposits both crests and troughs of wave ripples were preserved. Undulatory laminae appear to be associated with parts of the bay that were inhabited by *Diplanthera wrightii*, wavy laminae commonly contain remains of this plant.

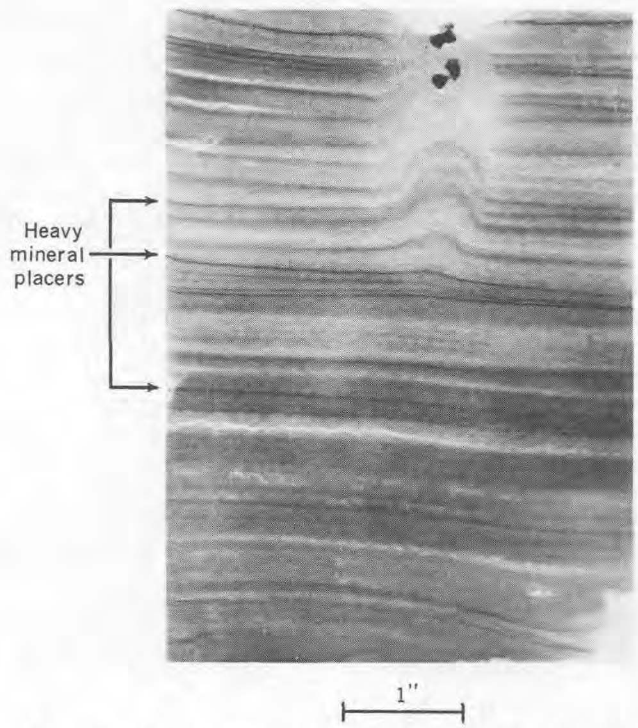


FIG. 35. Radiograph of reworked distal fan sediment. Wave approach from the left.

Stratification in this sample is of parallel laminae comprised of well-sorted, fine quartz sand, clay pellet sand, and heavy minerals. Distortion of laminae in upper part of the sample resulted from water draining out of the can. Small trough sets are not present in this sample; the bed form in the area from which the sample was taken was plane bed. The sample was taken about 50 feet bayward of the destructional phase bar of the inactive middle lobe. Depth of water at the time the sample was taken was about 2 inches.

GUM HOLLOW DELTA AS A PRODUCT OF LAND USE PRACTICES

GENERAL LAND USE

The dominant land use in San Patricio County is agricultural; approximately 86 percent of the area is under cultivation, about 6 percent is urban land, and only 9 percent is native range land and tidal flat land. Because of the dominant land use and the relatively flat topography of the county a network of artificial channels is required to facilitate drainage.

One of these man-made drainage systems, Drainage District No. 2, served as the sediment-water feeder system for Gum Hollow fan delta. This delta stands as a sedimentary monument to some 30 years of uncontrolled erosion in this drainage system. Drainage District No. 2, with 18 square miles in area, is one of the two largest subwatersheds in San Patricio County. It is continually expanded in size by northward extension of the main channel and by cutting of new lateral ditches to the east and west of the main channel. Expansion of the drainage system is necessary for more rapid and efficient drainage of farm land. This expansion increases sediment and water discharge into Nueces Bay and causes progradation of the delta.

ARTIFICIAL CHANNELS: EROSION AND DEPOSITION

Gum Hollow delta owes its existence to the acceleration of fundamental geomorphic processes by man. Construction of a network of artificial channels to drain the flat farm land in the Portland-Taft area was initiated in the early 1930s. Prior to development of the drainage channels the natural system of Gum Hollow was small (about 1.5 square miles), densely covered with vegetation, and, therefore, contributed only a small volume of sediment to Nueces Bay. There was no delta at this time. A relatively large sediment volume was made available for transport to the bay by enlarging the drainage system and increasing the area of cultivation. After completion of the artificial drainage system a fan delta began to form at the mouth of Gum Hollow. Sedimentation rates are extremely high on Gum Hollow delta; as much as 270,000 cubic yards of sand were deposited in two days.

Since the completion of Drainage District No. 2 in the late 1930s, oil field brine and other contaminants have been discharged into Nueces Bay through the drainage system. Because of this contamination the commercial oyster *Crassostrea virginica* in Nueces Bay is no longer edible. In addition to contributing to the change in water chemistry of Nueces Bay, oil field brine has accelerated both vertical and lateral erosion of the drainage channels. In early 1969 as many as 21 wells were discharging brine through Drainage District No. 2. At present (November 1969) three wells are still discharging brine through the system. The result of salt water input into the upper reaches of the system is the complete sterilization of the main channel. As long as brine is discharged through the system erosion will be uncontrollable. There is no vegetation to retard erosion, therefore the channel continually becomes deeper and wider, and this creates vertical, unstable banks. Lateral channels that drain into the main system do not have salt water discharged into them. These channels have banks that are stabilized by a dense vegetation cover.

RECOMMENDED MEASURES FOR EROSION CONTROL

An engineering firm (Lockwood, Andrews & Newman, Inc.) has recently completed a watershed survey for San Patricio County Commissioners Court. Drainage District No. 2 (Gum Hollow) was part of their survey. Some of the specific problems that they believed should be dealt with in the immediate future are erosion control in drainage ditches and enlargement of channels to accommodate the run-off. Existing channels are adequate to handle only run-off up to the two-year storm period (a little over 4 inches in 24 hours). They also recommended regrading the channels so that channel gradients are decreased in areas of erosion and increased where sedimentation is excessive. Another measure recommended by this firm is the construction of earthen dams along the channels to damp the flow temporarily and lessen discharge.

Two additional factors should be considered in the design of stable drainage channels in the Gum Hollow area. The first is tropical storm frequency along the Texas Gulf Coast (0.67 storms per year, Hayes, 1965). Storms such as Hurricane Carla (1961) and Hurricane Beulah (1967) triggered exceptionally heavy rainfall. Beulah was accompanied by up to 20 inches of rainfall in the Portland-Taft area. It is doubtful that earthen dams across drainage channels would survive exceptionally high discharge of the hurricane aftermath. These dams could serve to accelerate erosion by temporarily ponding flood waters, and with dam failure a large volume of water would be available for erosion. This is what happened in England during the Exmoor storm of 1952 (Kidson, 1953). Secondly, a thorough knowledge of the geology of the area would help alleviate future erosion problems. Drainage channels of Drainage District No. 2 are cut into Pleistocene deposits collectively known as the Beaumont Formation. Pleistocene deposits in the Corpus Christi-Sinton-Taft-Portland area were laid down as a delta system by the ancestral Atascosa-Nueces Rivers. Much of the sediment in this area is mud and silt that accumulated in interdistributary bays and on the delta plain; channels cut into this material should be relatively stable. However, there are elongate sand bodies that transect the mud areas. This sand represents sediment accumulation in distributary channels of the delta. Drainage channels out into this material will be relatively unstable and could require revetting. A geological map of the area delineating sand and mud units is essential for the planning of a stable drainage system.

SUMMARY

Gum Hollow fan delta is a unique depositional feature along the mainland shore of Nueces Bay. Previous geological events created the proper conditions, a shallow body of water adjacent to the erosional escarpment, for fan delta construction.

Because of the small drainage area, local heavy rainfall and hurricanes control the sporadic growth of the fan. Periods of progradation or aggradation coincide almost exactly with rainfall periods. Water level in Nueces Bay at the time of sediment influx determines the extent the fan will increase areally, or whether it simply aggrades.

Rainfall maxima in May and September coincide with times of dominant southeast winds. The September rainfall maximum is greater than the spring maximum; the season of tropical cyclones (August-October) accounts for the greater September maximum. Water level in the bay is essentially the same (normal) in May and September, and sediment influx at this time progrades the fan. Hurricanes or tropical storms that strike the Texas coast in the vicinity of Corpus Christi cause a rise in water level in Nueces Bay sufficient to inundate the fan. Sediment influx associated with the hurricane aftermath aggrades the fan. Northers lower water level along the north shore of Nueces Bay, temporarily lowering base level, and deposition under these conditions progrades the fan in a narrow zone in front of the channel mouth.

The mechanics of development of the Gum Hollow fan are somewhat analogous to the development of alluvial fans in arid regions, and the sedimentary processes are related to braided streams and sheetfloods. During floods under normal sea level conditions the braided stream is the dominant depositional agent across the entire fan surface. In the winter months, particularly when water level is lowered by northers, the braided stream process is confined to a main channel system, and the main channel is extended several hundred feet into the bay, beyond the channel mouth position during normal sea level conditions. Sheetflood is the agent of deposition when the fan is completely inundated.

Fan deposits laid down by the constructional processes described above are subsequently modified by beach, sheet wash, and aeolian processes. Beach processes erode distal parts of the fan, creating an erosional escarpment; sand bars develop atop the escarpment. Segments of the inactive fan that face the dominant southeast winds are eroded at a rate of about 50 feet per year. Aeolian processes are effective in redistributing sand only where this material is sufficiently elevated above the water table to allow thorough drainage. Windblown sand, under the influence of southeast wind, is drifted toward the higher parts of the fan where it accumulates behind some type of wind shadow. The fan is further modified by sheet wash that serves mostly to rework surface sediment, to widen active and abandoned channels, and to fill abandoned channels.

Mechanics of fan development and sedimentary processes arc reflected in the fan shape and sediment characteristics. In plan the Gum Hollow fan is trilobate. Each lobe is an area of localized deposition that can be thought of as an individual fan. There is either an active or abandoned channel along the axis of each lobe, and these channels are the most obvious surficial features of the fan. The fan surface has been divided into three depositional areas, main channels, fan plain, and distal fan (Pl. III).

The fan plain is the product of sheetflood and braided stream processes. It and the distal fan formed concurrently and prior to development of a main channel system. No surficial feature serves to sharply differentiate fan plain and distal fan depositional areas. These two areas are more or less arbitrarily separated by the inland extent of wind tide inundation and by the most bayward extent of longitudinal bars. Main channels are erosional features that are not the major dispersal systems for sediment that accumulates on the fan plain and distal fan; they develop after the fan plain and distal fan, during waning flood stages. Succeeding floods fill these channels with sediment that is partly removed as discharge (water depth) decreases.

Surficial features of the fan plain are longitudinal bars, crescent-shaped scours at proximal ends of bars, and shallow braided channels. Even though most of the Gum Hollow fan sediment falls in the fine-sand range, stratification types in fan plain sediment are similar to those reported for braided streams carrying a coarse-sand bed load. Longitudinal bars are characterized by a dominance of parallel laminae that, in some instances, grade laterally or downfan into foreset cross-stratification. Scour troughs are both symmetrically and asymmetrically filled. They are filled by laterally accreting longitudinal bars when upper-flow régime conditions prevail, by foreset cross-strata and small trough sets when lower-flow régime conditions prevail, and by mud drape as flow stagnates. Stratification types of shallow braided channels are small trough sets, or parallel laminae. Fine sand is the dominant textural type, with local lenses of gravel near the fan apex. Gravel consists of shell debris, caliche and calcareous mudstone fragments, and locally derived mud clasts.

Sedimentary structures of the distal fan result from the interplay of wind tide and fluvial processes. Stratification types are similar to those present in beaches, tidal flats, and braided streams. There is little depositional relief on the distal fan with the exception of local occurrences of destructional phase bars. In addition to these bars the distal fan surface is characterized by filamentous algal mats, desiccation cracks, and drag marks; the last are common to both fan plain and distal fan areas. Grain size decreases from the fan apex toward the distal fan; gravel is generally limited to the region near the fan apex and rarely reaches the distal fan region. In general, as the grain size decreases, there is a corresponding increase in

clay-pellet sand and silt content of fan sediment. The distal fan is characterized by a greater abundance of clay pellets than either fan plain or main channels. Clay pellets have a preferred occurrence with climbing ripple cosets. Stratification types in destructional phase bars are parallel laminae on the bayward side, climbing ripple cosets in the central part, and commonly foreset cross-strata on the landward side. Sediment comprising these bars consists of quartz and clay-pellet sand, whole and fragmented shell, and plant debris.

Main channels have straight to slightly sinuous trends. Gum Hollow channels show various stages of activity and fill: the active eastern channel is braided from the apex to channel mouth and increases in width downchannel; the abandoned western channel is ponded in the northern half, the southern part serves as a tidal creek, and the middle channel is, for the most part, completely filled. Stratification types of the filled channel are those that characterize braided streams. Several periods of channel activity and abandonment are indicated in the filled channels by alternating braided stream and pond-slope wash deposits.

A high clay-pellet sand content and a dominance of current and wave ripple stratification characterize prodelta deposits. Single depositional events are commonly indicated by a lower, small, trough-set sand that is succeeded by a mud drape. Biological activity is apparently restricted to prodelta areas adjacent to the presently inactive fan segments. Here the sediment is being reworked by an infauna of worms, mud shrimp, and angel-wing clams.

Knowledge of relationships between modern fan deltas and contemporaneous bay and marsh deposits should aid in distinguishing ancient fan deltas and alluvial fans. Primary sedimentary structures cannot be expected to serve as a single criterion for differentiating between ancient braided-stream and fan-delta depositional features. Perhaps directional features can be utilized to distinguish between ancient braided-stream and fan-delta deposits, especially if something is known about the trend of the sandstone body. Directional features measured on the Gum Hollow fan have wide spreads and range in trend from downfan to directions toward the fan apex. Fan plain and destructional phase bar features of the Gum Hollow fan do not indicate flow direction of the overall current system, main channel features have a general downfan trend, and drag marks are commonly aligned parallel to the dominant wind direction. Wide variability of directional trends should be a characteristic common to both alluvial fans and fan deltas, as flow across these features is relatively unconfined. Flow in a braided stream presumably is more confined than flow across the surface of either alluvial fans or fan deltas, and directional features therefore should more closely approximate the overall current system.

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Plates I and II

Plate I

Development stages of Gum Hollow fan delta

A. Vegetated depositional feature at the mouth of Gum Hollow, 1939; artificial drainage system had just been completed. Earthen dam (1) breached by small channel. Small alluvial fan (2) is shown on the 1966 plane-table map (Pl. III) at the base of the erosional escarpment; it lies just east of the north-south fence line near the western limit of the fan delta.

B. Initial stages of fan development. Position of small alluvial fan (3) relative to the earthen dam indicates the amount of progradation. The existence of two main channel systems and early development of the western (1) and middle (2) lobes are shown on this photograph (1948).

C. In 1950 only the middle lobe channel appeared to be active (2). The fan had not prograded beyond the small alluvial fan (3), and the western lobe (1) had changed little since 1948.

D. The western lobe (1) had prograded well beyond the small alluvial fan (3) by 1956. No evidence of the middle lobe channel (2) can be seen on this photograph.

E. The middle lobe was an elongate, narrow feature in 1958. The main channel of the middle lobe was crevassed in 1958, and the crevasse splay (4) produced a small bulge along the eastern periphery of the fan delta.

F. The western lobe was the active fan segment in 1961, prior to the passage of Hurricane Carla (September 1961).

Photographs courtesy of Edgar Tobin Aerial Surveys, San Antonio, Texas.

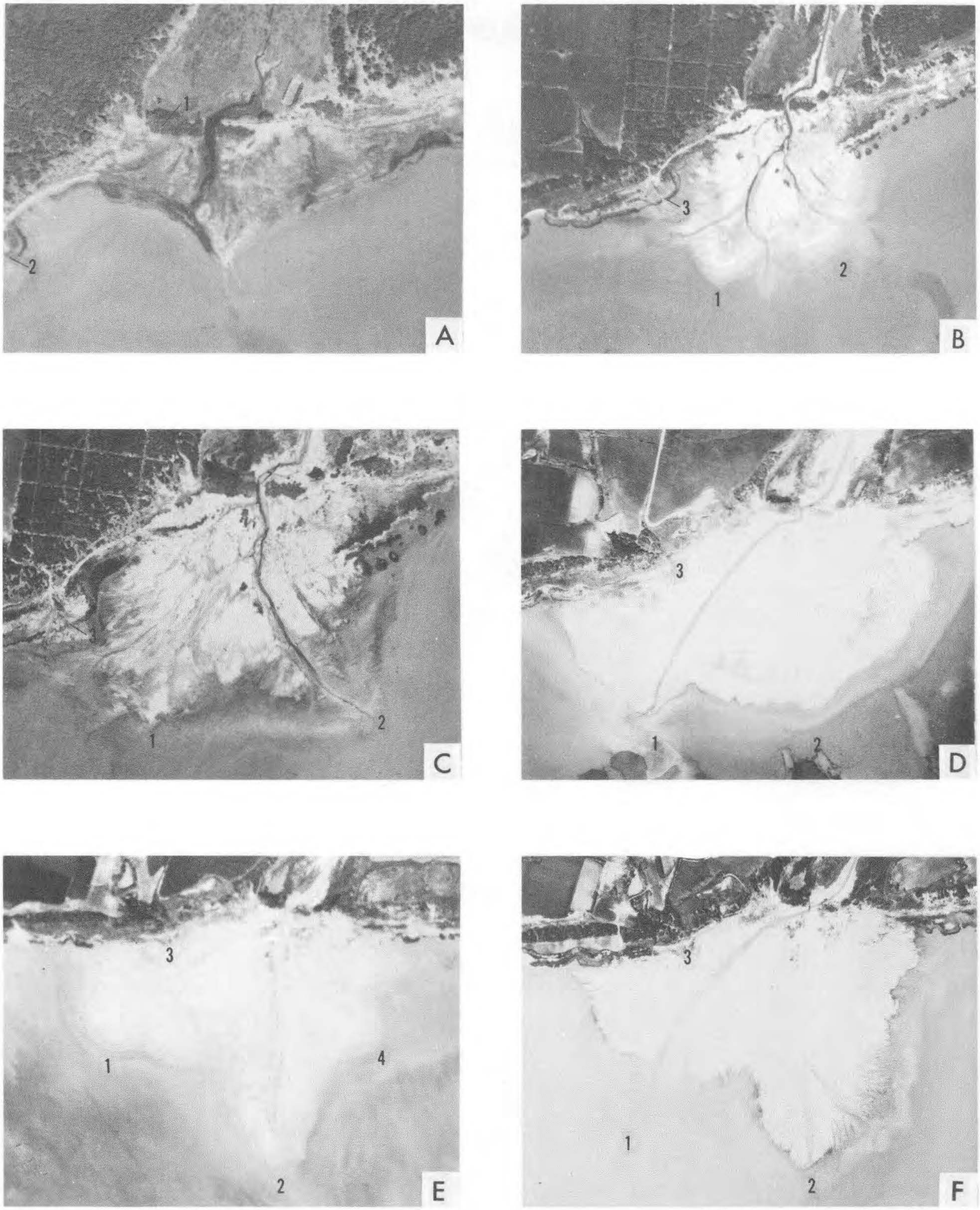

1
2
A
3
2
1
B
3
2
1
C
3
1
2
D
3
1
4
2
E
3
1
2
F

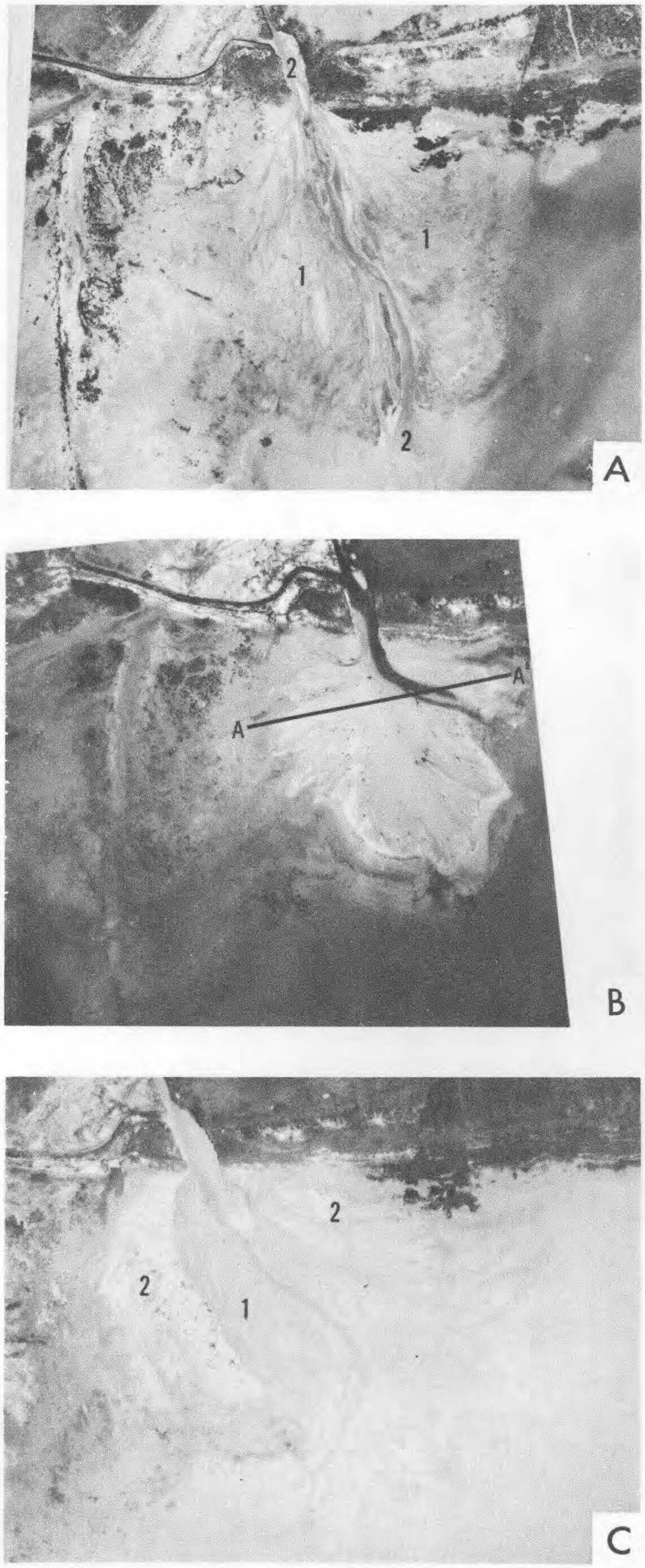
Plate II

Development of the presently active fan segment of Gum Hollow fan delta

A. This is the initial emergent fan (1966). The fan attained this size in the spring of 1966; this photograph was taken about six months later. Fan plain (1) is characterized by shallow, braided channels and low-relief longitudinal bars. Main channel (2) is braided along its entire length; bars are larger and more prominent near the channel mouth.

B. Hurricane Beulah fan (storm in September 1967) deposited upon the 1966 fan (*see* A above). The Beulah fan did not prograde the active fan but accreted the surface from 2 to 3 feet. The main channel was diverted to the east following the lowering of water level in Nueces Bay (this photo was taken in October 1967).

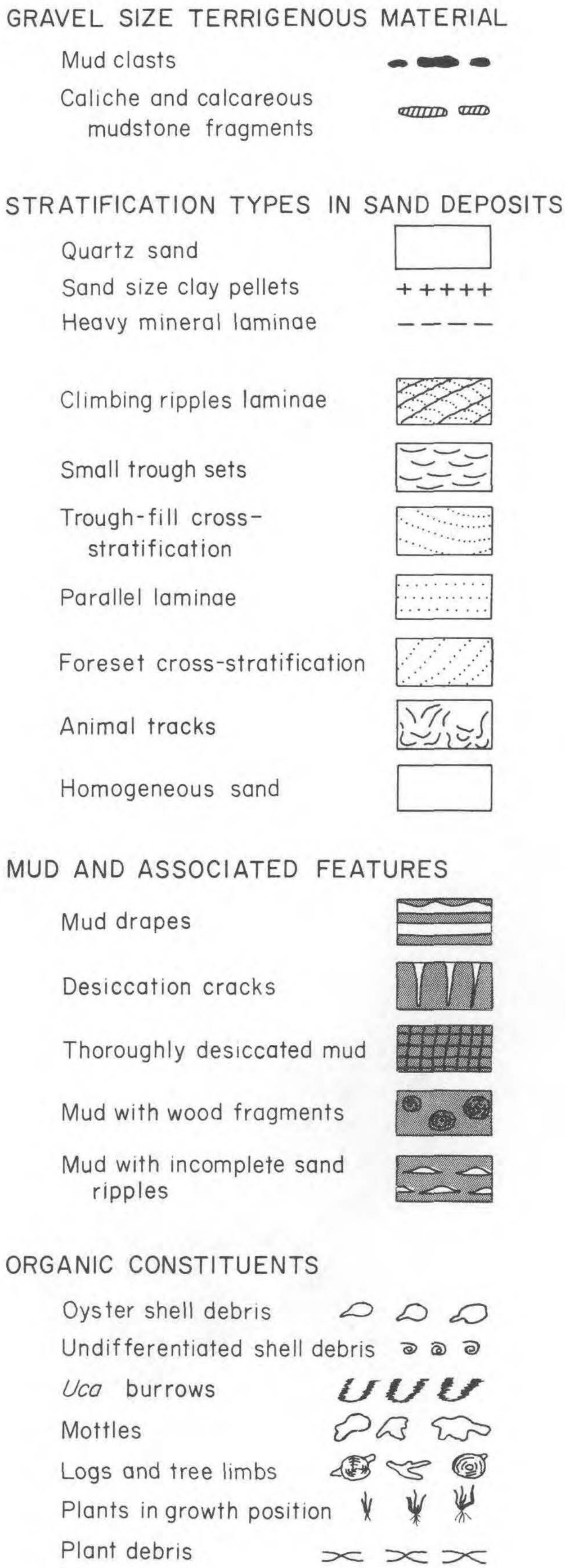
C. Remnants of the Beulah fan (2) flank fan plain deposits (1) that were laid down in June 1968. Many small, braided channels traverse the fan plain; brush piles dot the surface. Sediment deposited in June 1968 lies from 4 to 3 feet topographically lower than the Beulah sediment (this photograph was taken in July 1968).

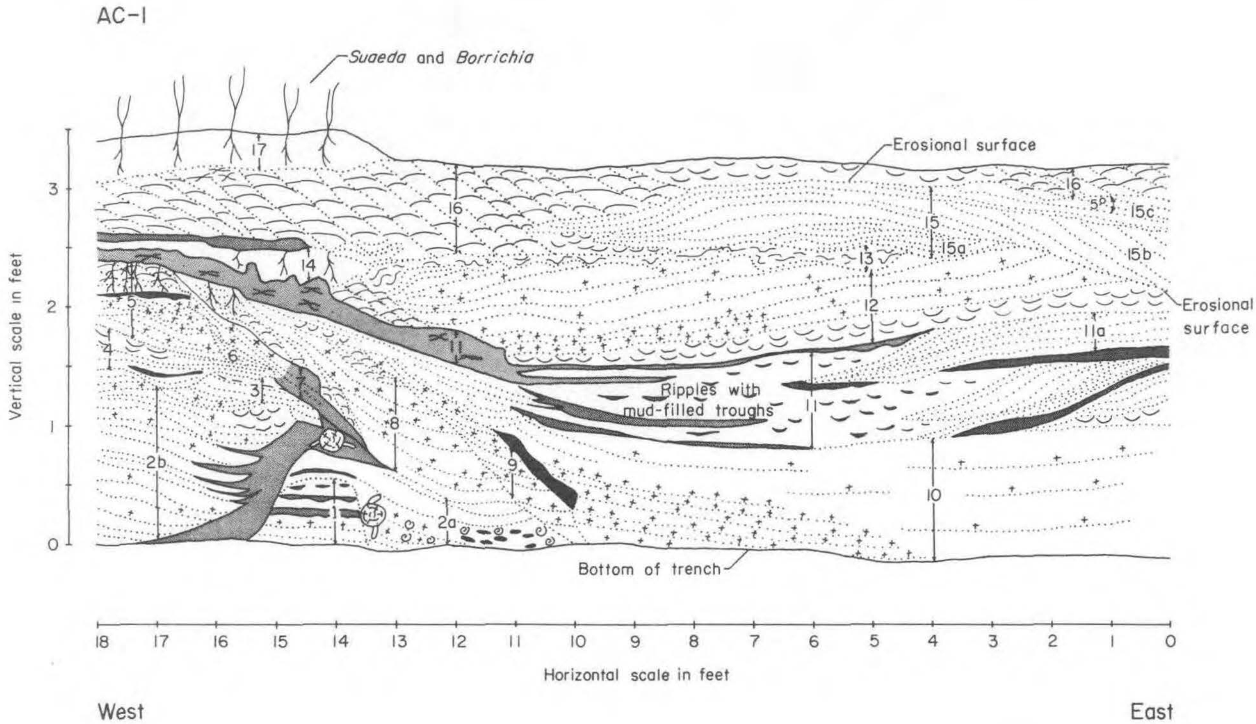

2
1
1
2
A
A'
A
B
2
2
1
C

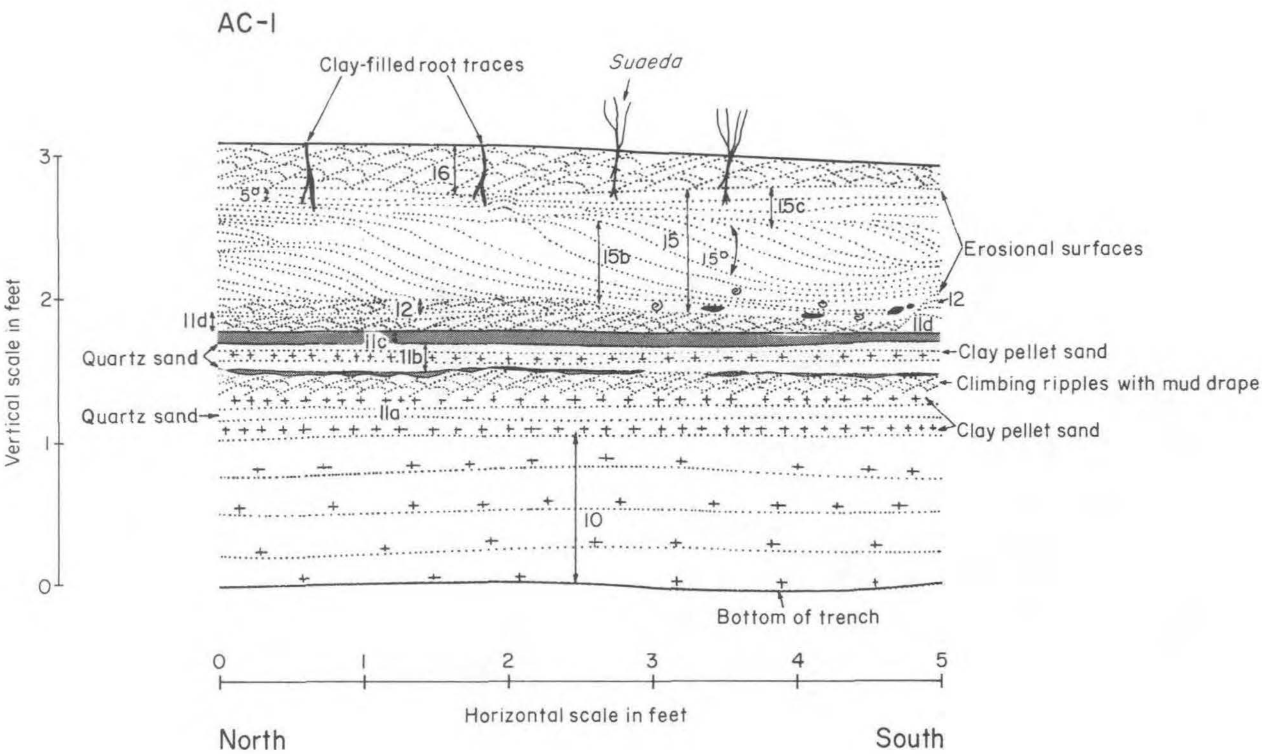
APPENDIX

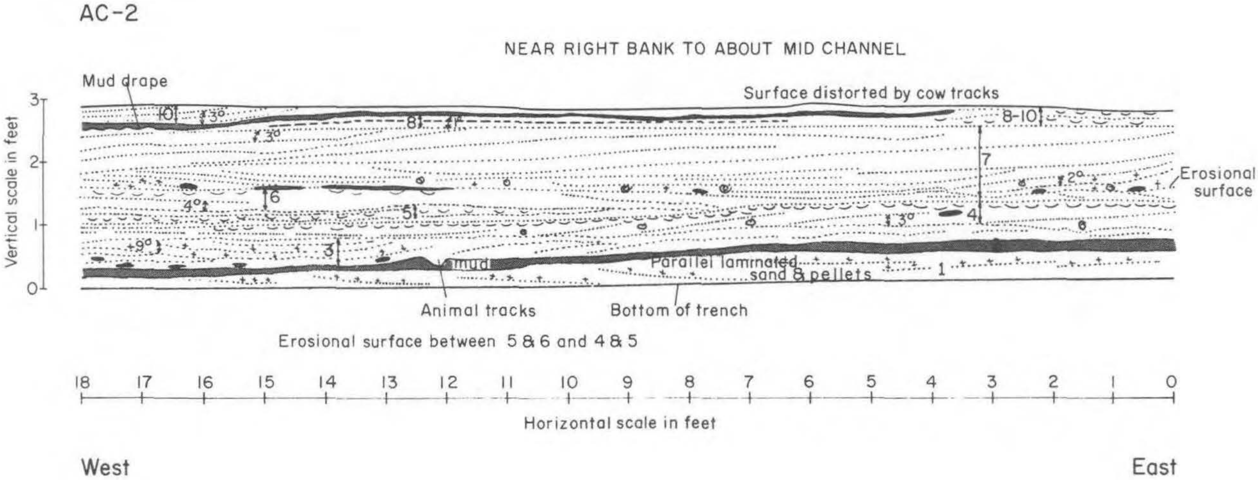
TRENCH SECTIONS

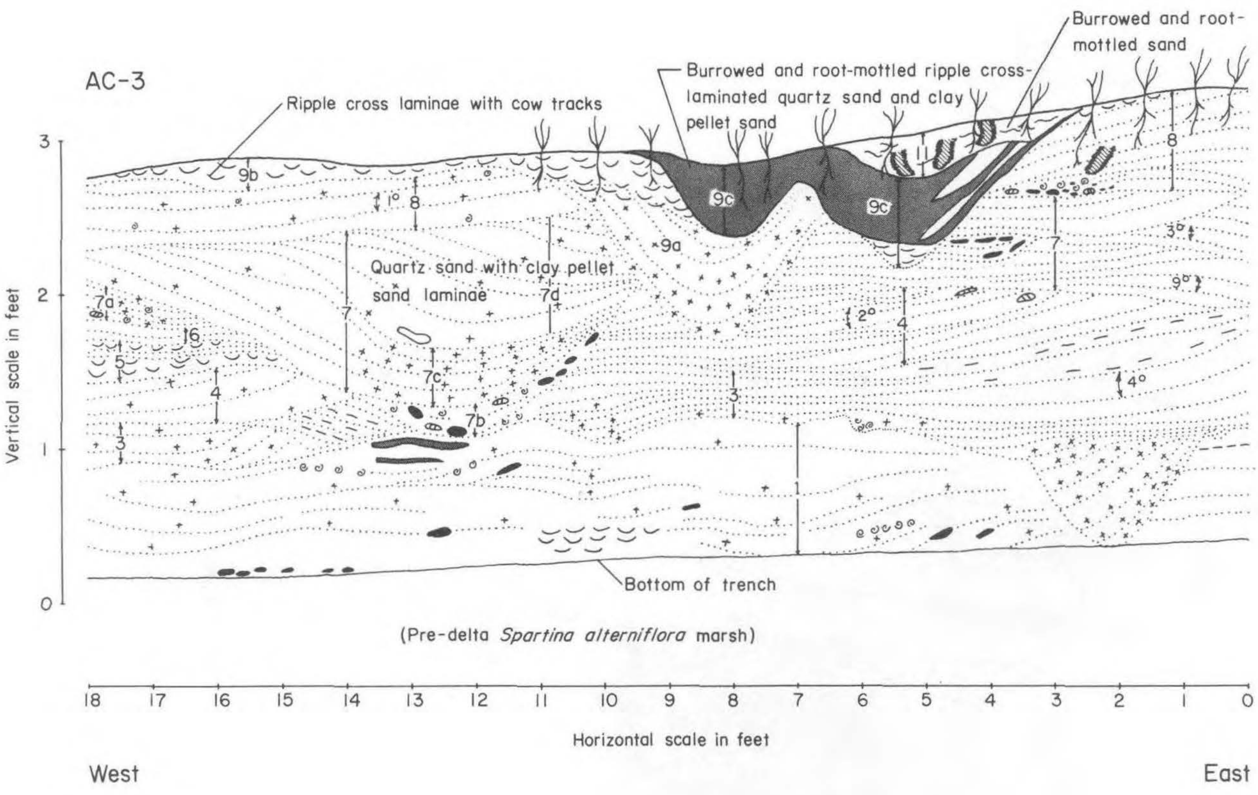
Trenches were cut into fan plain, distal fan, destructional bars, and filled channels (trench localities are shown on Pl. IV). Trenches provide much better data than do cores as sedimentation units can be observed over considerable lateral distances and geometry of these units can only be obtained in trenches. Sketches of trenches were made in the field using a grid system of 1-foot squares placed on the trench wall to locate contacts between sedimentation units. Characteristic features of sedimentation units, such as primary sedimentary structures, gross texture, and biological constituents, are graphically shown on the following trench sections. Dip angles of inclined laminae are shown on the trench sketches at the point where a reading was taken.


GRAVEL SIZE TERRIGENOUS MATERIAL
Mud clasts
Caliche and calcareous mudstone fragments
STRATIFICATION TYPES IN SAND DEPOSITS
Quartz sand
Sand size clay pellets
Heavy mineral laminae
Climbing ripples laminae
Small trough sets
Trough-fill cross-stratification
Parallel laminae
Foreset cross-stratification
Animal tracks
Homogeneous sand
MUD AND ASSOCIATED FEATURES
Mud drapes
Desiccation cracks
Thoroughly desiccated mud
Mud with wood fragments
Mud with incomplete sand ripples
ORGANIC CONSTITUENTS
Oyster shell debris
Undifferentiated shell debris
Uca burrows
Mottles
Logs and tree limbs
Plants in growth position
Plant debris

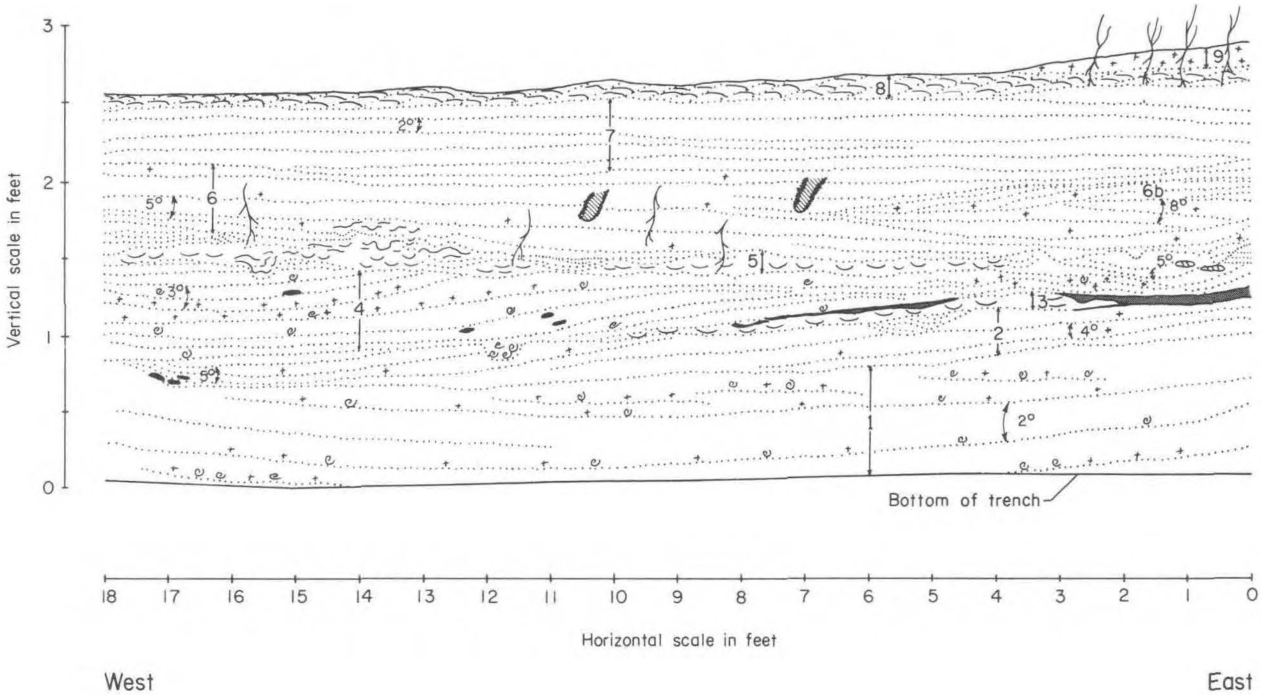

AC-I
Suaeda and Borrichia
Erosional surface
Erosional surface
Ripples with mud-filled troughs
Bottom of trench
Vertical scale in feet
Horizontal scale in feet
West
East


AC-I
Clay-filled root traces
Suaeda
Erosional surfaces
Quartz sand
Quartz sand
Clay pellet sand
Climbing ripples with mud drape
Clay pellet sand
Bottom of trench
Vertical scale in feet
Horizontal scale in feet
North
South

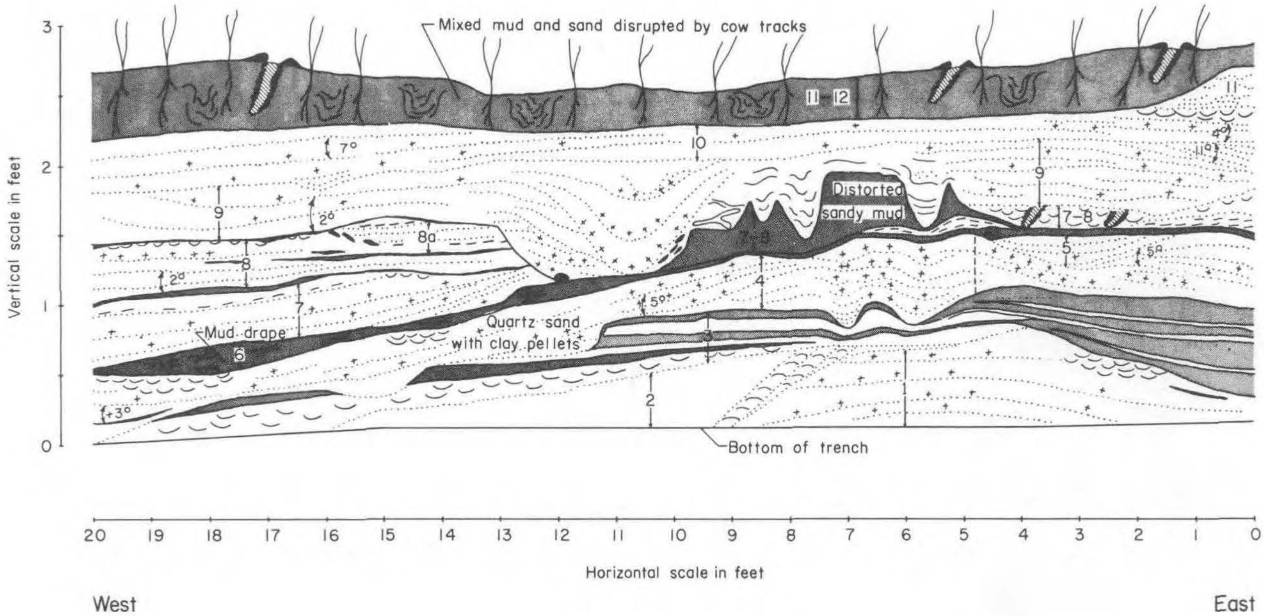

AC-2
NEAR RIGHT BANK TO ABOUT MID CHANNEL
Mud drape
Surface distorted by cow tracks
Erosional surface
Parallel laminated sand & pellets
mud
Animal tracks
Bottom of trench
Erosional surface between 5 & 6 and 4 & 5
Horizontal scale in feet
Vertical scale in feet
West
East


AC-3
Ripple cross laminae with cow tracks
Burrowed and root-mottled ripple cross-laminated quartz sand and clay pellet sand
Burrowed and root-mottled sand
Quartz sand with clay pellet sand laminae
Bottom of trench
(Pre-delta Spartina alterniflora marsh)
Horizontal scale in feet
Vertical scale in feet
West
East

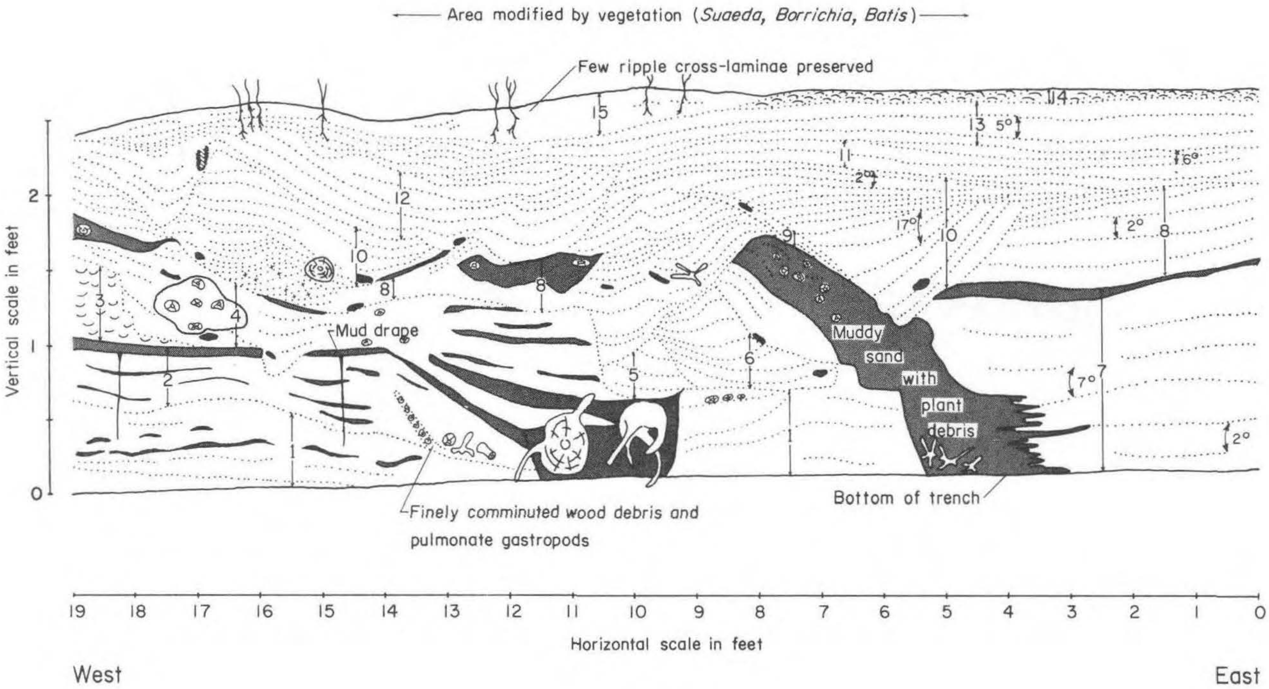
AC-4


Vertical scale in feet
Bottom of trench
Horizontal scale in feet
West
East

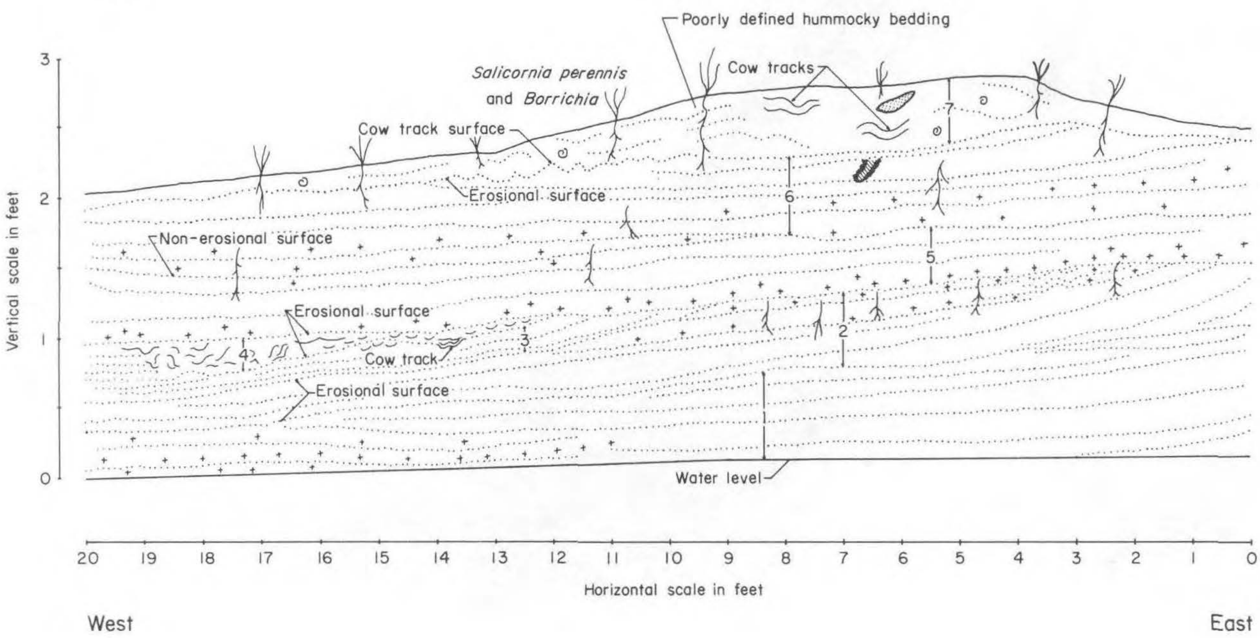
AC-5

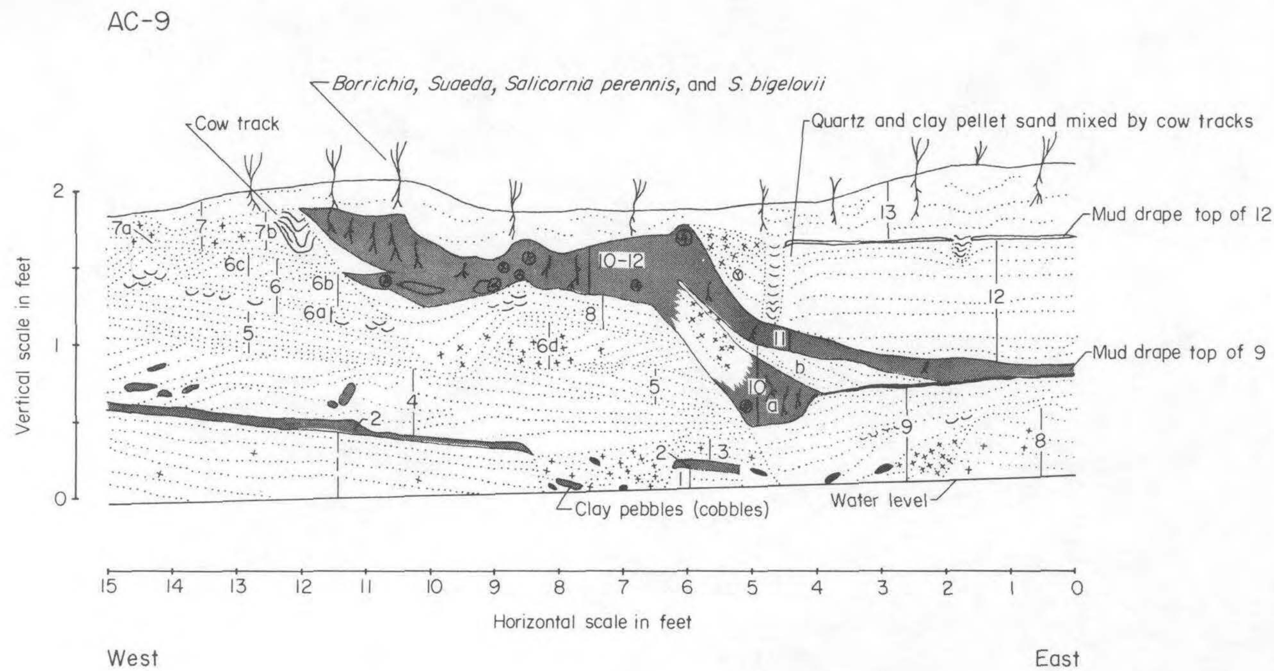

Mixed mud and sand disrupted by cow tracks
Distorted sandy mud
Quartz sand with clay pellets
Mud drape
Bottom of trench
Vertical scale in feet
Horizontal scale in feet
West
East

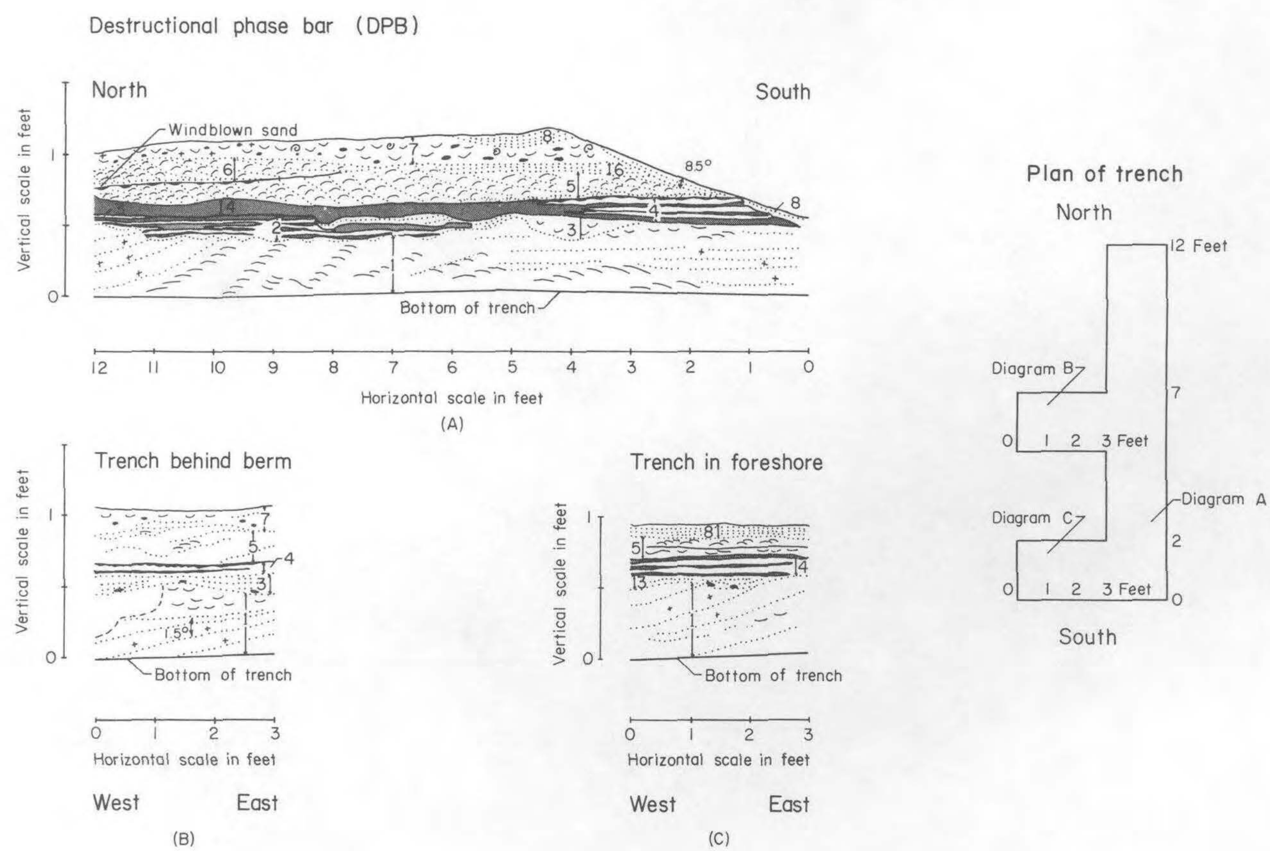
AC-6


Area modified by vegetation (*Suaeda, Borrichia, Batis*)
Few ripple cross-laminae preserved
Mud drape
Muddy sand with plant debris
Bottom of trench
Finely comminuted wood debris and pulmonate gastropods
Vertical scale in feet
Horizontal scale in feet
West
East

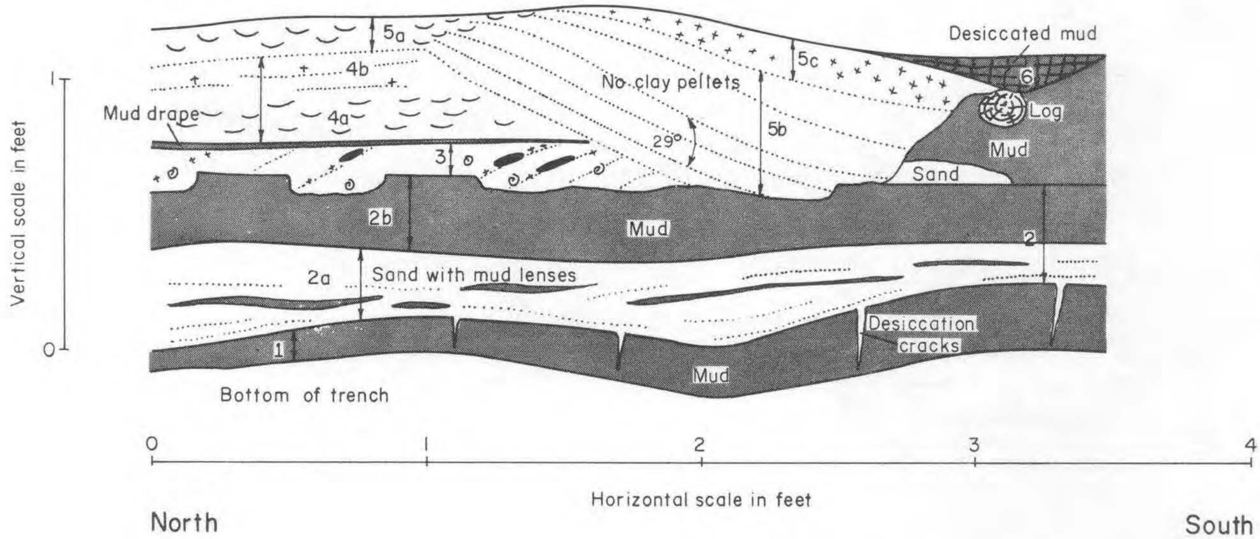
AC-7


Poorly defined hummocky bedding
Salicornia perennis and *Borrichia*
Cow tracks
Cow track surface
Erosional surface
Non-erosional surface
Erosional surface
Cow track
Erosional surface
Water level
Vertical scale in feet
Horizontal scale in feet
West
East

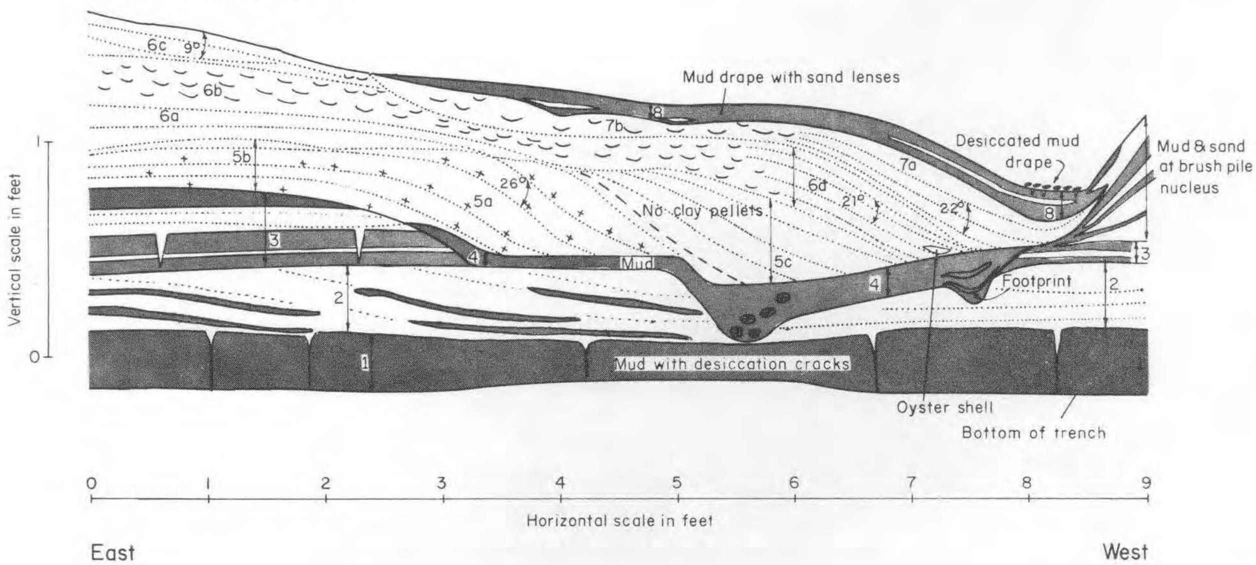

AC-9
Borrichia, Suaeda, Salicornia perennis, and S. bigelovii
Cow track
Quartz and clay pellet sand mixed by cow tracks
Mud drape top of 12
Mud drape top of 9
Clay pebbles (cobbles)
Water level
Vertical scale in feet
Horizontal scale in feet
West
East
7a
7
7b
6c
6
6b
6a
5
4
2
10-12
8
6d
11
10
a
b
12
13
9
3
1
0
1
2
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

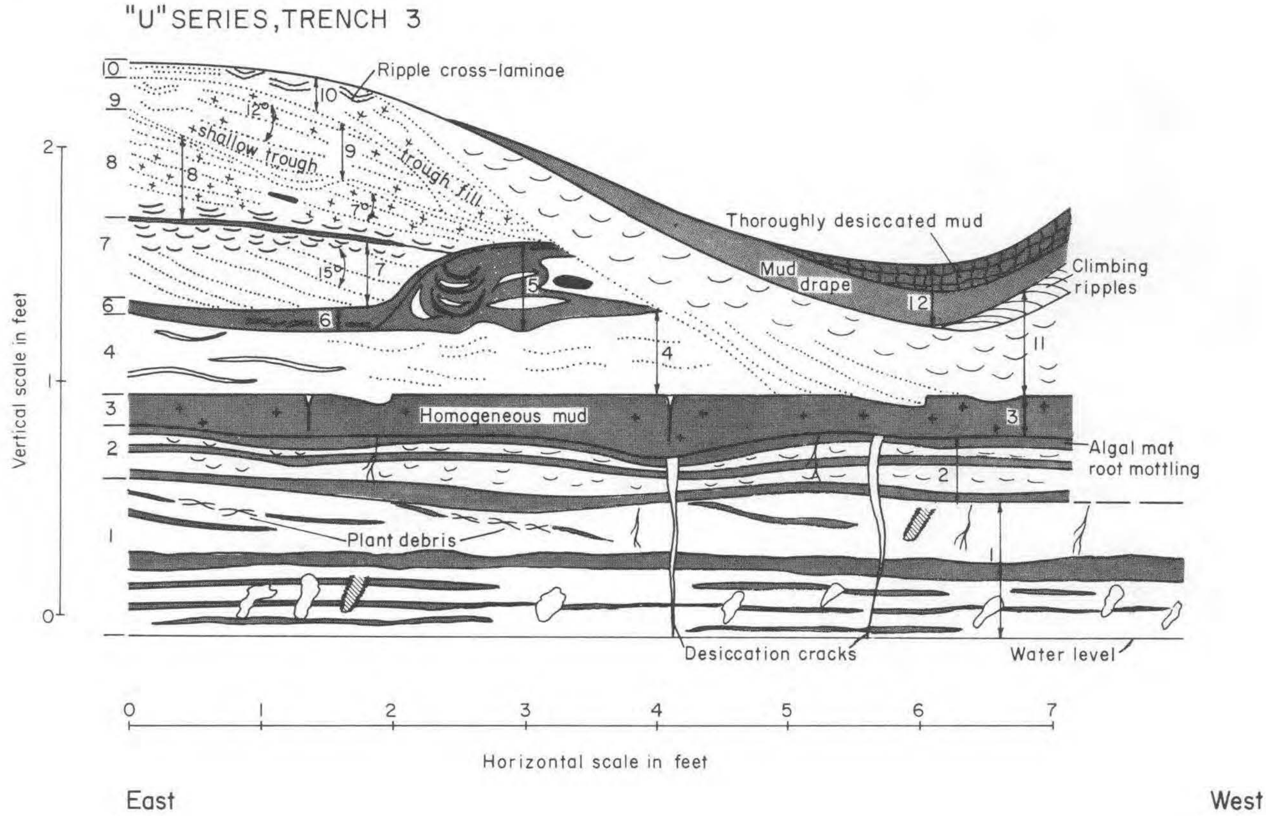

Destructional phase bar (DPB)
North
South
Windblown sand
Bottom of trench
8.5°
Vertical scale in feet
Horizontal scale in feet
12 11 10 9 8 7 6 5 4 3 2 1 0
(A)
Trench behind berm
5°
Bottom of trench
Vertical scale in feet
Horizontal scale in feet
0 1 2 3
West
East
(B)
Trench in foreshore
Bottom of trench
Vertical scale in feet
Horizontal scale in feet
0 1 2 3
West
East
(C)
Plan of trench
North
12 Feet
Diagram B
7
0 1 2 3 Feet
Diagram C
Diagram A
2
0 1 2 3 Feet
0
South

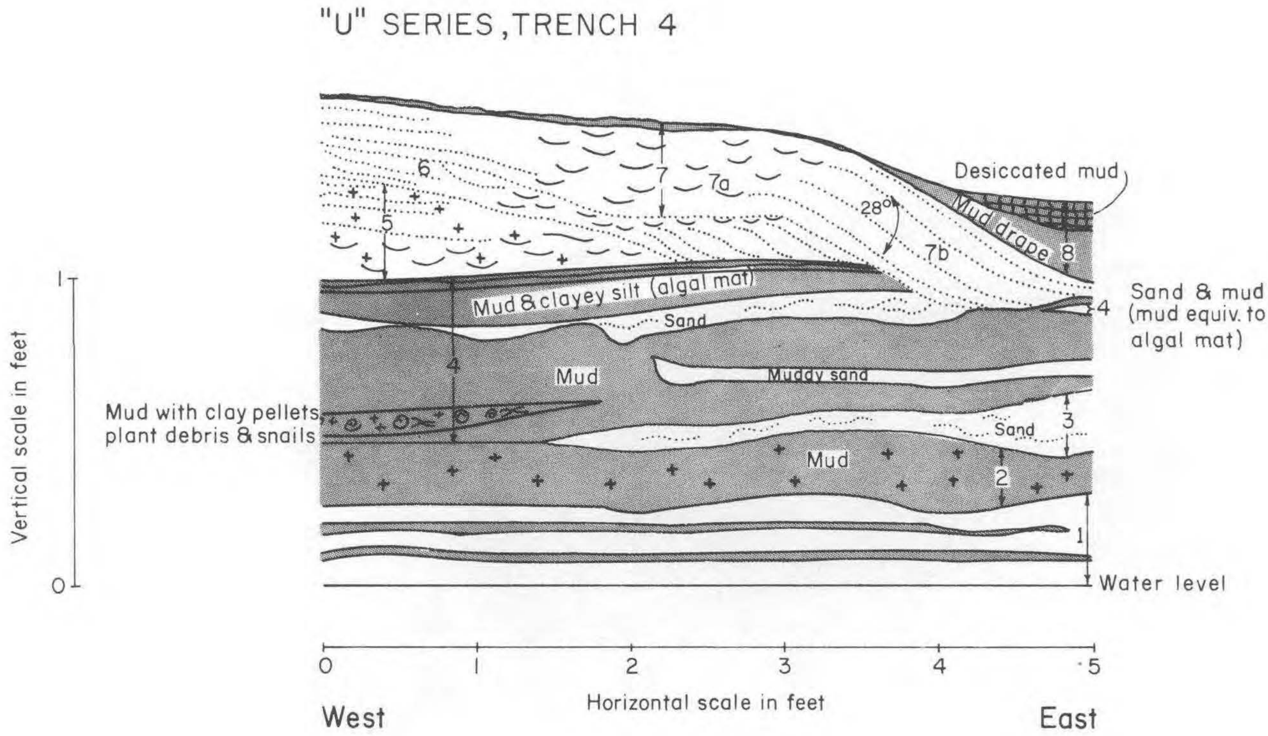
"U" SERIES, TRENCH I



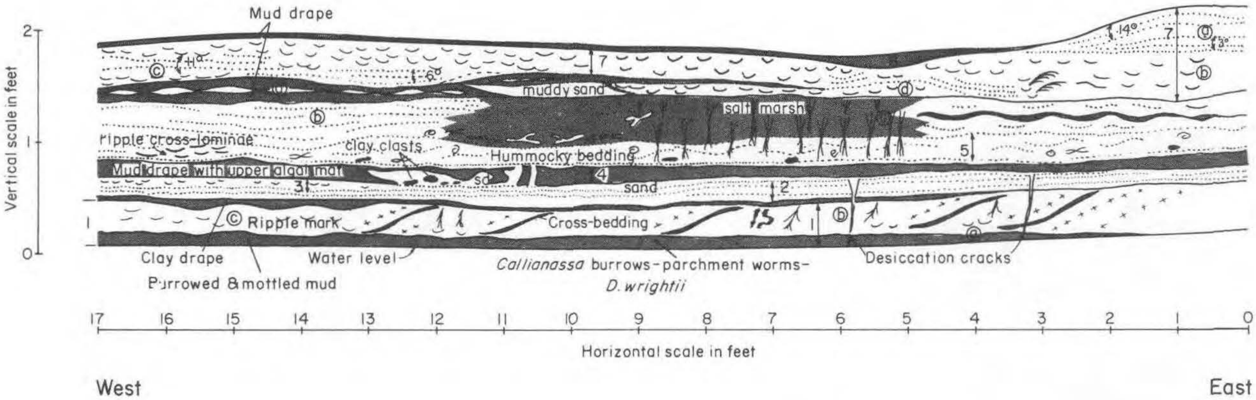
"U" SERIES, TRENCH 2



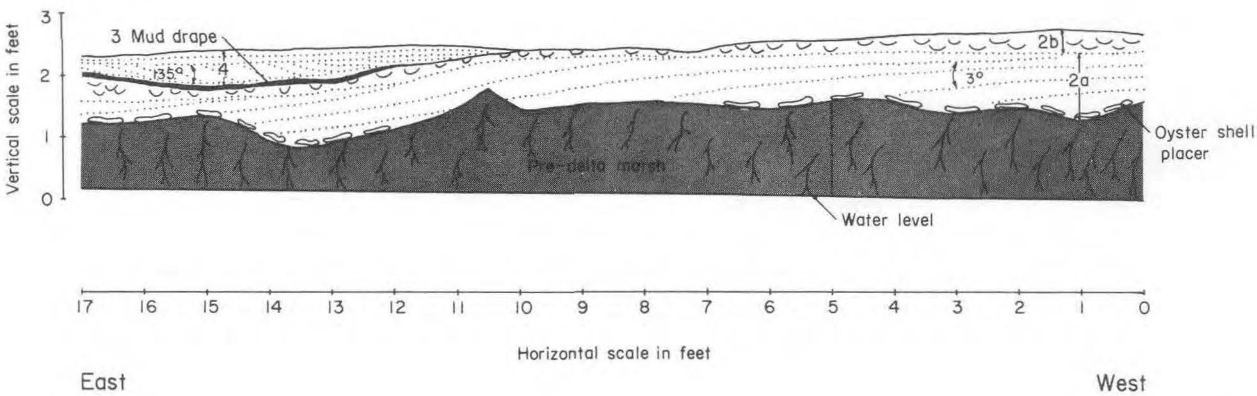

"U" SERIES, TRENCH 3
Ripple cross-laminae
shallow trough
trough fill
Thoroughly desiccated mud
Mud drape
Climbing ripples
Homogeneous mud
Algal mat root mottling
Plant debris
Desiccation cracks
Water level
Vertical scale in feet
Horizontal scale in feet
East
West


"U" SERIES, TRENCH 4
Desiccated mud
Mud drape
Mud & clayey silt (algal mat)
Sand
Sand & mud (mud equiv. to algal mat)
Mud
Muddy sand
Mud with clay pellets, plant debris & snails
Water level
Vertical scale in feet
Horizontal scale in feet
West
East

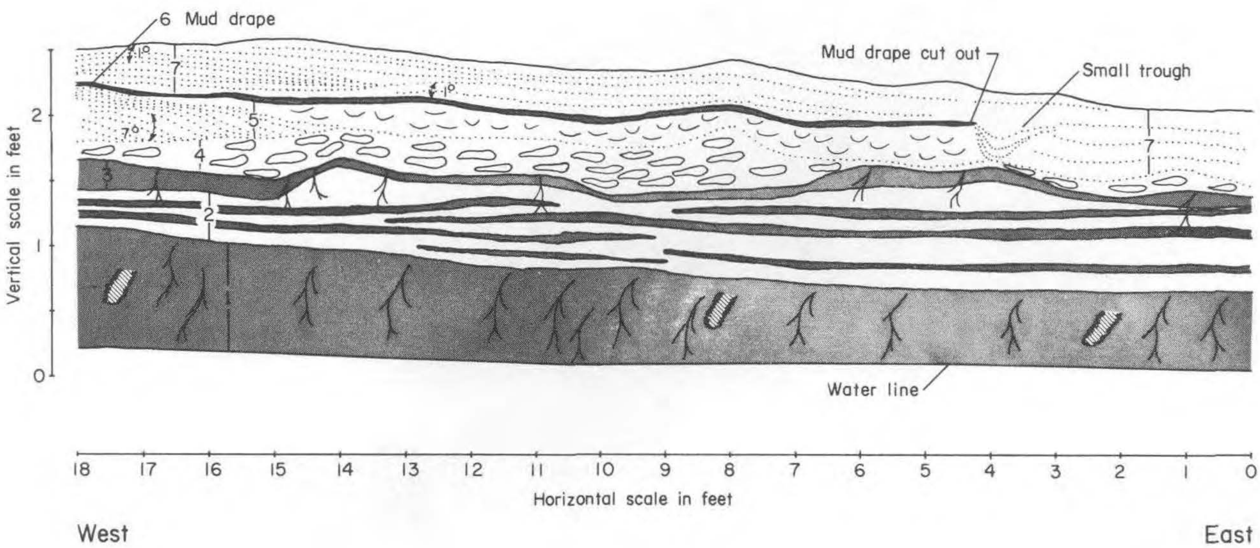
"U" SERIES, TRENCH 5

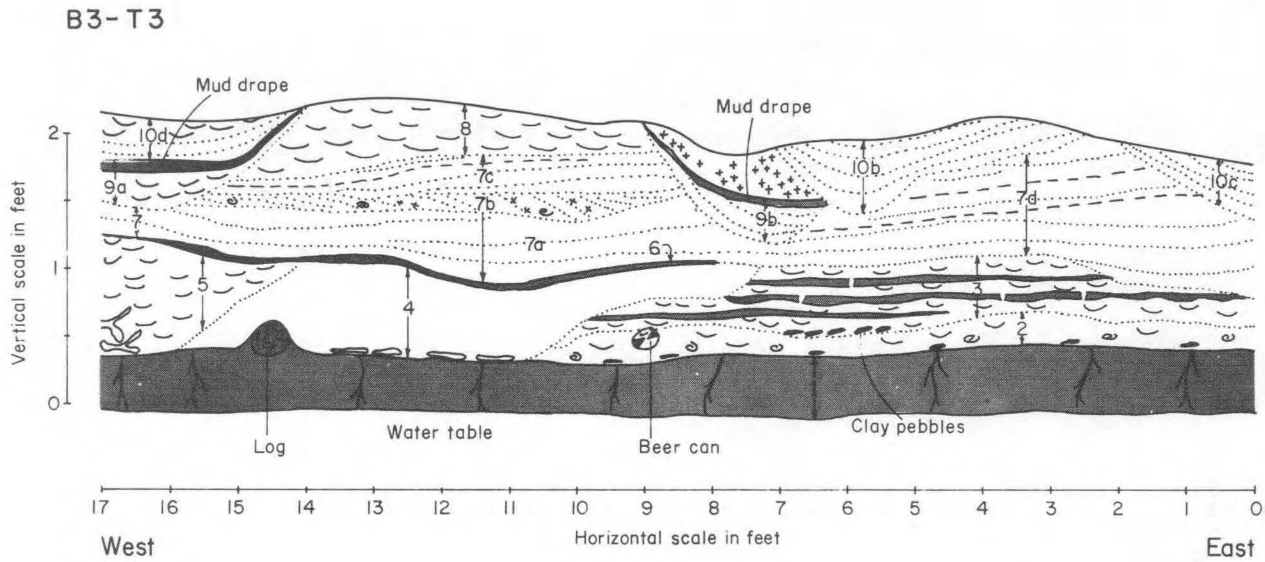


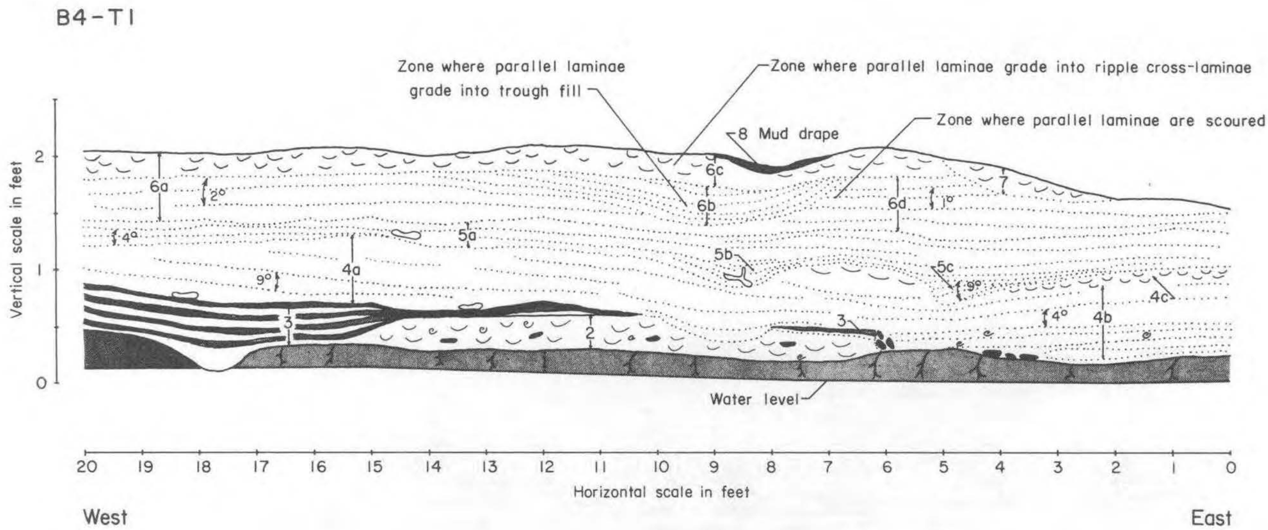
B3-T1



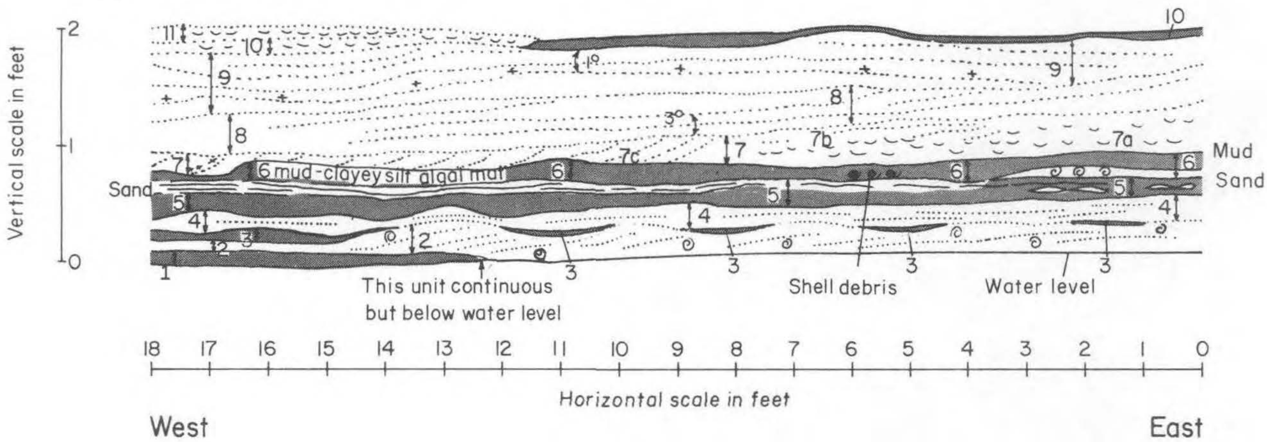
B3-T2

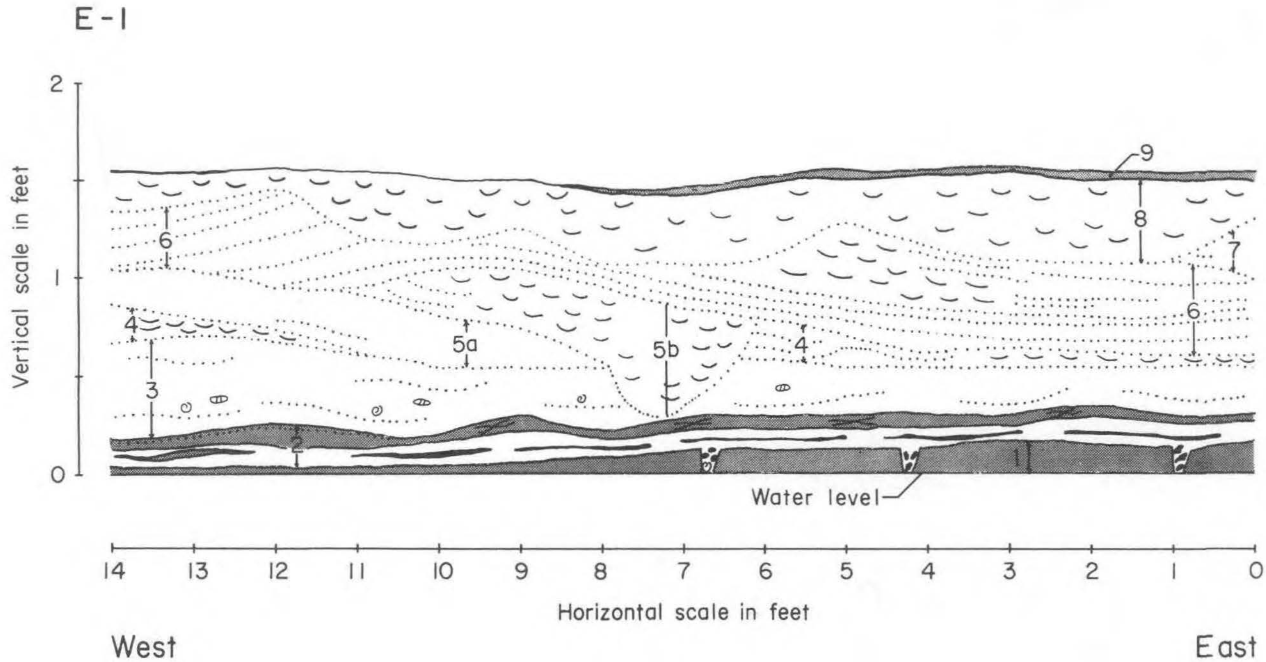


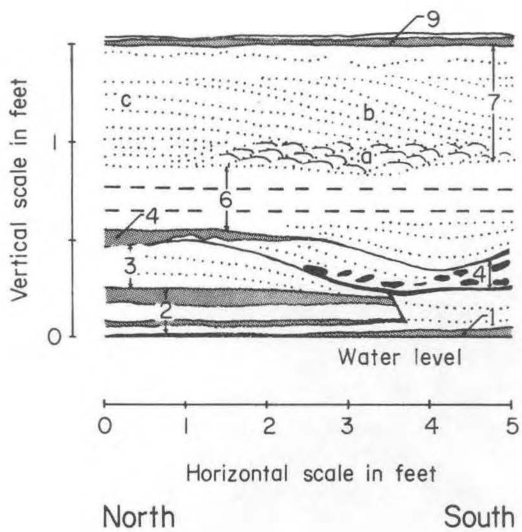

B3-T3
Mud drape
Mud drape
10d
8
9a
7c
7b
7a
7
6
5
4
10b
9b
7d
10c
3
2
Log
Water table
Beer can
Clay pebbles
Vertical scale in feet
0
1
2
17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East


B4-T1
Zone where parallel laminae grade into trough fill
Zone where parallel laminae grade into ripple cross-laminae
Zone where parallel laminae are scoured
8 Mud drape
6a
6b
6c
6d
7
5a
5b
5c
4a
4b
4c
3
2
Water level
Vertical scale in feet
0
1
2
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

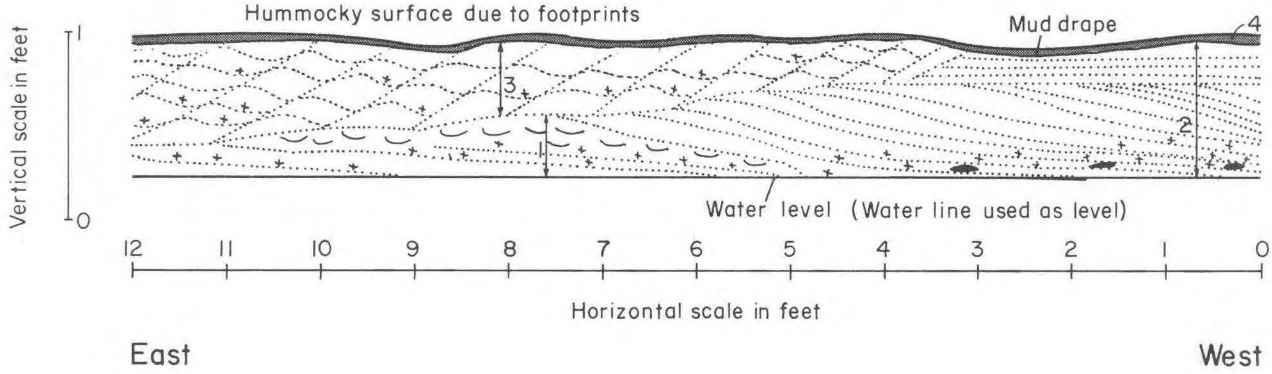
B3–T4

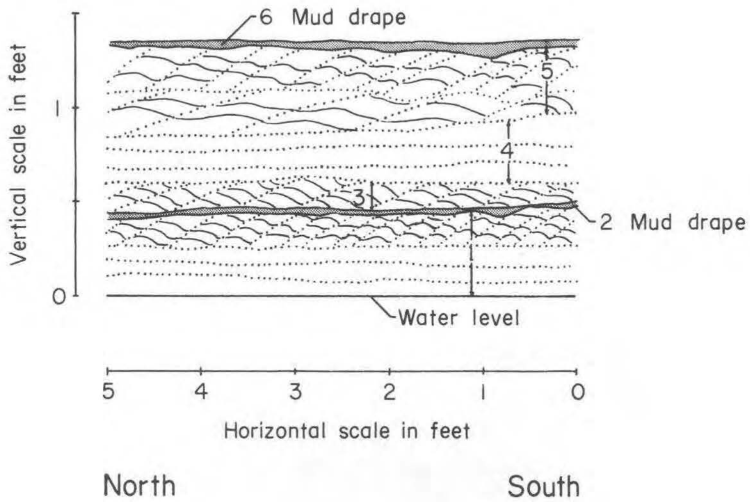

Vertical scale in feet
2
1
0
11
10
9
8
7
7c
7b
7a
6 mud-clayey silt algal mat
6
5
4
3
2
1
Mud
Sand
Sand
This unit continuous
but below water level
Shell debris
Water level
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

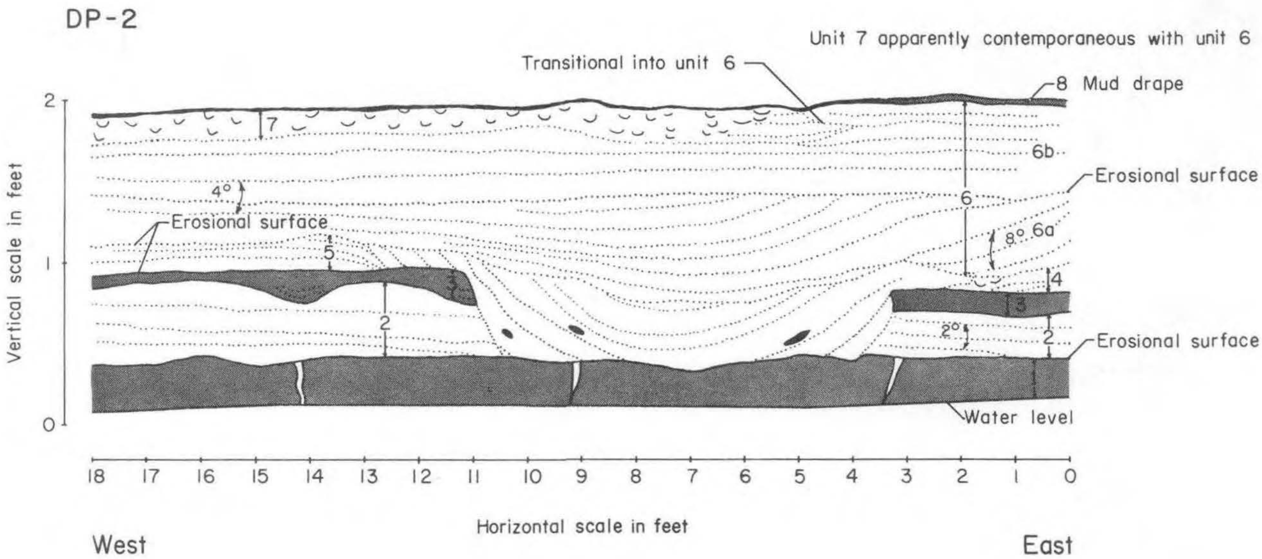

E-1
2
1
0
Vertical scale in feet
9
8
7
6
4
5a
5b
4
6
3
2
1
Water level
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

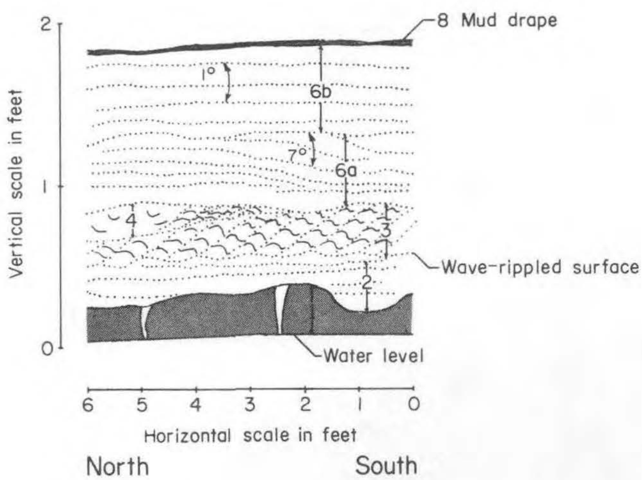

9
c
b
a
7
6
4
3
4
2
1
1
0
Vertical scale in feet
Water level
0 1 2 3 4 5
Horizontal scale in feet
North
South

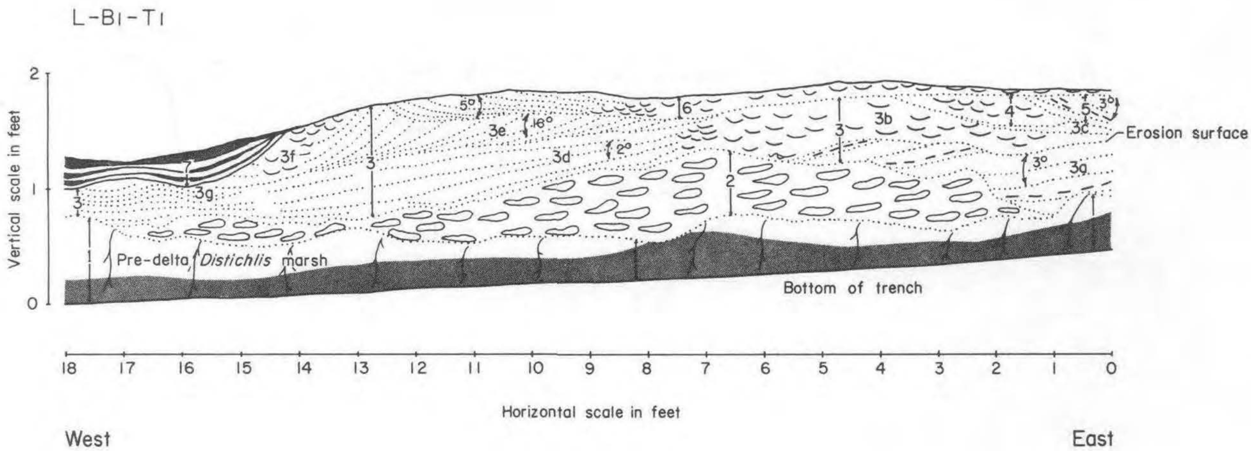
F-1

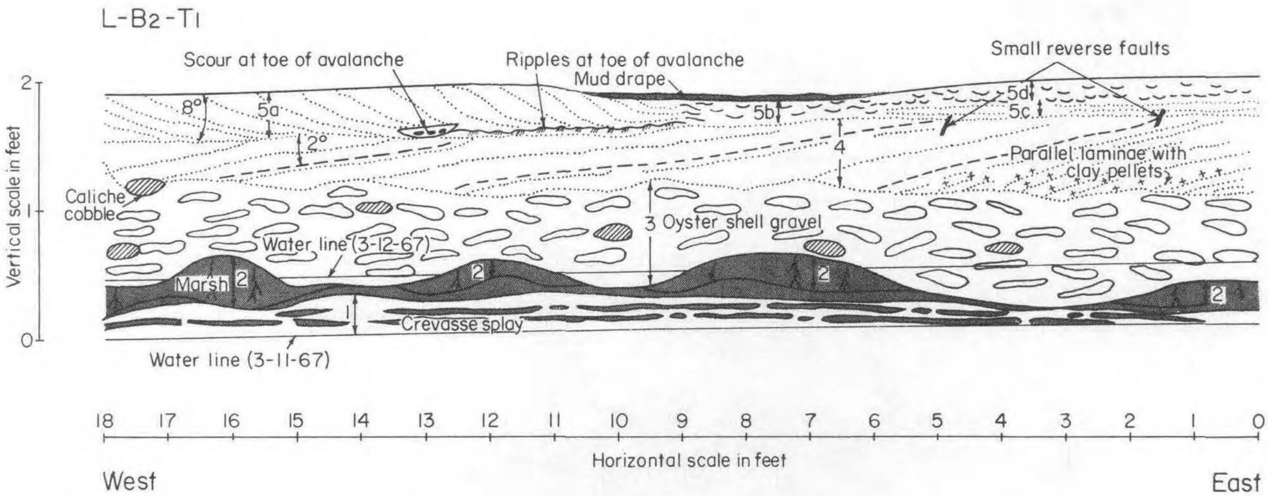

Hummocky surface due to footprints
Mud drape
4
3
2
1
Vertical scale in feet
1
0
Water level (Water line used as level)
12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
East
West

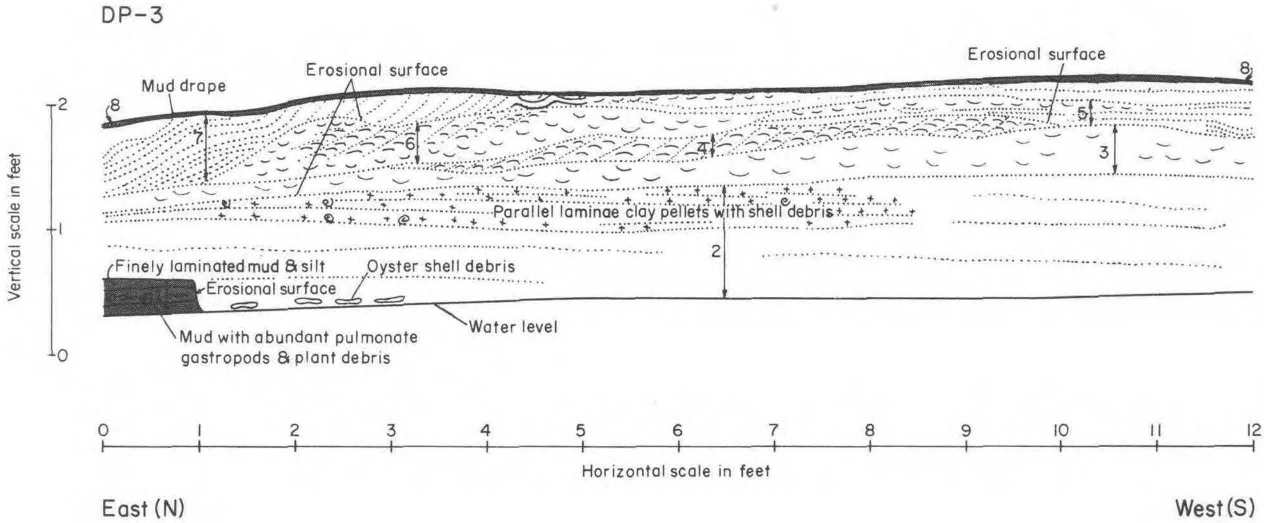

6 Mud drape
5
4
3
2 Mud drape
1
Vertical scale in feet
1
0
Water level
5 4 3 2 1 0
Horizontal scale in feet
North
South

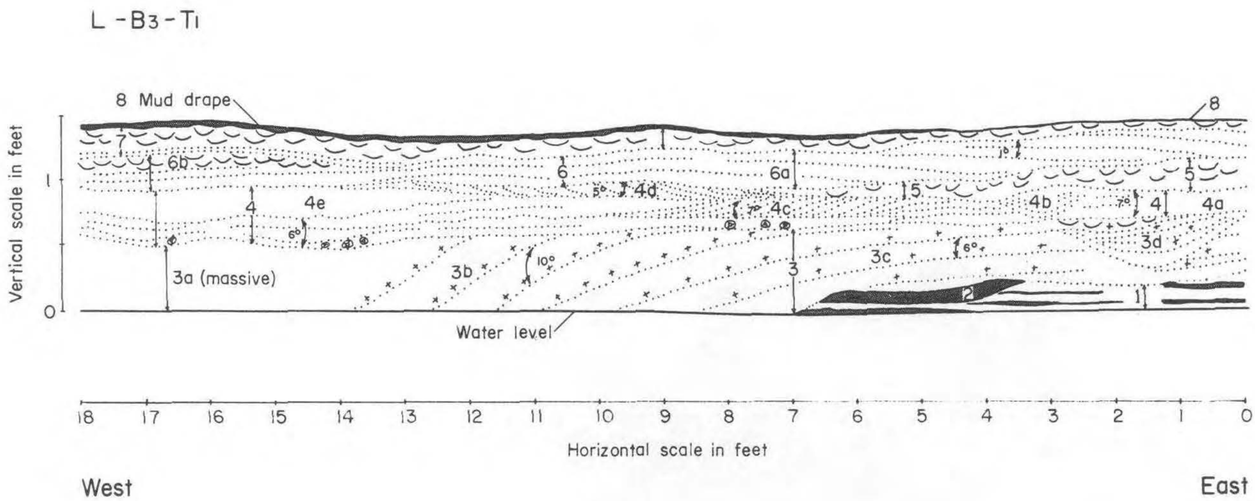

DP-2
Unit 7 apparently contemporaneous with unit 6
Transitional into unit 6
8 Mud drape
7
6b
6
Erosional surface
4°
8°
6a
Erosional surface
5
3
4
3
2
2°
2
Erosional surface
Water level
Vertical scale in feet
0
1
2
18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East


8 Mud drape
1°
6b
7°
6a
4
3
Wave-rippled surface
2
Water level
Vertical scale in feet
0
1
2
6 5 4 3 2 1 0
Horizontal scale in feet
North
South

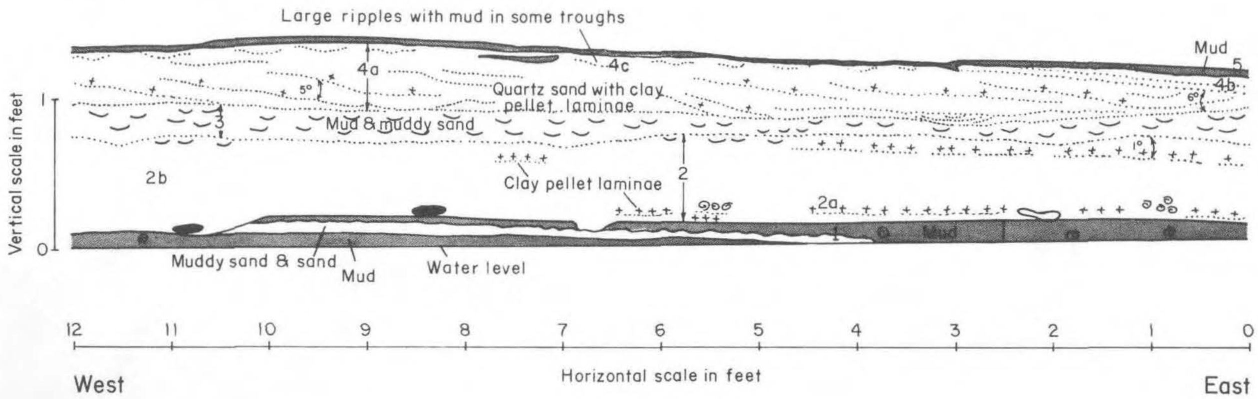

L-B1-T1
Vertical scale in feet
Erosion surface
Pre-delta Distichlis marsh
Bottom of trench
Horizontal scale in feet
West
East


L-B2-T1
Scour at toe of avalanche
Ripples at toe of avalanche
Mud drape
Small reverse faults
Parallel laminae with clay pellets
Caliche cobble
3 Oyster shell gravel
Water line (3-12-67)
Marsh
Crevasse splay
Water line (3-11-67)
Vertical scale in feet
Horizontal scale in feet
West
East

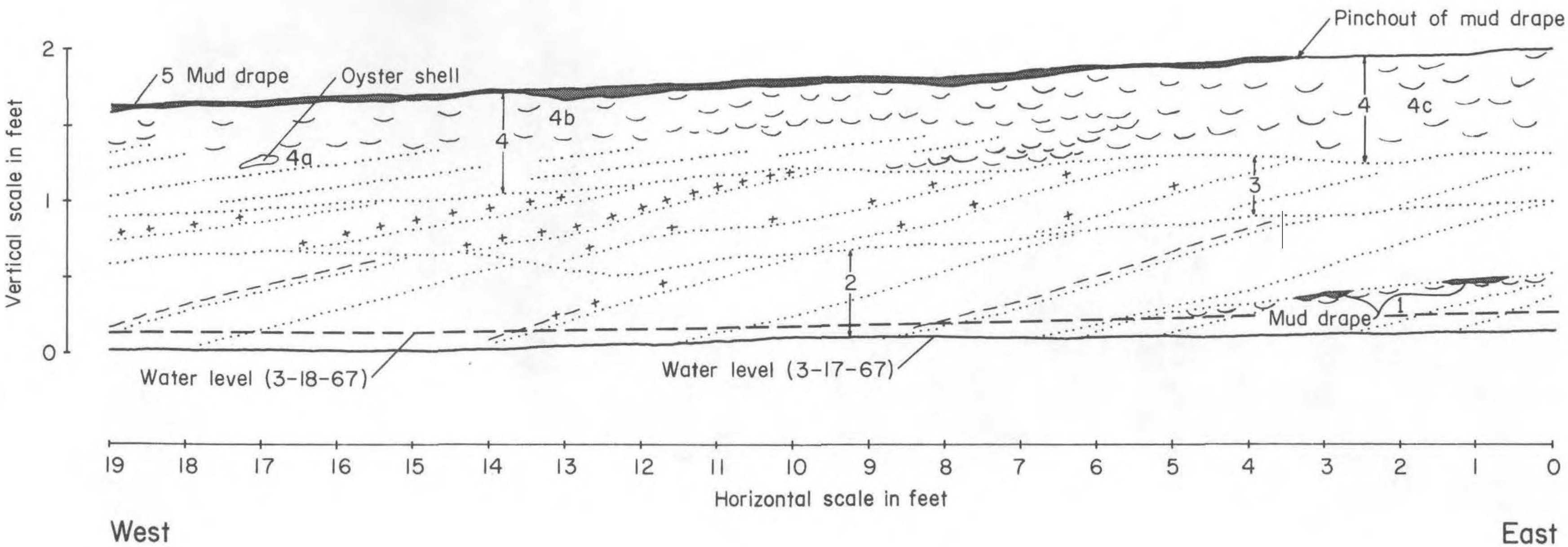

DP-3
Mud drape
Erosional surface
Erosional surface
Vertical scale in feet
Parallel laminae clay pellets with shell debris
Finely laminated mud & silt
Oyster shell debris
Erosional surface
Mud with abundant pulmonate gastropods & plant debris
Water level
Horizontal scale in feet
East (N)
West (S)


L-B3-T1
8 Mud drape
Vertical scale in feet
3a (massive)
Water level
Horizontal scale in feet
West
East

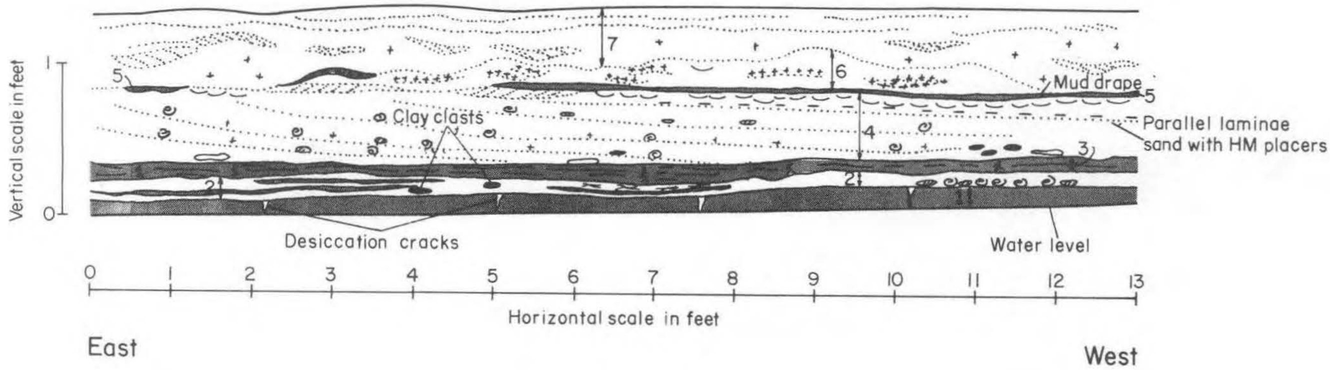
DP-4


Large ripples with mud in some troughs
Mud
4a
4c
5
4b
Quartz sand with clay pellet laminae
Mud & muddy sand
3
2b
Clay pellet laminae
2
2a
1
Mud
Muddy sand & sand
Mud
Water level
Vertical scale in feet
12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

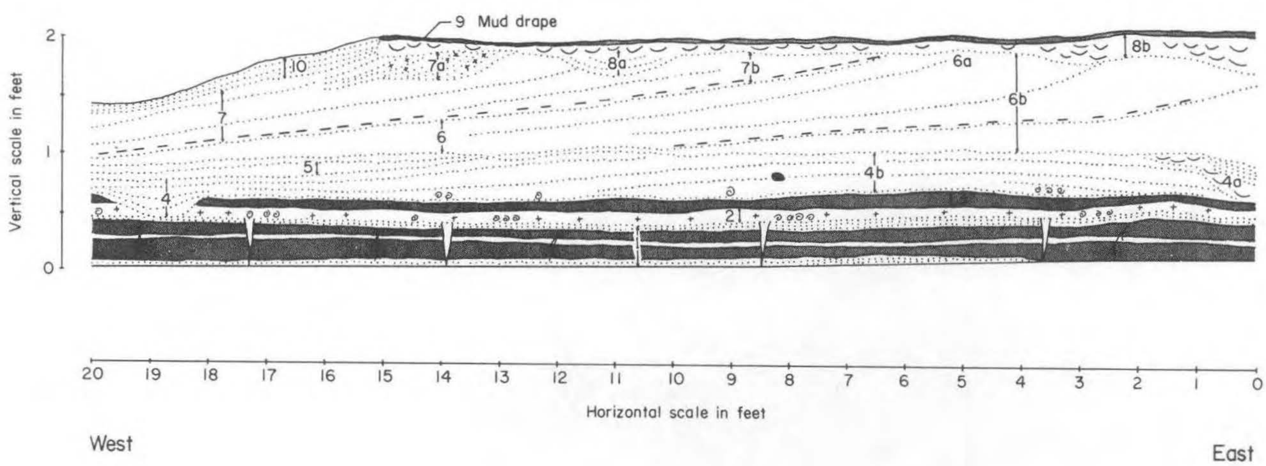
L-T-Ti

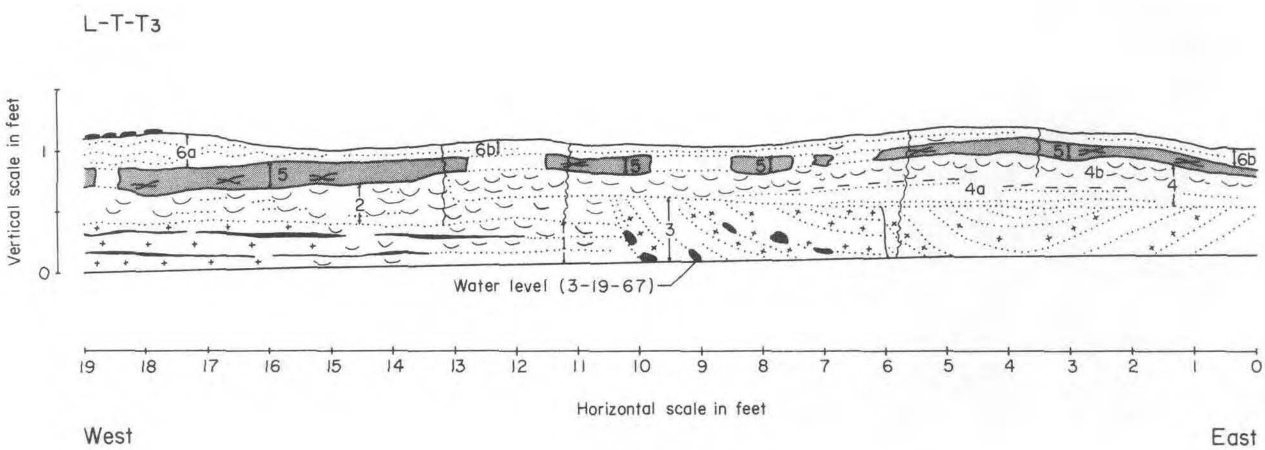

Pinchout of mud drape
5 Mud drape
Oyster shell
4a
4b
4
4c
3
2
1
Mud drape
Water level (3-18-67)
Water level (3-17-67)
Vertical scale in feet
19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

DP-5


Vertical scale in feet
1
0
7
6
5
4
3
2
1
Mud drape
5
Clay clasts
Parallel laminae
sand with HM placers
Desiccation cracks
Water level
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Horizontal scale in feet
East
West

L-T-T2


9 Mud drape
2
1
0
Vertical scale in feet
10
7a
8a
7b
6a
8b
7
6
6b
5
4b
4
4a
2
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East


L-T-T3
Vertical scale in feet
1
0
6a
5
2
6b
5
3
5
5
5
4a
4b
4
6b
Water level (3-19-67)
19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Horizontal scale in feet
West
East

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