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GUIDE TO MODERN BARRIER ENVIRONMENTS OF MUSTANG AND NORTH PADRE ISLANDS AND JACKSON (EOCENE) BARRIER/LAGOON FACIES OF THE SOUTH TEXAS URANIUM DISTRICT

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INTRODUCTION

Combining process and geomorphic description (supplied by studies of modern depositional systems) with the three-dimensional description of sedimentary units and their internal structures (accomplished in the stratigraphic record) produces an integrated facies model that can be applied to the interpretation of similar facies in other systems. Part I of this report briefly reviews modern depositional environments in the Corpus Christi area, followed by a more detailed look at modern barrier environments on Mustang and north Padre Islands (via a map of land and water resources, and a field trip). Emphasis is placed on active processes, and on physical, chemical, and biological characteristics as they are reflected through surface and near-surface conditions. Part II describes the geometry, internal features, and sedimentary structures of uranium-producing barrier island and associated coastal plain facies of the Jackson (Eocene) barrier system. The similarity between the Eocene and the Quaternary South Texas Coastal Plain depositional systems provides the basis of detailed facies interpretation and paleoenvironmental reconstruction. This interpretation and reconstruction is, in turn, the basis for understanding the nature and the distribution of uranium mineralization.

PART I: MUSTANG AND NORTH PADRE ISLANDS--MODERN BARRIERS IN THE CORPUS CHRISTI AREA

DEPOSITIONAL SETTING

Several Modern and Pleistocene depositional systems are present along the Coastal Zone in the Corpus Christi area. The major natural systems are fluvial-deltaic, barrier-strandplain, and bay-estuary-lagoon (Brown and others, 1976). The Modern systems include a chain of active barrier islands--north Padre, Mustang, and

St. Joseph Islands--which lie gulfward of the modern bay-estuary-lagoon system composed of Laguna Madre, and Corpus Christi, Nueces, Aransas, Redfish, and Copano Bays (fig. 1). Modern fluvial-deltaic deposits are present adjacent to and at the mouth of streams such as the Nueces River, which empties into Nueces Bay. The small size of the active Nueces bay-head delta (fig. 1) is partly a reflection of man's influence over modern drainage basins and river discharge. A small active fan delta, Gum Hollow, which is found along the northern shore of Nueces Bay, has been subjected to a detailed study of depositional processes and sedimentary structures (McGowen, 1970).

Ancient sedimentary facies, the result of depositional systems active during the Pleistocene, are present over an extensive area inland from, adjacent to, and underlying the modern sedimentary features of the Coastal Zone. Broad areas of relict interdistributary and flood basin muds are dissected by numerous linear and meandering sand bodies--the remnants of once-active distributary fluvial channels that fed prograding Pleistocene delta lobes (fig. 1). Relict marine delta front sands have been reworked; today, they are exposed locally in the Port Bay area, and along the western shore of Laguna Larga.

An ancient barrier-strandplain sand body lies landward of, but parallel to the trend of the modern barrier islands (Encinal Peninsula and Live Oak Ridge, fig. 1). Pleistocene barrier-strandplain sand bodies, collectively referred to as the Ingleside barrier (Price, 1958), occur (although locally discontinuous) along the Texas coast from Baffin Bay in South Texas to Sabine Lake at the Texas-Louisiana border, a distance of about 280 miles. The exact origin of these sand bodies--whether barrier islands similar to today's modern barriers, or strandplain deposits with only locally-associated landward-lying brackish bays and lakes--has been a subject of disagreement (Price 1933, 1958; Bernard and Le Blanc, 1965; Wilkinson and others, 1975; Brown and others, 1976). But whether these sand bodies were formed in offshore barriers or in shoreline strandplain deposits, or both, their presence--in the form of linear, well-developed and locally continuous sand bodies with a trend parallel to the local shoreline--is clear.

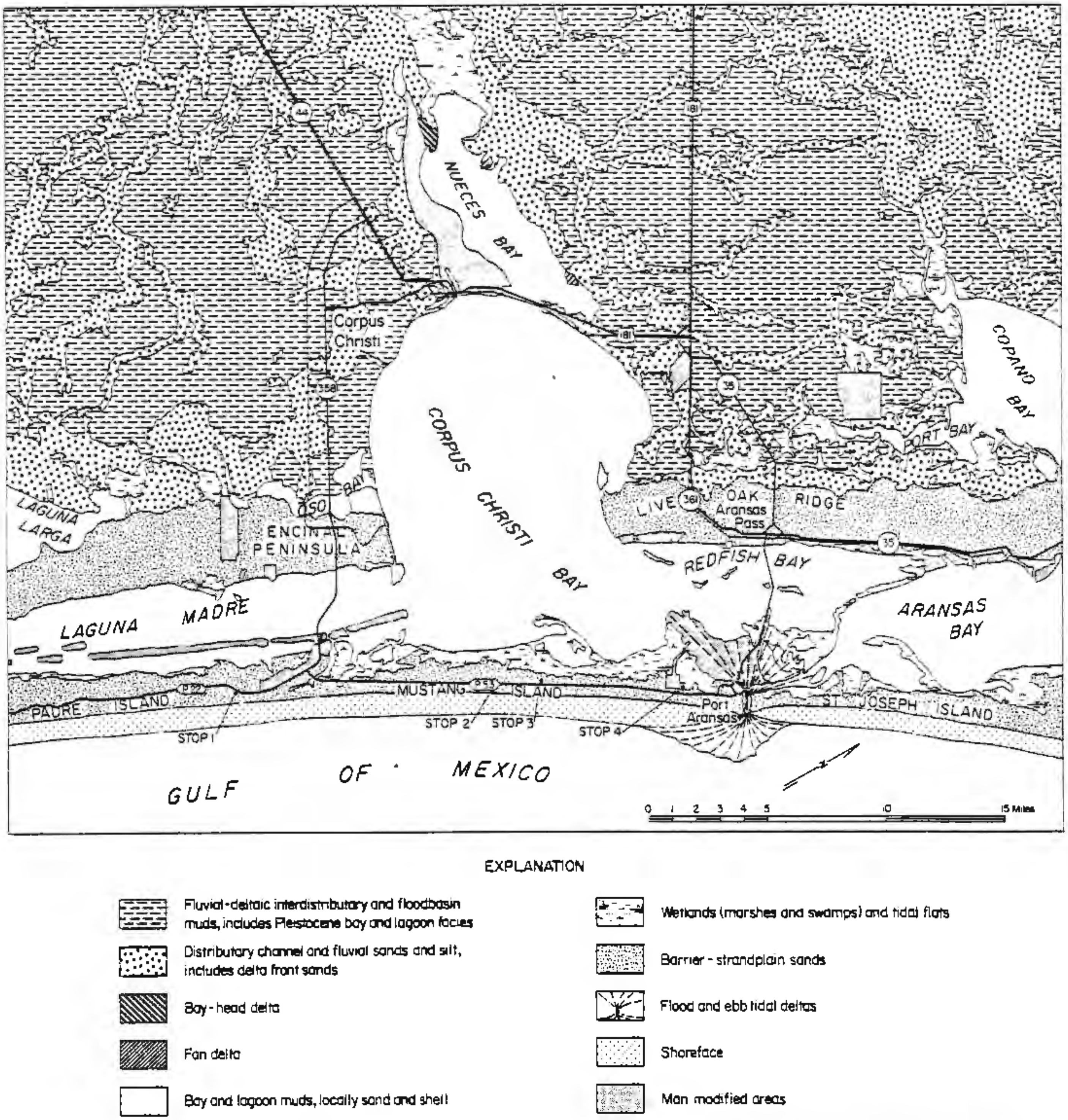

Figure 1. Modern and Pleistocene genetic facies characterizing the Corpus Christi area (modified from Brown and others, 1976). Note field trip localities.

A fluctuating Pleistocene sea level, controlled by periods of glacial advancement and decline, is responsible for many of the features preserved in the Corpus Christi area. For example, the present-day bays owe their existence to rapid down-cutting and valley formation when rejuvenated rivers cut through older Pleistocene fluvial and delta plain sediments during the last period of glaciation (when sea level was as much as 300 to 450 feet below that of interglacial periods) (Curray, 1960; Bernard and Le Blanc, 1965). Subsequent glacial melting and the accompanying rise in sea level, beginning about 18,000 years ago, flooded the relict Pleistocene valleys forming the present-day bay-estuary system.

A more detailed discussion of Modern, Holocene, and Pleistocene history, including a discussion of barrier island formation, is presented by Brown and others, 1976.

Modern depositional systems can be subdivided into numerous environments in which distinct processes and events have produced distinct sedimentary facies. The similarity between the present-day and the ancient sedimentary features establishes a link to the past. It also provides the mechanism for reconstructing and interpreting the paleoenvironments where ancient sedimentary structures, sequences, and other elements were deposited, and for analyzing the events associated with the deposition. The land and water environments characterizing the present-day barrier islands in the Corpus Christi area, which are discussed in the following sections of Part I, provide a basis for interpreting uranium host sedimentary facies of South Texas, discussed in Part II.

LAND AND WATER ENVIRONMENTS OF MUSTANG AND NORTH PADRE ISLANDS

The map of Land and Water Resources--Mustang and North Padre Islands, Texas (in envelope)*, depicts 16 land

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* The map, "Land and Water Resources--Mustang and North Padre Islands, Texas," was prepared by W. A. White and R. A. Morton, Bureau of Economic Geology, and W. B. Brodgen, Marine Science Laboratories (Port Aransas), to accompany a report to the National Science Foundation,

and water environments composing the modern barrier islands in the area of the Texas Coastal Bend near Corpus Christi. Vegetated barrier flats and marine grassflats are the two most extensive environments, including about 27 percent and 19 percent of the mapped area, respectively (table 1). Other environments are less extensive, but several, such as beaches, dunes, storm washover areas, and salt marshes, are significant island features. The general relationship of island environments is shown schematically in figures 2 and 3. Environments were mapped using 1974, black and white aerial photographic stereo pairs at a scale of 1:24,000.

Island environments are affected by a variety of active natural processes, including waves and longshore currents, tidal currents, eolian processes, tropical storms and hurricanes, and sea level rise and subsidence. Parameters of some of these processes are listed in table 2.

Using detailed field methods, the major natural environments shown on the map of land and water resources can be subdivided into component environments that are underlain by facies with distinctive characteristics. For example, the Gulf beach can be subdivided into a forebeach, berm crest, and backbeach. These environments can be distinguished through a combination of interrelated factors including slope, elevation, position with respect to the Gulf shoreline, biologic activity, wave and current energy, and internal sedimentary structures resulting from these interacting variables. As another example, those environments depicted as washover areas on the map of land and water resources include both subaerial and subaqueous features, which in turn can be subdivided into several component environments and associated facies, as described by Andrews, 1970.

Land and water resource maps, such as the one of Mustang and North Padre Islands, are different from typical geologic facies maps. Rather than showing detailed facies

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Resources Applied to National Needs Program, and the Division of Planning Coordination, Office of the Governor of Texas. Cartography was by D. F. Scranton, Bureau of Economic Geology.

TABLE 1

AREAL EXTENT AND PERCENTAGES OF TOTAL LAND AND WATER RESOURCES IN MAP AREA, MUSTANG AND NORTH PADRE ISLANDS (1974)*

(From White and others, in preparation)

Land and Water Resources	Area in Acres	Percentage of Total Map Area
Beach, coppice mounds, and wind-shadow dunes	614	1.9
Vegetated fore-island and back-island dunes	1,502	4.7
Vegetated barrier flats	8,589	26.8
Active dunes and sand blowouts	596	1.9
Washover areas	1,532	4.8
Wind-tidal, tidal, and shallow subaqueous flats		
sand flats	2,656	8.3
algal flats	2,056	6.4
salt marsh	95	0.3
Salt marshes--<u>Spartina alterniflora</u> dominant	178	0.5
Salt marshes--<u>Spartina alterniflora</u> sparse or absent	1,812	5.7
Grassflats	6,034	18.8
Local sand beaches and shell berms	54	0.2
Bay-margin sand and shoals	871	2.7
Subaerial spoil and made land	3,760	11.7
Subaqueous spoil	888	2.8
Navigation channels and permanent surface water bodies (does not include Corpus Christi Bay, Intracoastal Waterway, or Corpus Christi Ship Channel)	816	2.5
TOTAL	32,053	

* Areas were calculated on the Land and Water Resource Map (scale = 1:24,000) by using a grid-coordinate system in which the smallest unit area was equivalent to .23 acres.

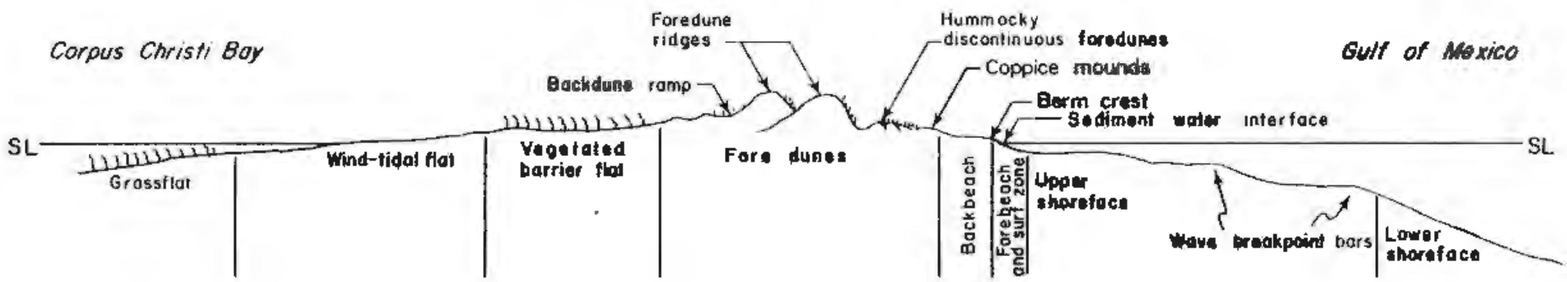

Figure 2. Generalized diagram of barrier island and associated environments gulfward of Corpus Christi Bay (modified from Scott and others, 1964).

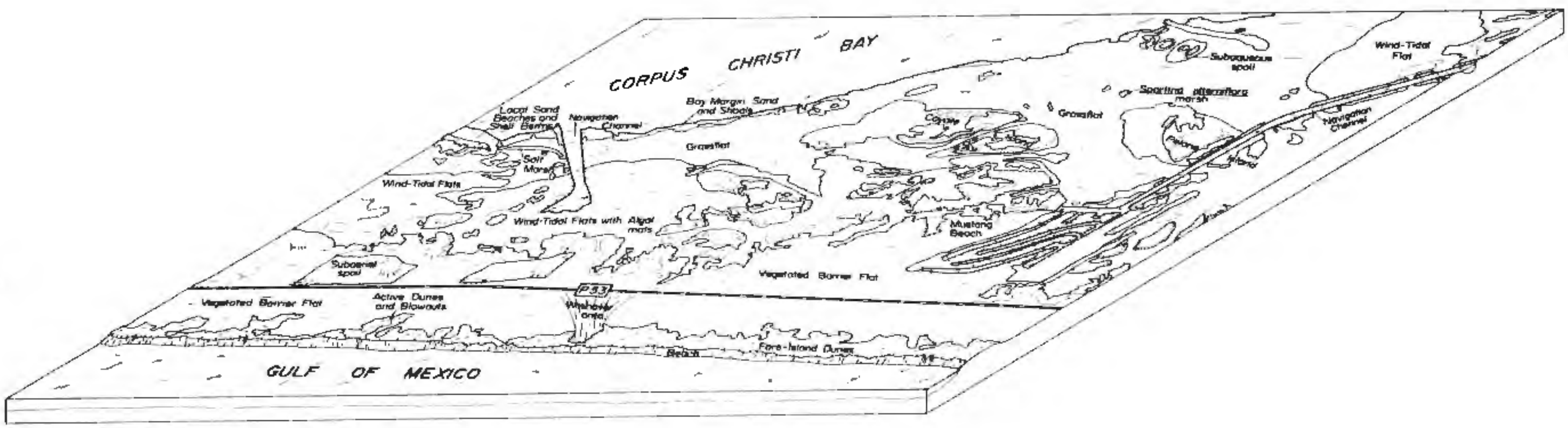

Figure 3. Generalized diagram of land and water environments on Mustang Island (from White and others, in preparation).

TABLE 2 GENERALIZED CHARACTERISTICS OF ACTIVE COASTAL PROCESSES AND CONDITIONS IN THE MUSTANG ISLAND AREA

Climatic zone	Dry Subhumid (Thornthwaite, 1948)
Mean annual precipitation	30-32 in/yr (Carr, 1967)
Dominant wind directions	Southeasterly; north-northeasterly (Lohse, 1955)
Direction of net sand transport by winds	Northwesterly (Hunter and others, 1972)
Astronomical tidal range	
Gulf shoreline	
Mean diurnal--Port Aransas	1.5 ft (Hayes, 1965)
Maximum diurnal	2.5 ft (Collier and Hedgpeth, 1950)
Bay shoreline, mean	Approx. .5 ft (1 foot lower than Gulf, Watson and Behrens, 1976)
Tidal current velocities	
Aransas Pass (after artificial deepening) average	1.45 fps (Caldwell, 1955)
Fish Pass	
Average maximum	3 fps
Usual value	below 2 fps (Defehr and Sorensen, 1973; Watson and Behrens, 1976)
Wave height	
Usual heights	below 4 ft (Davis and Fox, 1972)
Mean height	2.6 ft (Watson and Behrens, 1976)
Longshore current velocities	
Range	0-3.9 fps (Davis and Fox, 1972)
Average	.38 fps (fall) and .7 fps (winter) (Davis and Fox, 1972)
Direction of net long longshore sediment transport	Southwesterly (Lohse, 1955; Behrens and Watson, 1974)
Average rate of Gulf shoreline erosion over past 115 years (Mustang Island)	2.0 ft/yr (Morton and Pieper, 1977)
Maximum hurricane surge height recorded at Aransas Pass 1919 to 1977	11.5 ft (1919) (Price, 1956)

and their interrelationships, land and water resources maps depict environments on the basis of distinct, mappable surface features that are affected, modified and shaped through the interaction of eolian and hydrodynamic processes, and biological and chemical activity. Another aspect of land and water resource maps is that the mapped environments (both natural and man-made) are partly defined in terms of how they interact with man's activities.* Facies maps and land and water resources maps are inherently related in the sense that the natural forces that modify and shape surface features, and affect man and his activities, also modify, shape, and affect sedimentary facies.

Each of the environments delineated on the accompanying map of land and water resources of Mustang and North Padre Islands is described briefly below in terms of a general definition, areal extent, active processes, and vegetation (summarized from White and others, in preparation). Information regarding sedimentary structures of some of the mapped environments is presented in the discussion of field-trip stops following this section.

Beaches, Coppice Mounds, and Wind-Shadow Dunes

Paralleling the Gulf shoreline, this area of sand with scattered shell includes the forebeach, berm crest, backbeach, and partly-vegetated eolian dunes and mounds occurring seaward of the well-vegetated dunes and barrier flats (figs. 2 and 3). Areal extent of this unit represents less than 2 percent of the total mapped area; average width (determined at high tide) is approximately 245 feet.

The beach is a zone of high physical energy. The lower beach is subject to daily wave swash and tidal inundation; the backbeach and adjacent dunes and mounds are subject to inundation and alteration by storm tides, as well as to alteration by wind. Coppice mounds and dunes present between the backbeach and the well-vegetated fore-island dunes are sparsely to moderately well-vegetated. Bioturbation includes burrowing by mud shrimp, worms, and surf clams in the lower part of the forebeach, and crab and insect burrows and plant roots in the backbeach and coppice mound areas.

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* By definition, "land and water resource units are mappable entities, either natural or man-made, that are defined by the physical, chemical, and biological characteristics or processes which govern the type and degree of use that is consistent both with their natural quality and productive utilization" (St. Clair and others, 1975).

Extending gulfward of the beach is the shoreface, along the upper part of which are found parallel wave break-point bars (usually three) (fig. 2). Sedimentary structures in the bar-and-trough system include small-scale lenticular cross-bedding, planar laminations, and medium-scale cross-bedding (Hunter and others, 1972). Bioturbation is much more extensive in the shoreface than in the beach environment, resulting in a higher degree of destruction in primary sedimentary structures by burrowers such as Callianassa (mud shrimp), Mellita (sand dollar), and polychaetes (worms). Gulfward of the bar-and-trough system, sediments decrease in size, eventually becoming dominated by clay-sized particles.

Vegetated Fore-Island and Back-Island Dunes

Well-vegetated dunes and dune ridges are present along the Gulf side (fore-island dunes), and in some areas the bay side (back-island dunes) of the barrier islands. These environments include relatively continuous dune ridges and interlying swales and depressions, as well as irregular and hummocky blowout dune complexes stabilized by vegetation. Locally, ephemeral fresh-water ponds and marshes occur in interlying swales and depressions. Only major back-island dunes were mapped; others were grouped with the vegetated barrier flat environment.

Stabilized sand dunes compose about 5 percent of the mapped area. Elevations range up to almost 40 feet. Fore-island dunes mapped near Port Aransas include a rather broad expanse of smaller vegetated dunes lying between the beach and the main dune-ridge complex.

Sand blown from the backbeach into the vegetated dune area is trapped by a wide variety of salt-spray tolerant grasses and flowering plants, including sea oats (Uniola paniculata), bitter panicum (Panicum amarum), two varieties of morning glory (railroad vine) (Ipomoea pas-caprae, Ipomoea stolonifera), beach tea (Croton punctatus), and sea purslane (Sesuvium). Lower elevations in the fore-island dune areas are subject to inundation and erosion by storm waves and storm surge. Fore-island dunes provide important storm surge protection for bayward environments, both natural and man-made.

Vegetated Barrier Flats

Vegetated barrier flats are hummocky, grass-covered sandy environments of low relief generally lying between the fore-island dunes and bay marshes and tidal flats. The origin and history of this hummocky land are reflected through the presence of grass-covered stabilized dunes, deflation flats, and washover deposits. Ephemeral fresh-water ponds and marshes occur in this environment.

Vegetated barrier flats compose almost 27 percent of the mapped area; this environment is the most extensive of all in the map area, and perhaps could be called the heart of the island. Elevations are generally less than 10 feet (except where dunes have been included), and they decrease toward the bay. Although much of the vegetated barrier flat is protected by fore-island dunes and vegetation, some areas may be affected by storm tides and windblown sand.

A wide variety of grasses and flowering plants helps support a population of animals including the Texas pocket gopher. Burrowing animals, aided by root action, churn through the sandy substrate, erasing most primary sedimentary structures.

Active Dunes and Sand Blowouts

These environments, composed of migrating sand dunes and sand sheets, comprise almost 2 percent of the mapped area. Component environments include large, active back-island dune fields and associated deflation flats, as well as smaller areas of active dunes and blowouts in close association with vegetated fore-island dunes and washovers. Small sand blowouts along the seaward flanks of vegetated fore-island dunes were mapped with the beach, coppice mounds, and wind-shadow dunes.

Loose sand, directed primarily by prevailing southeasterly winds, and, to a lesser extent, by north winds associated with frontal passage, migrates bayward and, if not stabilized, may eventually be blown into bays and lagoons.

Dune elevations range up to more than 25 feet in the mapped area. Active dunes are generally barren, although they are locally sparsely vegetated by plants that can adapt to the unstable conditions. Early colonizing (pioneer) plants are important in eventually stabilizing the shifting sand.

Washover Areas

These low-lying environments, covering about 5 percent of the mapped area, are periodically inundated; they are subjected to intense wave and current energy during hurricanes. The largest washovers, which are related to inactive tidal inlets such as Corpus Christi Pass, Newport Pass, and Packery Channel, extend into Laguna Madre. Smaller washovers are present northeast of Corpus Christi Pass. Subaerial and subaqueous environments are included in this map unit.

Intense wave and current energy, concentrated in washover areas during storms, scour channels and transport sediments bayward, forming washover fans. Sediments also may be transported gulfward by flood waters flowing from the bays and lagoons, following passage of a hurricane (Hayes, 1967). Between storms, sand transported along the shore eventually straightens the Gulf shoreline and closes the mouths of the washover channels. Large, subaerial unvegetated washovers are subjected to extensive modifications by windblown sand.

Major washovers are generally barren of vegetation. Extant vegetation in and around washovers was mapped according to the type of vegetation--salt marsh, vegetated barrier flat, or grassflat, although these vegetation zones are subject to the effects of storm washover. Smaller washover channels north of Corpus Christi Pass extend bayward across the vegetated barrier flats and, locally, are filled with extensive marsh vegetation.

Wind-Tidal, Tidal, and Shallow Subaqueous Flats

Wind-tidal flats are generally bay-margin environments periodically inundated by wind and storm tides. Tidal flats are subjected to daily inundation by astronomical tides. Shallow subaqueous flats are either continuously inundated, or exposed only during extremely low tides. These environments, collectively comprising approximately 15 percent of the mapped area, have certain common characteristics. They are generally located on the bay side of the barrier islands; they are relatively flat, with little or no standing vegetation; and they are subjected to flooding. Blue-green algae may flourish on wind-tidal flats shortly after inundation, producing mats which bind the sandy sediment into a tough substrate.

Elevations in these environments generally range from about 3 feet above mean sea level on wind-tidal flats, to less than 3 feet below mean sea level on shallow subaqueous flats. Most of the tidal flats are composed of sand, although some mud may be present in depressed areas. Some of the flats on which algal mats are present have a characteristic sponge cake texture (see discussion of field trip stop 4). In a few wind-tidal flat environments, salt-marsh vegetation such as shoregrass (*Monanthochloe littoralis*), glasswort (*Salicornia spp.*), and saltwort (*Batis maritima*) is present.

Salt-Marsh--*Spartina alterniflora* Dominant

Marshes with high biologic productivity, composed predominantly of smooth cordgrass *Spartina alterniflora*, occur along bay margins north of Wilson's Cut (land and water resources map). Unlike extensive stands of *S. alterniflora*, which characterize marshes on the east coast of the United States and some areas of the Texas Coast, marshes along Mustang Island comprise only about 0.5 percent of the mapped area; they are composed of relatively narrow, discontinuous stands of *S. alterniflora* that generally fringe spoil islands and tidal flats. A major exception in the area is the relatively large marsh west of Port Aransas, which is supplied with nutrients from the Port Aransas sewage treatment plant outfall.

Marshes occupy areas of relatively low physical energy--areas that are protected from large waves and strong currents by adjacent grassflats, tidal flats, and shallow subaqueous sand flats and shoals. Firmly-rooted marsh plants dampen currents accompanying periods of tidal or storm inundation and, in so doing, help to trap sediment and inhibit erosion.

Salt Marshes--*Spartina alterniflora* Sparse or Absent

These types of marshes, which cover almost 6 percent of the mapped area, consist primarily of salt-marsh plants other than *Spartina alterniflora*. Typical salt marsh plants include *Monanthochloe littoralis* (shoregrass, *Distichlis spicata* (salt-grass), *Batis maritima* (saltwort), *Salicornia spp.* (glasswort), and *Borrichia frutescens* (sea-oxeye). These plants generally occur in slightly higher elevations with respect to mean sea level than does *Spartina alterniflora*; but they occur in lower elevations than do grasses typical of the vegetated barrier flat.

Marshes of this variety occupy two rather distinct environmental settings on the bay side of the barrier islands--(1) extensive environments adjacent to washover channels, wind-tidal flats, and vegetated barrier flats; and (2) less extensive environments with relatively close communication with bay margin subaqueous environments.

Sediment in these marsh environments is predominantly fine-grained sand, except in areas underlain by local sand beaches and shell berms. In these environments the sediment is much coarser, due to large quantities of shell material. Marshes occuring in and adjacent to washovers are likely to be affected by storm tides, waves, and currents. Marshes in close proximity to subaqueous bay margin environments may be subjected to frequent inundation, whereas marshes extending gulfward onto the vegetated barrier flats are rarely inundated.

Grassflats

Grassflats are shallow, subaqueous flats containing moderate to dense growths of marine grasses, providing a highly productive biologic environment. Locally, sparse stands of marine grasses are grouped with adjacent, more densely-vegetated flats. Grassflats occupy approximately 19 percent of the mapped area, and are most extensive along the margin of Corpus Christi Bay between Wilson's Cut and East Flats, and in Laguna Madre.

The most common grass in the Mustang Island area is shoalgrass (Halodule wrightii), with some turtlegrass (Thallasia testudinum) present in deeper areas. Macro algae make up a significant part of the grassflat environment. These marine grasses grow in water generally less than 6 feet deep. Substrates are composed of sands, muddy sands, and sandy muds.

Marine grasses commonly grow in environments protected to some extent from wave energy. The dense vegetation tends to trap suspended sediments, a process which alters the original sandy substrate. Currents and waves resulting from strong and persistent winds, however, occasionally agitate the flats, resulting in considerable exportation of plant debris that accumulates along the bay margin. This mass of organic debris may eventually produce the peat found in some bay-margin facies. Peat has been observed in association with vegetated sand and with shell berms north of Wilson's Cut.

Local Sand Beaches and Shell Berms

On Mustang Island, beaches and shell berms along the margins of Corpus Christi Bay occupy about 0.2 percent of the total area. Bay-margin beaches are similar to those along the Gulf, but are thinner, lower-energy features that contain a much greater shell content. During storms, coarse shell debris is deposited above normal water levels along bay margins, forming storm berms or aprons. Older beaches and berms become vegetated and stabilized, and are, therefore, classified and mapped according to the dominant type of vegetation.

The width of unvegetated beaches and berms varies from a maximum of 500 feet (at Shamrock Point) to less than 10 feet. Beaches and berms are highly susceptible to erosion, modification, and flooding during tropical storms and northers.

Bay-Margin Sand and Shoals

Shallow subaqueous sands, which occur along the margin of Corpus Christi Bay, underlie an environment where relatively intense wave and current energy induces considerable movement of sand back and forth, and along the shore.

Transportation and redistribution of sediment is especially dominant in this environment, which is unprotected from waves generated by north winds blowing over broad reaches of Corpus Christi Bay. These narrow, relatively high-energy environments, where sorting of sediments is an important process, somewhat resemble the upper shoreface environment on the Gulf side of the barrier island. Like the Gulf shoreface, offshore sand bars are common within the bay-margin sand and shoal environment.

Bay-margin sand and shoals account for 2.7 percent of the total mapped area. The width of this environment ranges from more than 1,500 feet, to less than 50 feet. Water depths vary, but maximum depth is generally less than 6 feet below mean sea level.

Subaerial Spoil and Made Land

Subaerial environments that either have been created by or significantly altered by man's activities occur at many locations adjacent to Mustang and north Padre Islands. Subaerial spoil is generally composed of sand, shell, and some mud. Composition varies, depending upon what parent material was dredged. The term "made land" refers to areas that have been filled, graded, or otherwise altered from a natural state for developmental and industrial purposes. Much of the made land is, of course, composed of spoil. Subaerial spoil and made land comprise 11.7 percent of the total area. Both vegetated and unvegetated areas are included in this unit.

Subaqueous Spoil

In many areas, spoil forms subaqueous environments either as a result of initial disposal operations, or as a result of natural dispersion by erosion or by transportation processes. Most subaqueous spoil, which makes up almost 3 percent of the Mustang and north Padre Islands map area, fringes subaerial spoil environments paralleling dredged channels. Where marine grasses have become established on subaqueous spoil, the areas were mapped as grassflats.

Subaqueous spoil is susceptible to extensive reworking by waves and currents, a process which concentrates coarse material, while spreading finer, dredged sediment into adjacent, low-energy, subaqueous environments.

Navigation Channels and Permanent Surface Water Bodies

In many areas of north Padre and Mustang Islands, canals and channels have been dredged for recreational, commercial, industrial, and biological purposes. These channels are generally narrow, with relatively straight boundaries.

Of the natural water bodies present in the area, only those inferred to be permanent are shown on the map of land and water resources, although many ephemeral, fresh-water ponds exist on the vegetated barrier flats and in interdune depressions. This environment, which comprises 2.5 percent of the total mapped area, does not include the Gulf, Corpus Christi Bay, the Intracoastal Waterway, or the Corpus Christi Channel.

Tidal Inlets

Although not shown on the map of land and water resources, tidal inlets (passes), which function as passageways connecting Gulf and bay waters, are important environments in the barrier and bay-lagoon system. Sediments are transported through the inlets by flood- and ebb-tidal currents, forming tidal deltas at the bayward and gulfward ends of the inlets, respectively (fig. 1). Subaqueous ebb-tidal deltas are continuously reworked by waves and longshore currents operating along the Gulf shoreline, while flood-tidal deltas may become emergent, normally as a result of sediments deposited by hurricanes and tropical storms above average tidal levels.

Aransas Pass is a tidal inlet separating Mustang and St. Joseph Islands (fig. 1). Until stabilized by jetties, Aransas Pass migrated southwestward in the direction of longshore drift, leaving behind a thick accretionary sequence of sand overlying a scoured base; consequently, the southern end of St. Joseph Island accreted southward at the expense of Mustang Island (Brown and others, 1976). Lying bayward of Aransas

Pass is Harbor Island, which, although extensively modified by man, is a natural flood-tidal delta.

Packery Channel (also known as the old Corpus Christi Pass) is a relict tidal inlet that was closed about 1924 as a result of man's activities (Price, 1952). Along with Newport and Corpus Christi Passes, Packery Channel functions today as a storm-washover channel. Fish Pass, a man-made channel, currently provides a passageway for the exchange of waters between the Gulf and Corpus Christi Bay.

FIELD TRIP TO MUSTANG AND NORTH PADRE ISLANDS

The field trip focuses primarily on modern barrier islands by investigating environments at four locations (stops) on Mustang Island and north Padre Island (fig. 1). The preceding brief discussion of the geologic setting and environments of barrier-strandplain systems in the Texas Coastal Bend sets the stage for a more detailed look at a few of the modern barrier environments, and their associated sedimentary facies.

Stop 1: Active Dune Field--North Padre Island

This stop is located adjacent to and east of Park Road 22, about 2.8 miles south of the intersection of Park Road 22 and Park Road 53 (fig. 1). This particular active dune field lies southeast of and off the area shown on the land and water resources map (in envelope).

Points of Interest

1. Orientation and position of dune field with respect to other island environments.

This dune field, like most on Padre Island, originated from eolian blowouts (localized sand areas susceptible to wind erosion because of devegetation) in the area of fore-island dunes. From the orientation of the major sand body and the position of interlying deflation areas, one can conclude that net migration is generally to the northwest. Migration of sand is controlled by two major wind systems (table 2)--prevailing southeasterly winds, and northerly to northeasterly winds associated with frontal passages. The direction of net sand migration is in the northwest quadrant, 15° north of the resultant vector (301°) of yearly wind directions (Hunter and others, 1972).

Migration rates of sand dunes on north Padre Island have been reported up to 75 and 85 feet per year (Hunter and Dickinson, 1970; Price, 1971).

2. Slipfaces and resulting cross-bedding

a. Orientation--Orientation of slipfaces is, of course, controlled primarily by wind direction. In figure 4, slipfaces strike approximately NE-SW, or transverse to the southeasterly winds which were dominant when the photo was taken. Figure 5 shows truncated cross-bedding, which was exposed in a deflation area windward of migrating dunes on north Padre Island. The beds strike approximately NE-SW.

Following the passage of a dry frontal system, slipfaces may turn southward, approaching a NW-SE strike, in response to northerly and northeasterly winds. If precipitation accompanies the frontal passage, however, the moistened sand will greatly inhibit the effectiveness of the north wind as a transporting agent.

Dune cross-bedding in back-island dune fields generally dips toward the northwest quadrant in response to the prevailing southeasterly winds (Hunter and others, 1972). In a study of fore-island dunes on Mustang Island, however, McBride and Hayes (1962) found that dip direction was bimodal, with dominant dip directions toward the north and west-southwest. These dip directions were not expected, in light of the dominant winds. Hayes and McBride (1962) postulated that the bimodality of the cross-bedding was the result of the uniquely-shaped fore-island dunes formed though the combined effects of the predominant winds and stabilizing vegetation. Hayes later modified the hypothesis to one favoring southeasterly winds and the accumulation of sand in wind-shadow zones leeward of vegetated mounds (1967).

Figure 4

Figure 5

Figure 4. Active dune field, north Padre Island. Photograph was taken in June, 1976, when southeasterly winds were dominant. Large avalance face in right foreground strikes approximately NE-SW. View is southward.

Figure 5. Truncated eolian cross-nedding. Sunglasses on this near-horizontal, wind-eroded surface serve as a scale. This deflation surface formed windward of a migrating dune when sand was deflated (eroded) down to the moist capillary fringe overlying the shallow water table. Moisture stabilized and prevented removal of additional sand, allowing crossbeds to be etched as dry sand migrated over the moisture-stabilized surface. Beds strike approximately NE-SW.

b. Angle of Repose--The angle of repose near the top of well-developed and relatively large slipfaces on dunes in the active field should be near 31° (± 2°). This angle agrees with dip measurements made near the top of foreset beds in most modern dunes (Bigarella, 1972). But cross-bedding in some fore-island dunes on Mustang Island may dip up to 42°, although average dip is 24° (McBride and Hayes, 1962). One explanation for this unusually high angle, according to McBride and Hayes, is that salt spray binds the sediment so that it achieves steeper angles of repose.

Relict dune cross-bedding observed in sedimentary rocks generally exhibits lower dip angles (20-29°) than those in present-day dunes. Bigarella (1972) attributes these lower angles to the fact that the base of the foresets (where angles of dip in the large tangential cross beds are lower than near the top) are more frequently stabilized and preserved by rising ground water than the top portion of the foresets, which are "eroded before deposition of the next overlying sets."

This discussion of dune stratification has focused on medium- to large-scale cross-bedding resulting primarily from fine-grained, well-sorted sand avalanching on dune slipfaces. Other kinds of eolian stratification are present in dune deposits, however, including those associated with ripple surfaces, smooth leeward-sloping surfaces, and deformation on slipfaces as a result of slumping (Hunter and others, 1972).

Barrier island dunes are rarely preserved in the stratigraphic record because they are commonly destroyed during subsequent erosional and depositional events.

Stop 2: Beach and Washover Area--Mustang Island

This locality is situated along the Gulf beach, approximately 800 feet north of Beach Access Road No. 2, which is the first access road along Park Road 53 northeast of Fish Pass (fig. 1).

Points of Interest

1. Beach.

a. Composition and sub-facies--The beach, composed of well-sorted, clean, predominantly quartz sand, with minor amounts of shell material and heavy minerals (in this area), can normally be subdivided into forebeach and backbeach (also known as foreshore or beachface, and backshore or berm). These two areas are normally separated by an interlying berm crest (fig. 2), which generally "runs" parallel to the shoreline. The gulfward-sloping forebeach reflects the influence of the swash zone as it moves landward and seaward with the tidal cycle. Occasionally, more than one berm crest may occur, indicating neap to spring, or storm-induced variation in the tidal cycle. Also, on occasion, storm tides may level and smooth the entire beach, temporarily eradicating the berms. On central Padre Island, in the area of longshore convergence, beaches have a high shell content. The coarse material is instrumental in producing a much steeper forebeach, with more highly accentuated berms, than in the Mustang Island area, where beach sediment is principally fine-grained quartz sand.

b. Internal sedimentary structures--Sedimentary structures in the forebeach deposits of Mustang Island are primarily of seaward dipping, low-angle cross strata similar to those shown in figure 6 (2-5°, McKee, 1957; 2-7°, Milling and Behrens, 1966; 1-6°, Moiola and Spencer, 1973). Some strata, however, may dip in divergent directions, affected by the presence of beach cusps with trends transverse to the shoreline (McKee, 1957).

The backbeach is characterized by irregular cross strata, with beds that locally dip landward as well as seaward. Dip angles range from a few degrees to as high as 6-12° (McKee, 1957), and 9-16° (Millings and Behrens, 1966) locally in trough-fill cross beds. Eolian sand and beach sands are commonly interbedded in backbeach areas (Dickinson and others, 1972).

c. Bioturbation--Moiola and Spencer (1973) subdivided the forebeach (foreshore) into upper and lower zones on the basis of tidal influence and related bioturbation. The upper foreshore extends from high tide to mean sea level, and the lower foreshore extends from mean sea level to low tide. Mud shrimp (*Callianassa*) burrows, which may extend several feet into the sediment, are the dominant biological feature in the lower foreshore, although the surf clam, *Donax variabilis*, is also an active burrower, often disturbing sediment near the surface. Polychaetes (worms) are also important burrowers

Figure 6

Figure 7

Figure 6. Beach trench, Mustang Island. This trench, about 9-10 inches deep, exposes fine-grained, well-sorted sand in layers dipping gently gulfward. Slight convex-upward bedding shown by upper layers reflects effects of a low mound associated with a beach cusp at the location of the trench. Gulf is left of trench.

Figure 7. Washover area, just northeast of Beach sccess Road #2, Mustang Island. Note absence of well-developed fore-island dunes gulfward of washover channel. Fences have been placed across mouth of washover in an unsuccessful effort to trap and accumulate sand. Shortly before the photograph was taken in August, 1976, high Gulf waters flowed across the beach cutting a narrow, slightly sinuous channel and forming a small washover fan at the gulfward edge of the washover body of ponded water (remnant of an older chanel).

in beach sediments (McGowen, personal communication). The upper part of the foreshore is characterized by very few Callianassa burrows and some ghost crab (Ocypode spp.) burrows (Moiola and Spencer, 1973).

Biologic structures in the backbeach include ghost crab burrows, some insect burrows, and root traces.

2. Washover Area.

a. Surface characteristics--Although the washover at this locality is much smaller than those at Corpus Christi Pass, Newport Pass, and Packery Channel (see land and water resources map), aerial photographs show fore-island and back-island features which indicate that a much larger relict washover occurs in this area. The present active washover (fig. 7) has certain typical characteristics that indicate the probable intercommunication of the area with Gulf or bay waters during storms. These characteristics include the following: (1) absence of well-developed, protective fore-island dunes gulfward of the washover; (2) generally flat topography with low elevations interrupted by scattered eolian mounds; (3) ponded water in scoured channels; (4) absence of barrier flat vegetation; (5) presence of scattered marsh plants and local algal mats; and (6) distinctive position and orientation with respect to the Gulf shoreline.

b. Sedimentary features--Washover facies include washover fans and distributary channel center and margin facies which may be interbedded with marsh, mudflat, pond, oysterbank, and eolian deposits (Andrews, 1970). Andrews (1970) found that washover sands overlie a sharp scour surface, and that they consist of sediments grading upward from a basal shelly deposit into "horizontally laminated, shell-free clean sand." He also noted that in most facies associated with the washover, except the washover sands, primary sedimentary structures are "masked or destroyed by animal burrowing and/or root growth." Dark-colored organic-rich layers characterize pond sediments in the washover channel, indicating that reducing conditions are associated with decaying organic material (Dickinson and others, 1971).

In June, 1977, shallow trenches in the washover area at stop 2 revealed that reducing conditions prevailed near the water table, which is only millimeters below the surface as one approaches the ponded water in the relict washover channel. Thin algal mats commonly cover the surface sediments around the pond, indicating an earlier, higher pond level. Numerous insect and crab burrows, as well as plant roots, penetrate the dark-gray reducing zone, destroying primary stratification and promoting oxidation. This oxidation is reflected by interconnected "cylindrical halos" of yellow iron oxides that contrast strikingly with the surrounding darker-colored sediments (fig. 8). Trenches in topographically-higher eolian sediments, deposited along the edge of the relict channel, display a much thicker oxidized layer above the gray reducing zone associated with the water table (fig. 9). Sediments from the reducing zone have a characteristic hydrogen sulfide (H_2S) odor.

Milling and Behrens (1966), who encountered the dark reducing zone near the water table in trenches dug in the backbeach and dunes on Mustang Island, noted that after several hours of exposure to the atmosphere, the dark sands became lighter, approaching the color of the surface sands.

According to Berner (1971), anaerobic waters are common in sediment interstices because of organic oxidation by aerobic bacteria which live at the sediment surface, rapidly consume oxygen, and prevent its diffusion into the sediment below. In the absence of oxygen, further oxidation of organic material must be accomplished with other oxidizing agents such as $S0_4^{--}$. Berner (1971) also notes that the relatively high $S0_4^{--}$ content of sea water makes formation of H_2S in organic sediments extremely common. Furthermore, once the H_2S is formed in anaerobic sediments, it may be oxidized through reaction with overlying oxygenated water, either by diffusing along a sharp interface, or by mixing as a result of storm stirring or burrowing organisms.

Although Berner's explanation of oxidation-reduction deals with aerobic waters overlying anaerobic sediment conditions, some of the oxidation-reduction relationships found in the washover area are probably similar. The algal mats that cover much of the sediment surface may provide much of the organic material necessary for the aerobic bacteria; the occasional influx of sea water may provide necessary $S0_4^{--}$

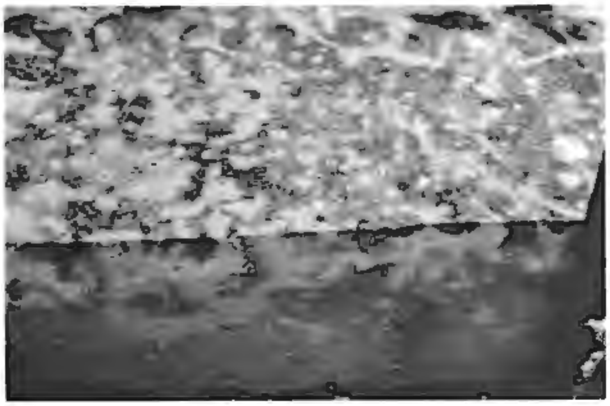


Figure 8

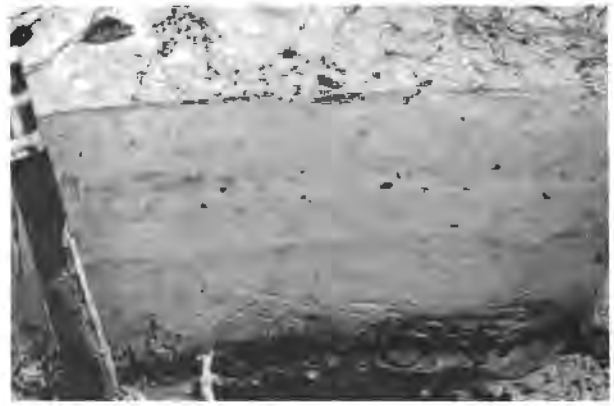


Figure 9

Figure 8. Burrows in sand exposed in trenches in washover channel shown in figure 7. This shallow trench shows the effect of burrowing organisms (mostly insects, crabs, and worms) that occupy sands in the washover channel bayward of the backbeach and coppice dune area. A thin surface veneer of light-colored oxidized sand was scraped away to produce the near horizontal surface shown in the upper half of the photograph; the vertical face shown in the lower half of the photograph extends to the water table and exposes about 5 inches of sediment. Mottling is caused by oxidation of sand forming a light rusty-yellow color around burrows that contrast with surrounding dark gray reduced sediments.

Figure 9. Mottled sand adjacent to washover channel. Root growth, organic debris, and burrows are exposed in trench (about 1 foot in depth) which was dug adjacent to, but in higher ground than the trench shown in figure 8. In this environment the zone of oxidized sediment is much thicker than in the washover channel. Note dark sediments that outline water table at the bottom of the trench.

Figure 10

Figure 11

Figure 10. Shoregrass on Mustang Island. Shoregrass (*Monanthochloe litoralis*) characterizes one type of salt-marsh environment shown on the land and water resources map. Photograph was taken along the bayside of Mustang Island west of Fish Pass.

Figure 11. Algal/wind-tidal flat, Mustang Island. Wind-tidal flat shown in photograph is just southwest of Port Arensas. Algal mat which formed when the flat was flooded, has cracked and contracted from desiccation.

for the formation of H_2S; and the burrowing insects and crabs may provide the mechanism for subsequent sediment mixing and oxidation. In a study of Laguna Madre flats bayward of central Padre Island, Fisk (1959) found anaerobic bacteria in a reducing zone just beneath surface algal mats. Below the mats was a zone of black mud with a strong H_2S odor; decomposition by the bacteria of the algal-associated organics produced gray massive clays. Gases released from this decomposition are discussed in the description of algal/wind-tidal flats at stop 4.

Stop 3: Salt Marsh--Mustang Island

Stop 3 is near the gulfward tip of Wilson's Cut, which in turn is near the center of Mustang Island, approximately 0.3 miles northwest of Park Road 53 (fig. 1). The marsh lies along the northeast edge of Wilson's Cut (land and water resources map).

Points of Interest

1. Type of marsh and location with respect to other island environments.

The salt-marsh vegetation of this environment is composed primarily of shoregrass (*Monanthochloe littoralis*) (fig. 10), although there are small areas of interlying sand which are barren, except for algal mats. Other plants common in this environment are listed elsewhere (p. 15).

The size of the marsh and its position with respect to the bay shoreline indicate that these marsh plants do not require frequent tidal flooding to survive. Shoregrass and associated marsh plants lie, topographically, between higher elevated plants typical of the vegetated barrier flat (normally gulfward), and plants like *Spartina alterniflora* that characterize the lower intertidal marshes (normally bayward). Formation of this particular marsh environment can be related to a past history of storm washovers. The marsh partly protrudes across the barrier flat core, and a small present-day washover channel lies gulfward of the marsh.

2. Sedimentary Features.

Trenches in this environment reveal a substrate with the following general characteristics: (a) massive, mottled, light-colored, fine sand, and slightly muddy sand containing scattered crab fragments; and (b) few distinguishable primary sedimentary structures because of root growth and decay and burrowing activity. In one trench a distinct contact between a relatively massive clean sand overlying a slightly muddy sand was encountered. Sediments were water saturated above the contact but not below, perhaps indicating a local, shallow, perched water table.

Stop 4: Wind-Tidal/Algal Flat--Mustang Island

This stop is located near the northeast corner of the Mustang Island airport, about 1.5 miles west of Port Aransas and approximately 0.3 miles northwest of Park Road 53 (fig. 1).

Points of Interest

1. Frequency of inundation and formation of algal mats.

This particular part of back-island tidal flats is far removed from the bay shoreline, where mean astronomical tides raise bay levels about 0.5 feet. Salt-water flooding of this area is, therefore, controlled by wind- and storm-tides. Strong winds, accompanied by spring high tides and a barometric low, can create tides 2 to 3 feet higher than those produced solely by astronomical conditions (McGowen and others, 1977).

After the flats are flooded, filamentous, blue-green algae flourish, creating a thin layer that covers the sandy substrate. When the flats dry, the algal layers form a leathery mat that eventually contracts, breaks, and curls during desiccation (fig. 11). Hoover (1968) noted that renewed inundation can heal the cracks with a new growth of algae.

Below the mat surface, decomposition of organic material by bacteria releases gases (primarily nitrogen, with smaller amounts of CO_2, NH_4, and O_2) that may raise portions of the mat, forming gas "mounds" (Fisk, 1959). On tidal flats in the Land Cut area of central Laguna Madre, Fisk (1959) found some mounds with diameters of more than 6 feet and heights of up to 6 inches. Zupan (1971) observed similar mounds in the Middle Ground area along central Laguna Madre. Formation of mounds seems to be related to a muddy, impermeable substrate.

2. Sedimentary Features.

Sediments on barrier-bordering, wind-tidal flats along the South Texas Coast are characterized by laminated blue-green algal mats and clay seams (deposited when the flats are inundated by wind-tides); these are interbedded with eolian sand (deposited from back-island dune fields while the flats are subaerially exposed) (Scott and Hayes, 1964). Hoover (1968) observed similar deposits (containing scattered shell fragments) in supratidal facies of Harbor Island, and noted that the relative amounts of algal mats, mud, and eolian sand depend upon frequency and duration of inundation, and upon available loose sand for eolian distribution. Small polychaete worms may rework and mix the sand and mud laminae (Hoover, 1968).

Trenches near this field trip stop primarily reveal a mottled sandy substrate with some interbedded muddy sand and scattered shells. Primary horizontal laminations are obscure because they are disturbed by burrowing organisms and root growth. Glasswort (Salicornia sp.) sometimes occupies these flats (some species on a seasonal basis), with consequent mottling of the tidal flat deposits. Apparently, glasswort is the only large plant with a tolerance for the salt-saturated soil (Siler and Scott, 1964).

As previously noted, this particular wind-tidal/algal flat is located some distance from the bay shoreline, which indicates that the flat is infrequently flooded by bay waters. This may account for the predominantly sandy substrate with minor amounts of muddy sand. Reconstruction of the sedimentary events is complicated by the possibility that some of the sand was deposited by storm washovers. Although well-vegetated fore-island dunes currently exist gulfward of this tidal flat environment, forming a barrier against storm surge waters, the dunes are partly restabilized, discontinuous blowouts. Consequently, the dune ridge has been breached by storm washovers. The washover was eventually "healed" by growth of vegetation-stabilized eolian dunes. Furthermore, the semicircular shape (in plan view) and the orientation of vegetated sand dunes lying bayward of and topographically higher than these flats, indicate that the dunes have become established on remnants of a washover fan.

"Sponge cake" textures that sometimes can be detected by walking on the algal flats are formed by the entrapment of gas in sand and muddy sand (Van Straaten, 1954; Zupan, 1971). The gas cavities (1-2 mm in diameter) "...are layered as laminae which sometimes show cross-stratification" (Zupan, 1971, p. 37).

In one trench in a vegetated mound adjacent to the tidal flats at this locality, calcareous cemented aggregates of sand grains up to 2 centimeters in diameter were encountered within a relatively thin zone, approximately 1.5 to 2 feet below the surface. The aggregates are riddled with small tubular holes, some of which are lined with traces of root fragments. Hoover (1968) reported aragonite-cemented sand grains associated with algal mats in supratidal facies on Harbor Island. Zupan (1971) also observed carbonate cemented sand aggregates in wind-tidal flat facies, but their occurrence was at no specific horizon.

PART II: THE JACKSON GROUP OF SOUTH TEXAS--URANIUM MINERALIZATION IN FACIES OF AN EOCENE BARRIER/LAGOON DEPOSITIONAL SYSTEM

INTRODUCTION

Although second in importance to fluvial and fan system facies as hosts for epigenetic uranium deposits, facies of barrier bar and associated lagoonal depositional systems contain significant quantities of ore reserves, and constitute future exploration targets. The Jackson Group (Eocene) of the Texas Coastal Plain provides a well-documented example of interrelationships between coastal barrier facies and associated ore deposits. Production from the upper sand units of the Jackson, which began in 1960, will exceed 20 million pounds of U_3O_8. To date, mining has been exclusively by open-pit methods and is centered in Karnes County (fig. 12).

Part II of this guide book summarizes sedimentary features of the Jackson barrier bar system which have been exposed by uranium mining, illustrates the principal facies and the criteria used in their recognition, and describes the known distribution of ore in each facies. The descriptions serve two purposes. First, comparing features in the Jackson with sedimentary deposits of similar modern coastal environments illustrates the usefulness of well-understood depositional models for detailed genetic facies interpretation. Second, the combining of process and geomorphic description (which is supplied by the study of modern depositional systems) with the three-dimensional description of sedimentary deposits and their internal structures (which is accomplished in the stratigraphic record) produces an integrated facies model which can be applied to the interpretation of similar facies in other depositional systems. Distribution of mineralization, as well as response to in situ recovery of the uranium, probably will be influenced both by internal and external characteristics of different genetic facies.

DEPOSITIONAL SETTING OF JACKSON GROUP (EOCENE)

The Jackson Group of the South Texas Coastal Plain consists of interbedded sand, mud, and lignite deposited in the upper part of a major progradational cycle that includes the underlying Yegua Formation. Secondary transgressive and regressive pulses punctuate the Jackson offlap sequence, which is, in turn, over-ridden

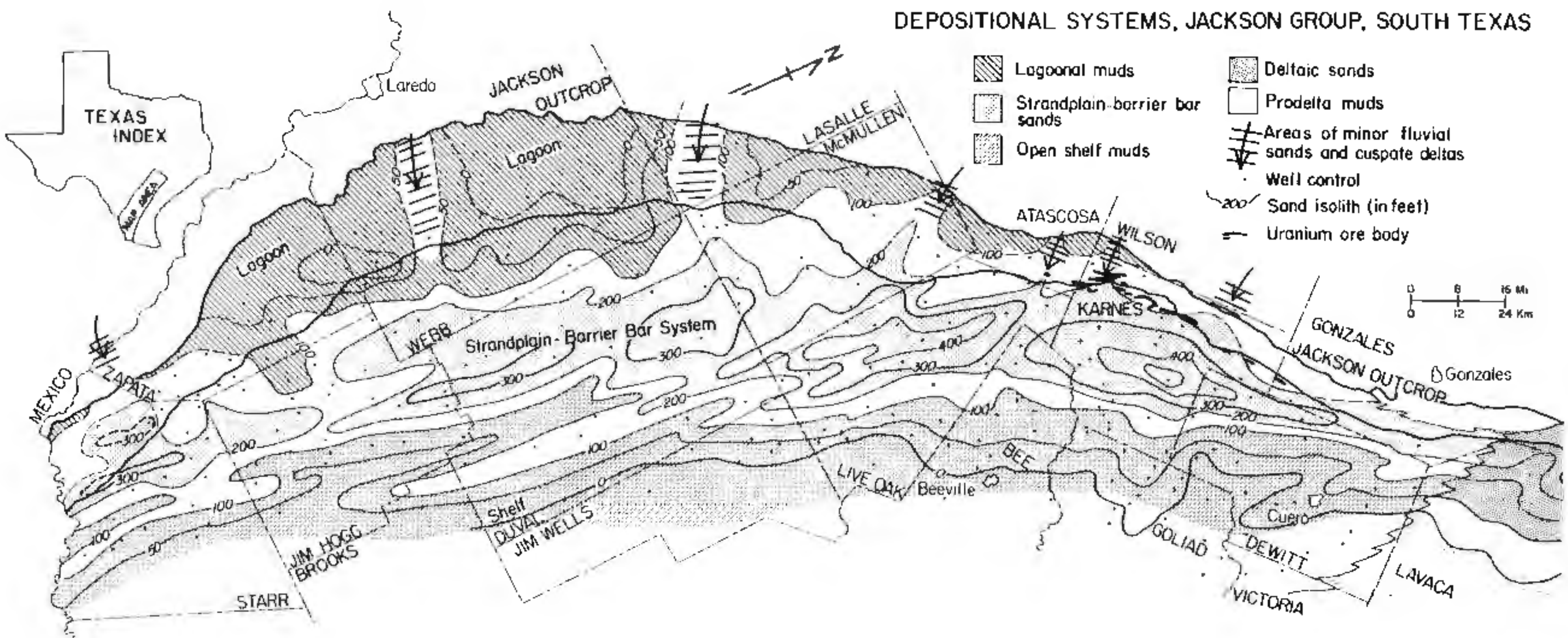


Figure 12. Net sand isolith map and depositional systems of the Jackson Group (Eocene), South Texas Coastal Plain. The broad, strike-oriented sand belt outlines the area of principal barrier bar deposition, and is bounded landward by lagoonal muds, and shelfward by marine muds. Sand was supplied to the coastal barrier system through numerous small rivers, and was reworked along depositional strike by wave action. Uranium deposits occur at the northern end of the barrier system in Karnes and adjacent counties. The barrier bar system grades northeastward into a sand-rich strandplain (Gonzales County), and then into a major delta system in East Texas (Fisher and others, 1970).

by the major Catahoula-Frio progradational cycle. The total South Texas Jackson section averages about 1,000 feet (300 m) in the subsurface; it becomes somewhat thinner at outcrop.

Principal Jackson depositional systems (genetically-defined, three-dimensional, rock stratigraphic units consisting of continuous assemblages of process-related sedimentary facies) include a strandplain and barrier-bar system bounded by shelf and lagoonal systems in South Texas (fig. 12), and a major delta system in East Texas (Fisher and others, 1970). Uranium occurs in the Whittsett Formation (upper Jackson Group) coastal barrier bar and in associated facies, where the northern updip margin of the regional, strike-oriented barrier sand belt intersects the outcrop (fig. 12). Framework elements of the system include strike-oriented coastal barrier sand units, and several small, wave-dominated cuspate deltas that prograded to the open Gulf across mud-dominated lower coastal plain and lagoonal areas. Several such delta sources are indicated by local dip-oriented isolith contours and associated sand thicks within the barrier sand belt. Jackson lagoonal sequences contain restricted marine faunas and lignite beds. Shelf deposits lie downdip from the barrier sand belt, and consist of light-colored, fossiliferous and glauconitic mud (Fisher and others, 1970).

Regional facies patterns within the Jackson Group suggest many similarities with the modern barrier coast of Texas, where a great variety of depositional environments, ranging from coastal barrier to bay, lagoon, tidal pass, bay-head delta, and cuspate delta, have been studied. These studies provide models for recognizing similar paleoenvironments in the upper Jackson barrier bar system, as well as in similar depositional systems in other Tertiary strata of the Gulf Coast Basin.

URANIUM HOST FACIES

Over 30 open-pit mines have exposed a variety of facies of the Jackson barrier bar system in the vicinity of Karnes County, Texas. Most of the pits intercepted ore bodies in one of two locally-named sand units of the upper Jackson--the Tordilla Sandstone and the Deweesville Sandstone Members. Numerous pit exposures, as well as abundant geophysical and sample logs, show that each individual sand unit is a complex mosaic of different genetic facies. These facies have been deposited as part of a coastal barrier and lagoonal coastline, interspersed with several small bay-head and cuspate deltas.

Figure 13 illustrates the interpreted distribution of genetic facies, contained in the Tordilla Sandstone, superimposed upon a generalized net sand isolith map of the member. Two parallel, strike-oriented sand belts approximately 1 mile (1.5 km) in width indicate that the Tordilla consists of deposits of at least two principal strandlines; coastal barrier complex 2, the younger, lies slightly basinward of coastal barrier 1. Both are overlain by lagoonal deposits associated with a subsequent downdip barrier (fig. 14). Local volcanic ash-rich fan deltas, or sediment splays, produced by small, ephemeral streams that prograded into the protected waters behind the barrier bars, occur in the lagoonal sequence; one is illustrated schematically on the map (fig. 13).

Principal genetic facies components of each upper Jackson sand member, such as the Tordilla, include the following: (1) coastal barrier bar sand and landward equivalent lagoon and back barrier flat deposits; (2) tidal inlet fill and associated ebb and flood deltas; (3) small, wave-dominated cuspate delta lobes, fed by one or more fluvial/distributary channels cutting across older barrier deposits to the active coastline; and (4) local, thin fan delta deposits in protected lagoons behind the main coastal barrier trend (figs. 13 and 14).

Sand, silt, and mud entered the basin margin through several small streams along the Eocene South Texas coast, producing small, wave-dominated cuspate deltas similar to that of the modern Brazos (Bernard and others, 1970). Most of the stream sediment load was reworked laterally along the coast from the distributary mouths, forming well-developed coastal barrier bars with protected lagoons located in the extensive interdeltaic areas. Tidal inlets through the barriers allowed the exchange of ocean water with lagoonal basins. Maximum thicknesses of sand were deposited near the mouths of distributaries and in areas of migrating tidal inlets (note 40-foot contours, fig. 13). Wave reworking produced a linear coastline dominated by laterally continuous, strike-oriented coastal barrier sand bodies (outlined by the 30-foot contour, fig. 13).

Each of the Jackson facies is characterized by recurrent associations of both internal and external sedimentary features. Distribution of permeability, as well as likely positioning of mineralization, is determined partly by these primary sedimentary attributes.

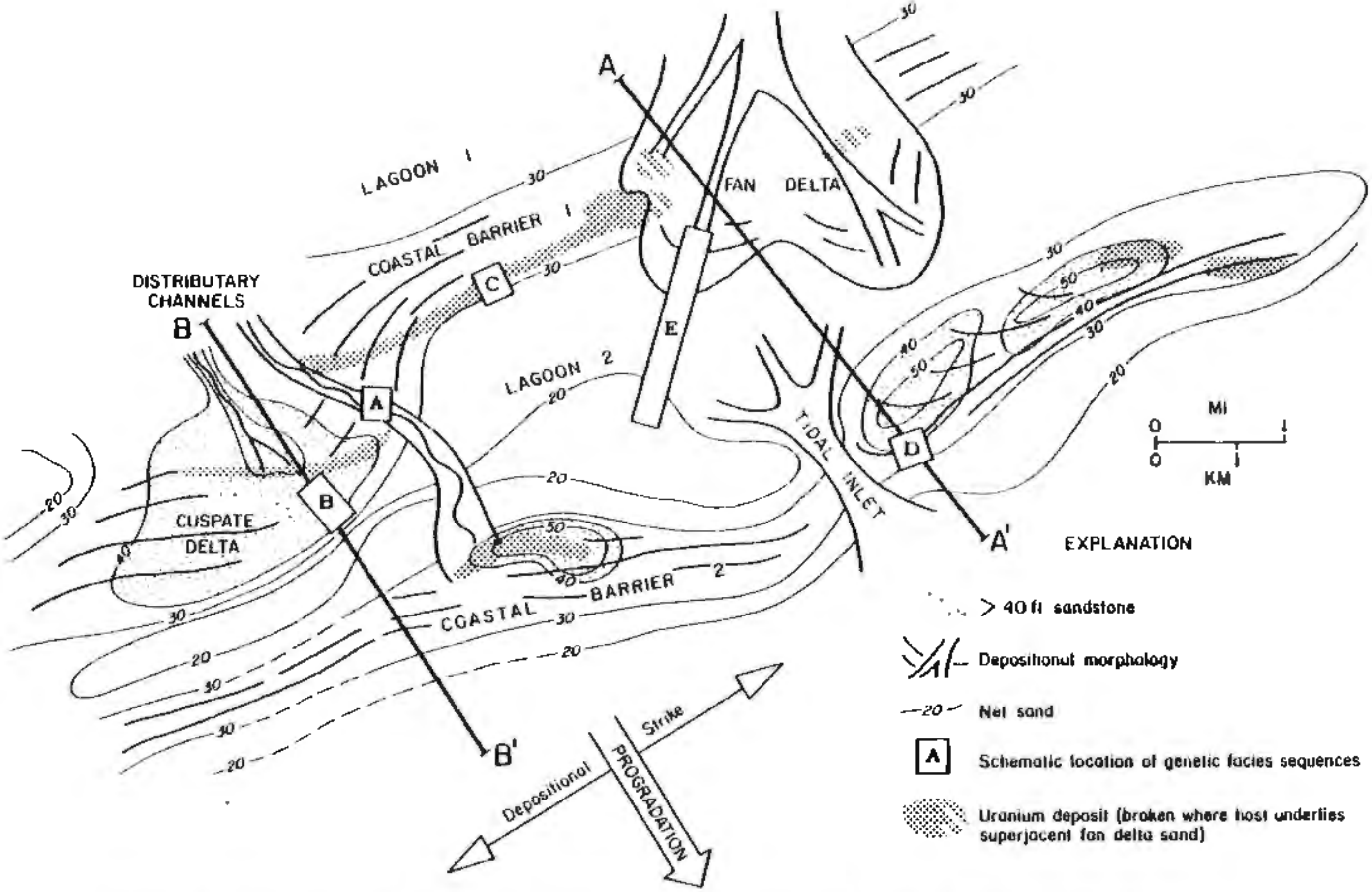


Figure 13. Generalized net sand isolith patterns of the Tordilla Sandstone Member (upper Jackson Group) in western Karnes County. Interpreted depositional morphology is suggested by fine lines, and appropriate positions for facies sequences illustrated in figures 15-19 are indicated by lettered squares. Sand geometry documents two offlapping coastal barrier sand bodies separated by about 2 miles of inter-bar lagoonal and back-bar flat mud, silt, and sand (lagoon 2). Distributary channels (A) fed small cuspate deltas (B), which formed local sand depocenters separated by coastal barrier bar trends (C). A migrating tidal inlet (D) is indicated by local thickening of the sand sequence in barrier 2. A thin splay, or fan delta, which prograded into the protected lagoon (E), is shown schematically to illustrate the genesis of this facies. Uranium deposits occur within various deltaic and coastal barrier facies.

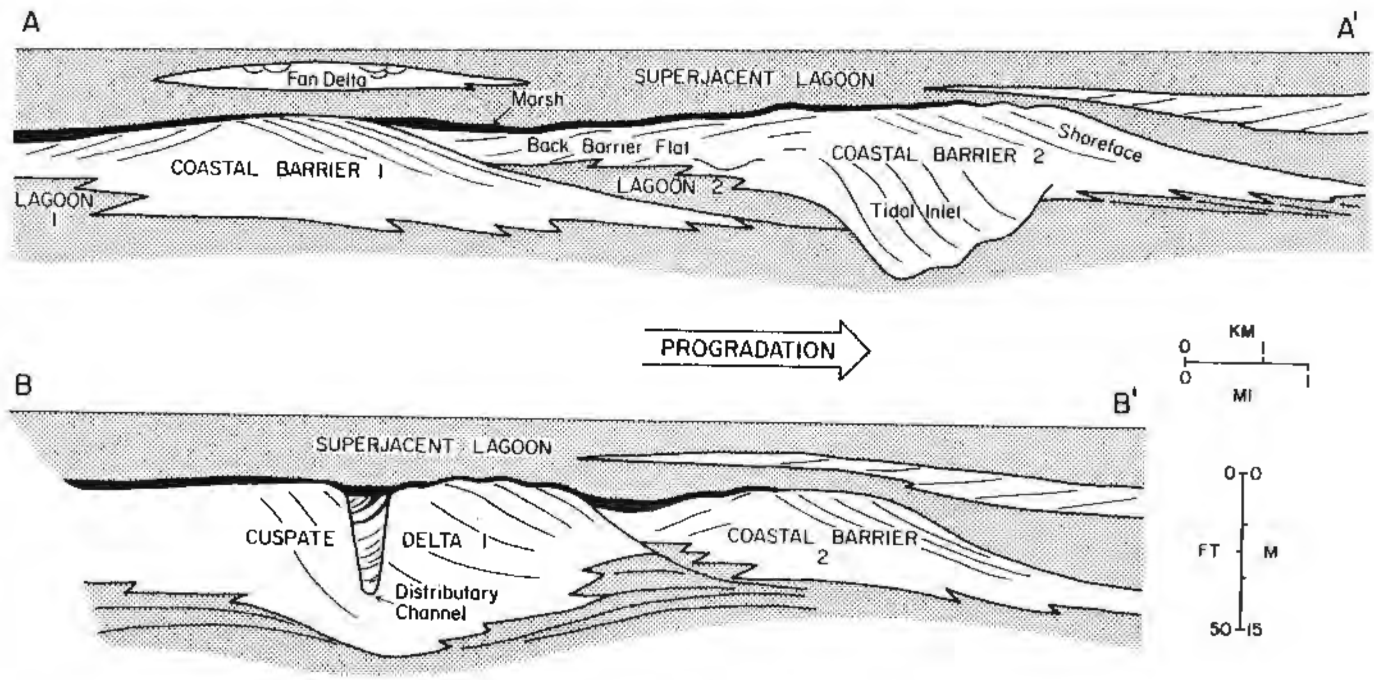


Figure 14. Cross-sectional geometry and interpreted facies relationships of deltaic, barrier, and lagoonal facies of the Tordilla Sand. For location of sections, see figure 13.

Cuspate Delta Facies

Two sand-rich facies were deposited by the small, wave-dominated cuspate deltas that punctuated the upper Jackson barrier coastline of South Texas. Distributary channel sands (fig. 13, A) form narrow, dip-oriented stringers, which can be mapped only with very dense well control. Cuspate delta-margin sand facies were deposited at or near the mouths of active distributaries (fig. 13, B), and form unusually thick sand bodies that grade along strike into coastal barrier bar sand bodies. Features of analogous distributary mouth sediments in the modern Mississippi delta system have been documented by Coleman and Gagliano (1965).

Distributary Channel Fill Facies (fig. 15)

Composition: Well- to moderately-sorted, fine- to medium-grained sand; abundant mud clasts and carbonized wood. Commonly overlain by horizontal to low-angle foreset beds of mudstone, ash, and silt containing concretionary zones and well-preserved terrestrial plant debris.

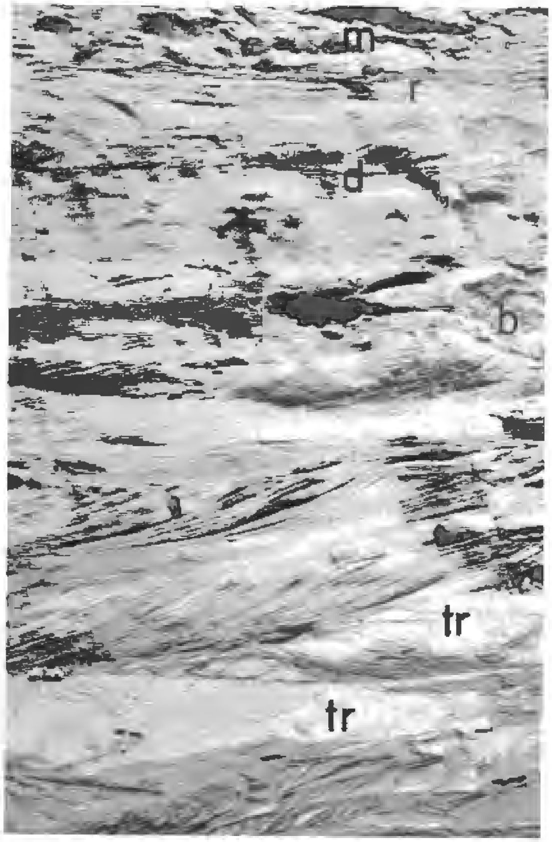
Internal geometry: Massive to thick-bedded with broad, cross-cutting scour-and-fill structures.

Sedimentary structures: Sand dominated by medium- to large-scale trough cross-stratification; dune and ripple-on-dune bedforms may be preserved; a few mud shrimp (Callianassa?) burrows at top of the sand unit.

Vertical sequence: Sharp, erosional base overlain by thick, homogeneous sand; a thin transition zone may separate the sand unit from the overlying mud plug. Sand body is up to 100 feet (30 m) thick.

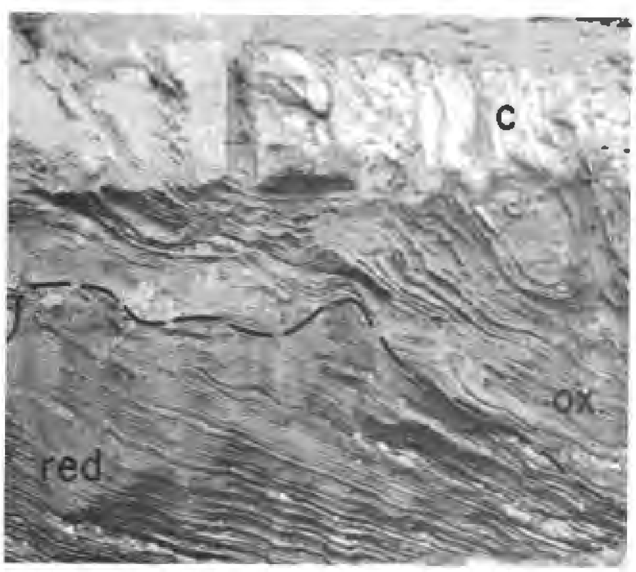
Cuspate Delta-Margin Sand Facies (fig. 16)

Composition: Well-sorted, fine- to very-fine-grained sand containing scattered, discontinuous clay lenses and drapes; abundant mud chips and larger clasts; and common disseminated and placer carbonaceous plant debris, including wood.



A

B



C

D

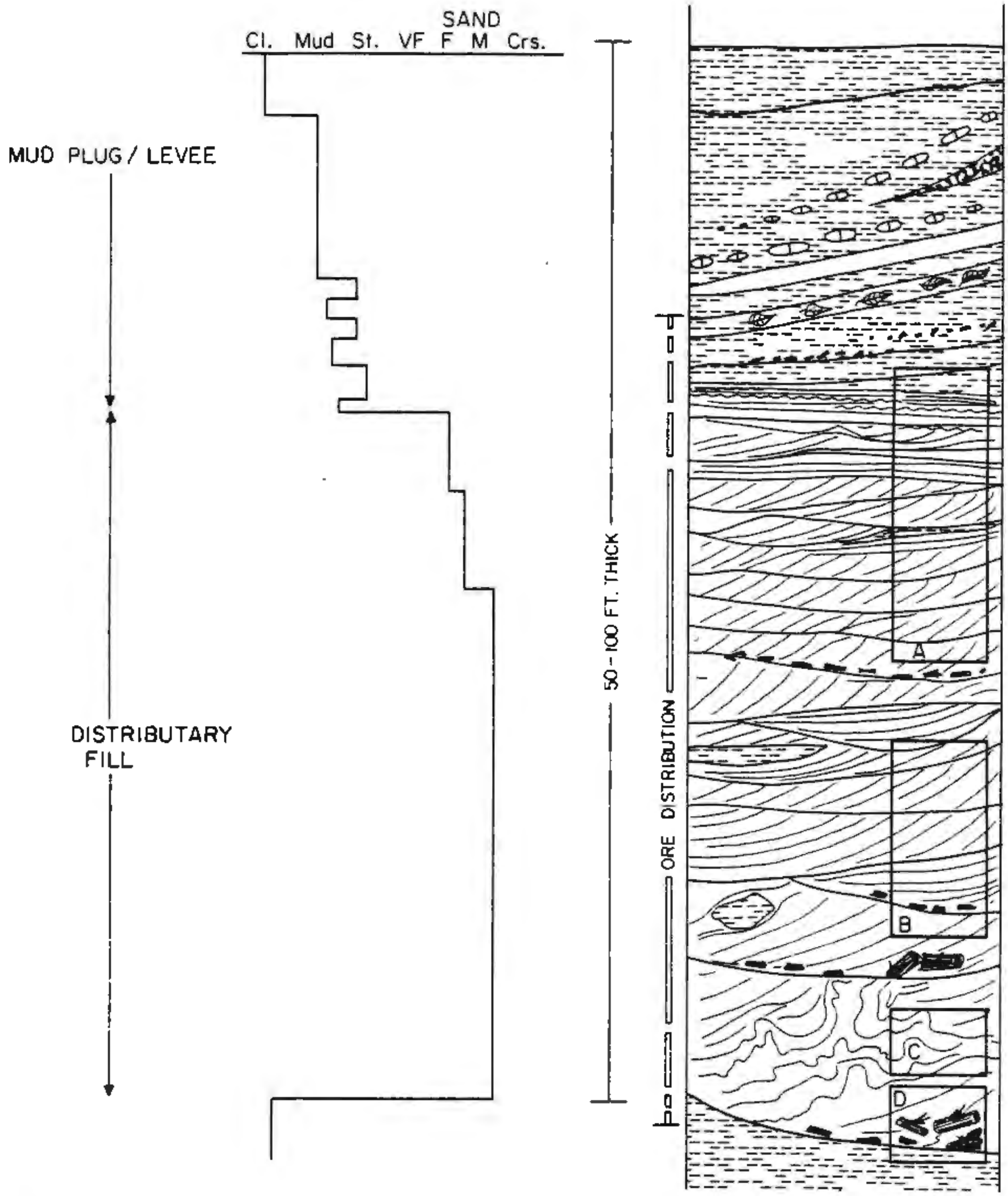
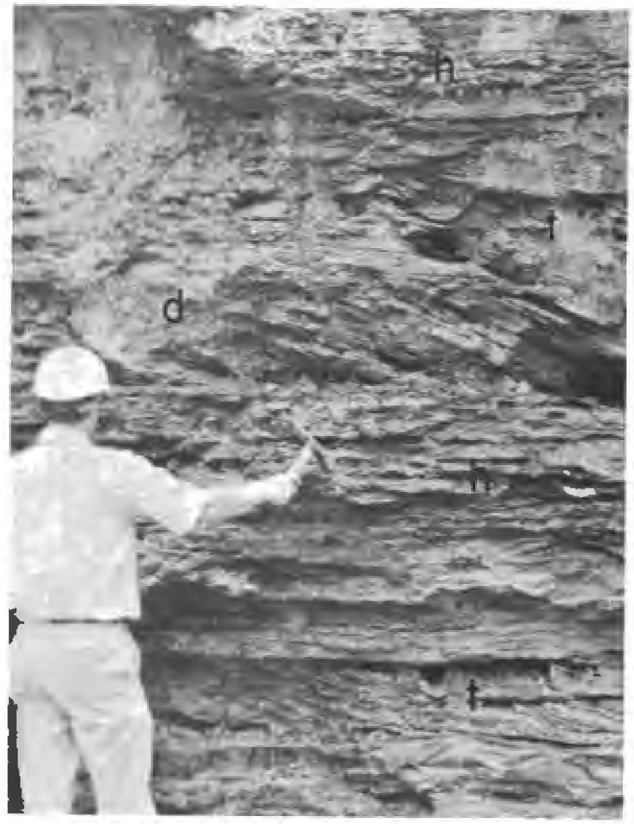


Figure 15. Sedimentary sequence and internal features of distributary channel-fill facies. For explanation, see figure 17. A. Upper part of channel-fill sand body. Sedimentary features include medium- to large-scale, trough cross stratification (tr), large mud blocks (b), accretionary sand-wave stratification with ripple-laminated, convex-dipping foresets (d), ripple lamination (r), and cap of fine silt and mud (m). B. Large-scale trough cross-stratification near base of channel fill. Vertical dimension of photograph approximately 7 feet (2.1 m). C. Convolute stratification within large-scale crossbed set at base of distributary channel fill. Lower, dark-gray portion of bedset is reduced (red); upper portion is bleached by near-surface oxidation (Ox). A calcite cemented zone (c) cuts across stratification. D. Large blocks of mineralized carbonized wood (w) mined from base of channel fill.

A



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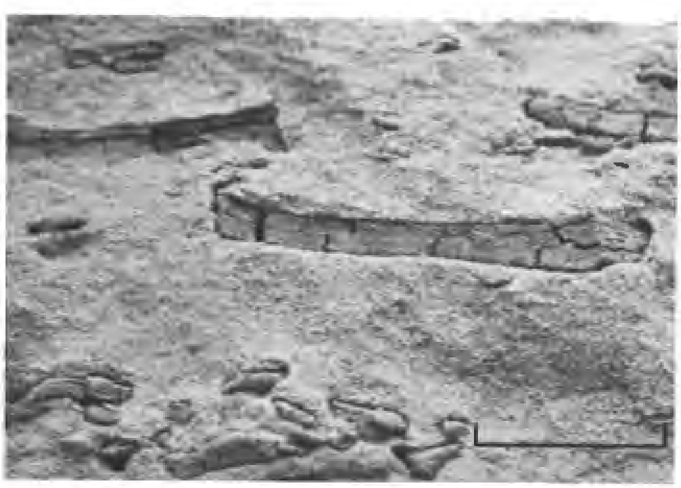

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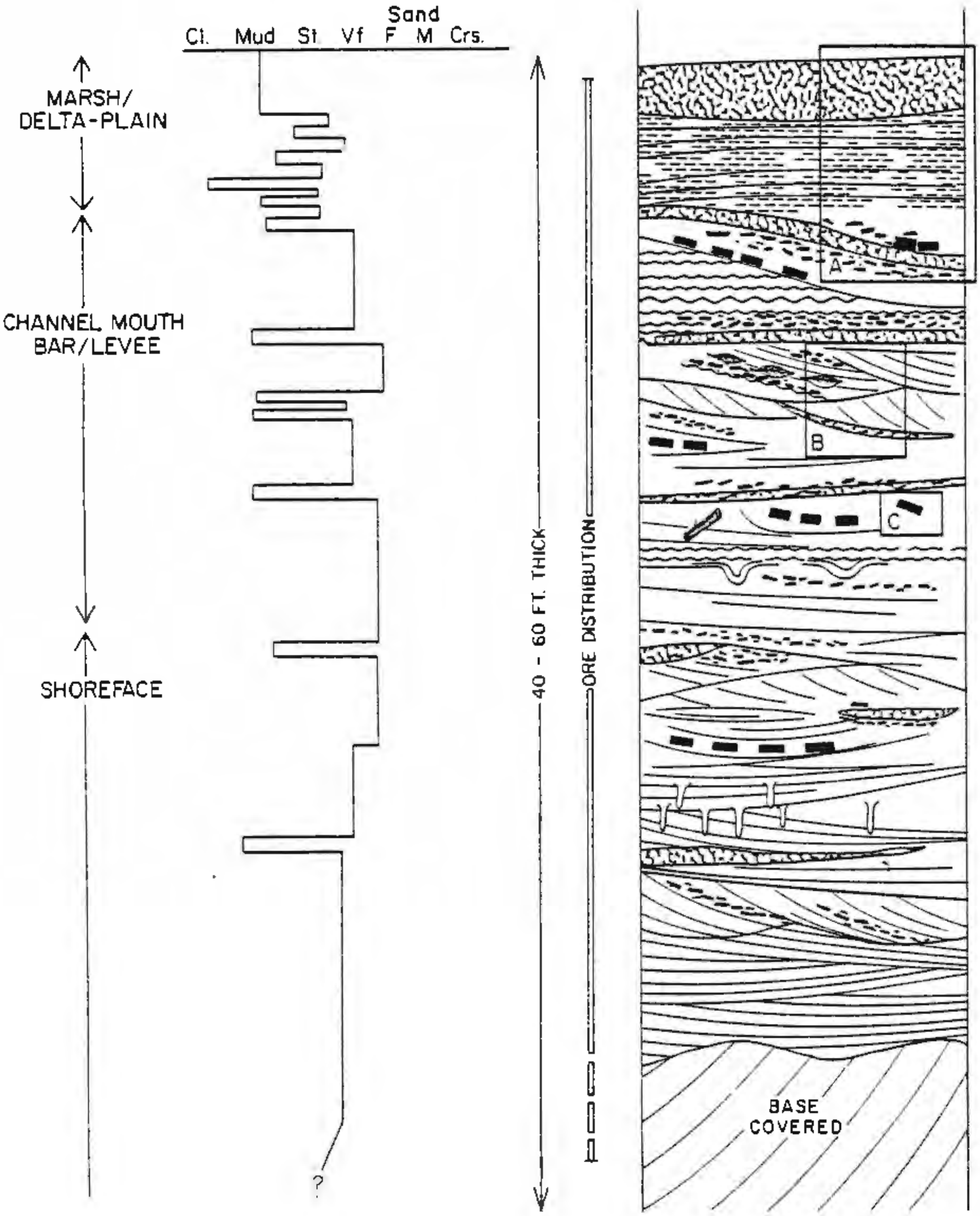

Figure 16. Sedimentary sequence and internal features of wave-dominated, delta-margin sand facies. For explanation, see figure 17. A. Upper portion of delta-margin sand deposited near an active distributary mouth. Broad, shallow scours (s) occur near top of the sequence, and are filled with parallel and wavy-laminated sand containing abundant finely-disseminated plant debris and mud chips. The sand unit is capped by horizontally bedded, ripple- and wavy-laminated sand (h), and by lignitic mud (l). B. Massive upper
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portion of delta-margin send displaying interbedded sand wave bedforms with dipping accretionary foresets (d), trough cross stratification (t) and horizontal stratification (h). C. Mud drapes, which are common in the sand unit, were locally ripped up and redeposited. Bar is approximately 1 inch (0.4 cm).

Internal geometry: Irregular, thick beds with broad scour-and-fill units near distributary mouth.

Sedimentary structures: Well-developed, small- to large-scale trough cross-stratification; irregular, parallel to wavy and ripple laminations are common. Load structures and convolute stratification, as well as locally preserved dune bedforms, indicate sporadic, rapid rates of sedimentation. A few permanent burrows (Callianassa?) occur below local bedding surfaces.

Vertical sequence: Sequence is poorly displayed in pits; sand unit is commonly capped by bedded silt, mud, and lignitic mudstone. Facies is characterized by lateral and vertical heterogeneity of grain sizes and structures. Sand body is 30 to 60 feet (10 to 20 m) thick.

Coastal Barrier and Lagoonal Facies

Sands of the cuspate delta-front facies grade laterally into strike-oriented, elongate coastal barrier sand bodies (fig. 13), which were deposited in a variety of barrier-bar environments (Dickinson, 1976). The upper Jackson barrier strandline generally prograded basinward. As illustrated by the modern Texas coast, however, accreting, eroding, and stable segments probably existed simultaneously, depending upon local sediment budget. Jackson coastal barriers bounded extensive interdeltaic lagoons or embayments, which filled with mud, silt, and volcanic ash. Tidal exchange between the open Gulf and lagoons produced tidal inlets through the barriers. These inlets migrated in the direction of longshore drift, reworking portions of the normal marine shoreface sediments of the barrier front. Small, intermittent coastal plain streams dumped locally derived sediment (rich in air-fall volcanic ash) into the lagoons, producing sediment splays, or fan deltas, similar to modern Gum Hollow delta, Nueces Bay, Texas (McGowen, 1970). Principal framework facies include coastal barrier sands (fig. 13, C), and inlet-influenced barrier sands (fig. 2, D). Lagoonal sections (fig. 13, E) are sand-poor.

Coastal Barrier Sand Facies (fig. 17)

Composition: Predominantly fine- to very-fine-grained, well-sorted sand grading at the base into silt and mud; abundant finely-divided plant debris, and local, discontinuous clay drapes. Back barrier-flat sands, which extend lagoonward from the thicker barrier core, consist of very-fine-grained sand, silt, and muddy sand. Typically capped by a thin, impure lignite bed.

Internal geometry: Massive to thin bedding. Back barrier-flat sands display lenticular depositional units; the barrier core is generally homogeneous.

Sedimentary structures: Barrier core capped by parallel laminated sand containing root traces, burrows, and local wavy and irregular laminations; underlain by low-angle trough cross-stratification. Beach ridge and swale topography locally preserved on top of sand body; abundant roots and diffuse bioturbated zones at top.

Vertical sequence: Sharp base with coarsest sediment at bottom of sand; fines upward but with second, slightly coarser zone near top; sharp upper contact with overlying lagoonal mud. The preserved sequence is a composite of inlet fill capped by accretionary shoreface and beach, and may be 100 feet (30 m) thick.

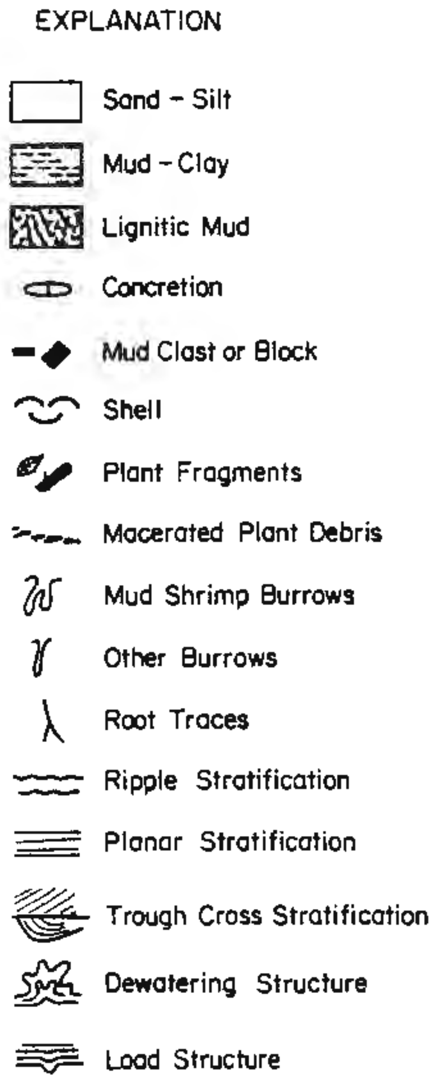
Inlet-influenced Barrier Sand Facies (fig. 18)

Composition: Well-sorted, very-fine to medium-grained sand containing plant debris and scattered muddy laminate and mud clasts.

Internal geometry: Massive to medium bedding with gently inclined foreset bedding near top.

Sedimentary structures: Parallel lamination grading downward into a densely burrowed zone (mud shrimp), which in turn grades downward into medium- to large-scale, low-angle trough cross-stratification. Beach ridge and swale topography locally preserved on top of sand body; abundant roots and diffuse bioturbated zones at top.

Vertical sequence: Sharp base with coarsest sediment at bottom of sand unit; fines upward but with second, slightly coarser zone near top; sharp upper contact with overlying lagoonal mud. The preserved sequence is a com-


EXPLANATION
Sand - Silt
Mud - Clay
Lignitic Mud
Concretion
Mud Clast or Block
Shell
Plant Fragments
Macerated Plant Debris
Mud Shrimp Burrows
Other Burrows
Root Traces
Ripple Stratification
Planar Stratification
Trough Cross Stratification
Dewatering Structure
Load Structure

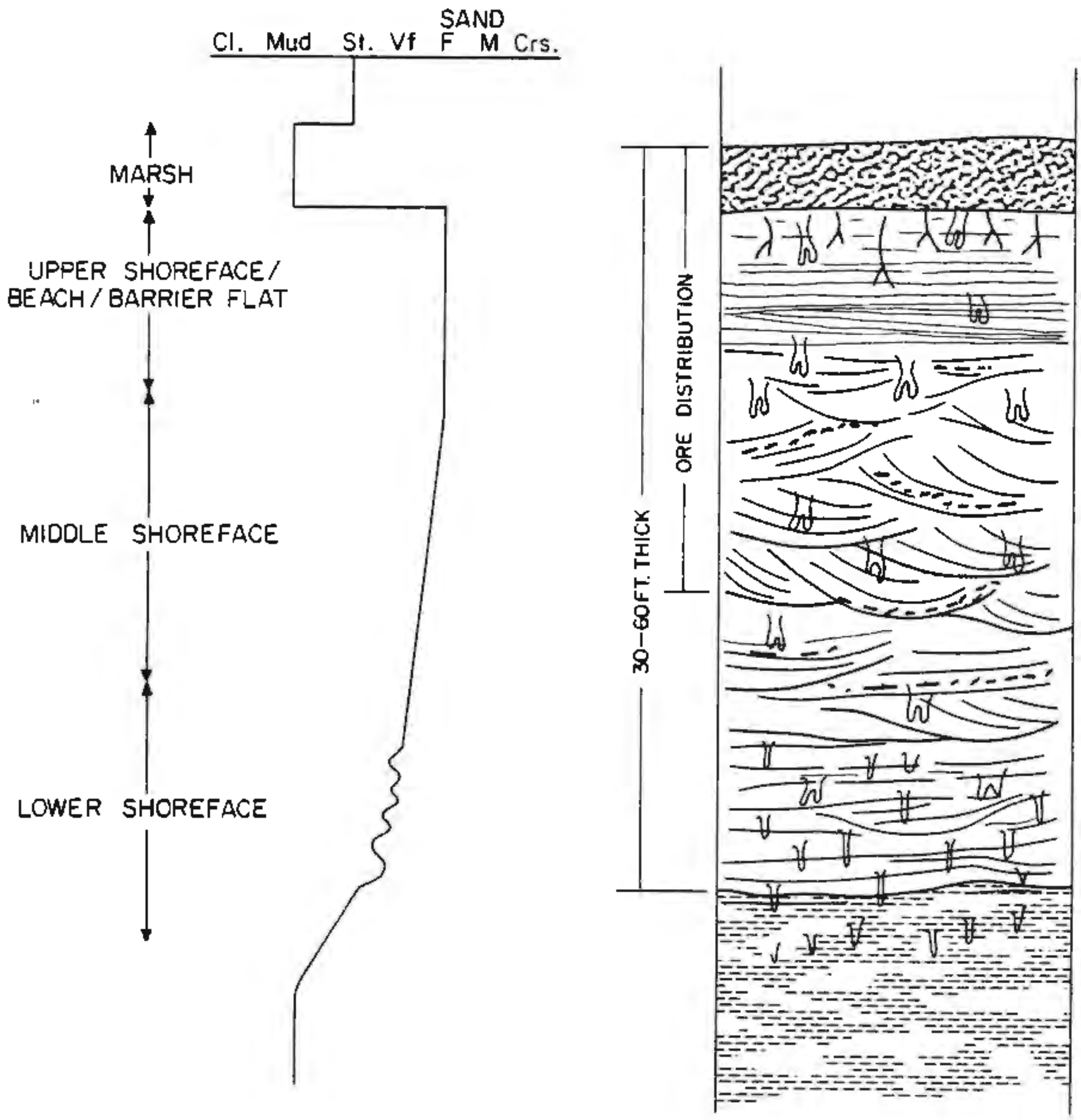
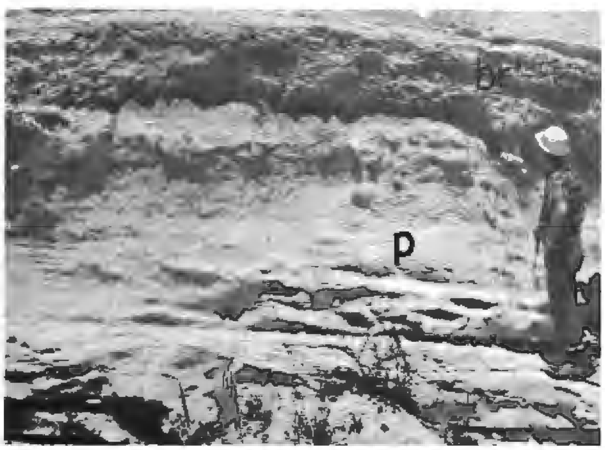


Figure 17. Sedimentary sequence displayed by coastal barrier sand facies. Only the uranium-bearing upper portion of the facies is exposed by mining; the lower shoreface characteristics are inferred from subsurface data.

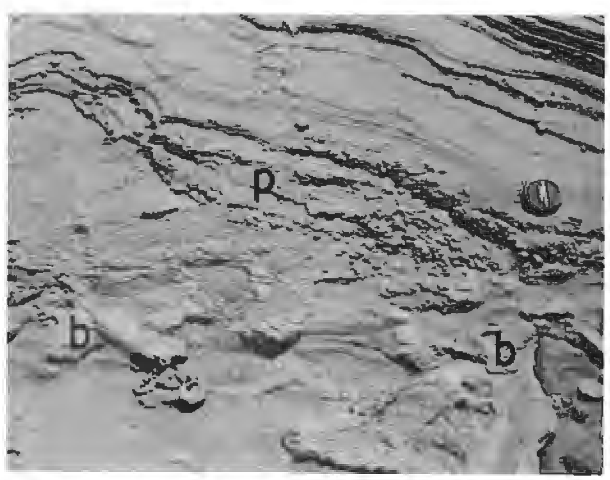
A



B

C

D



E

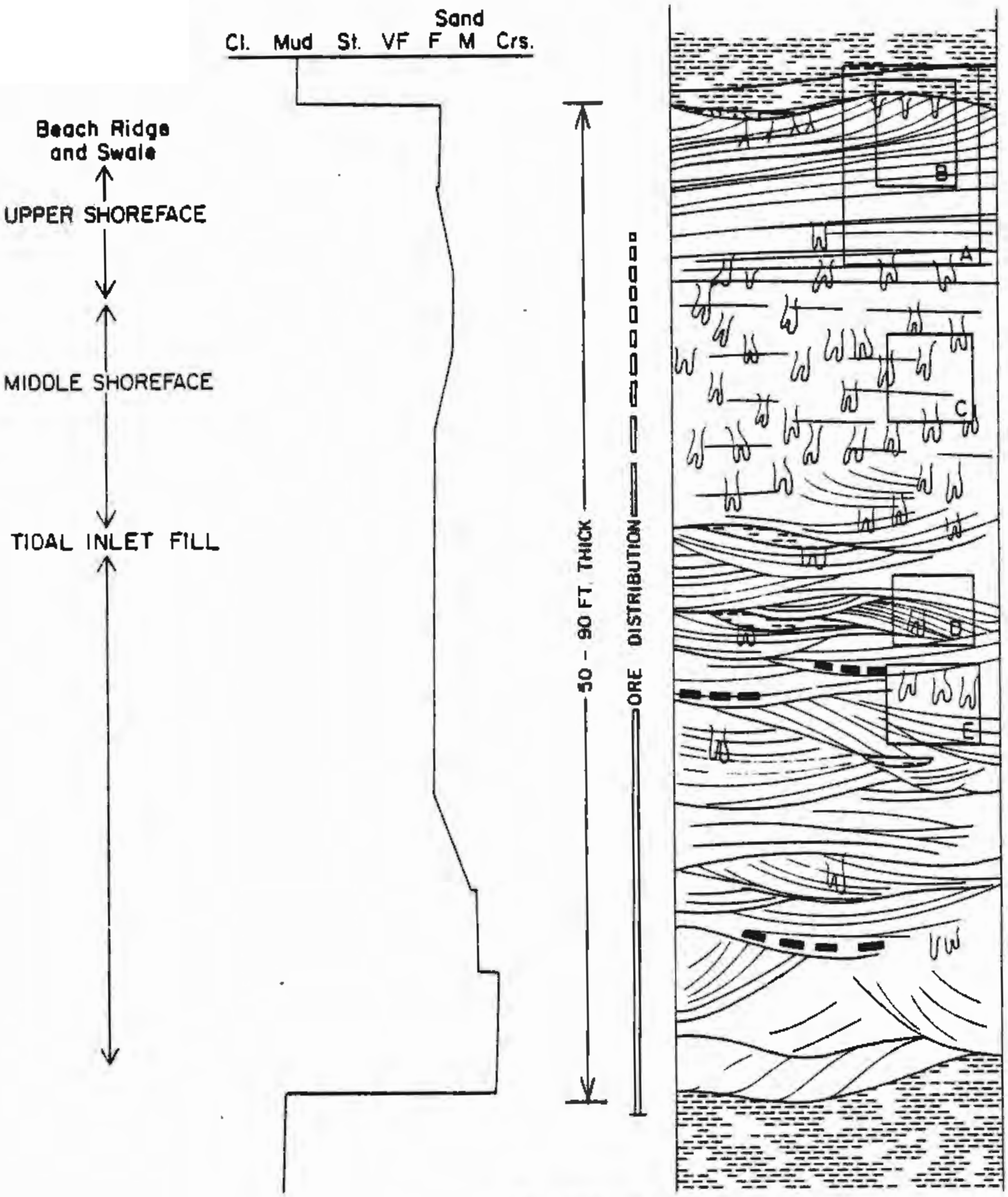
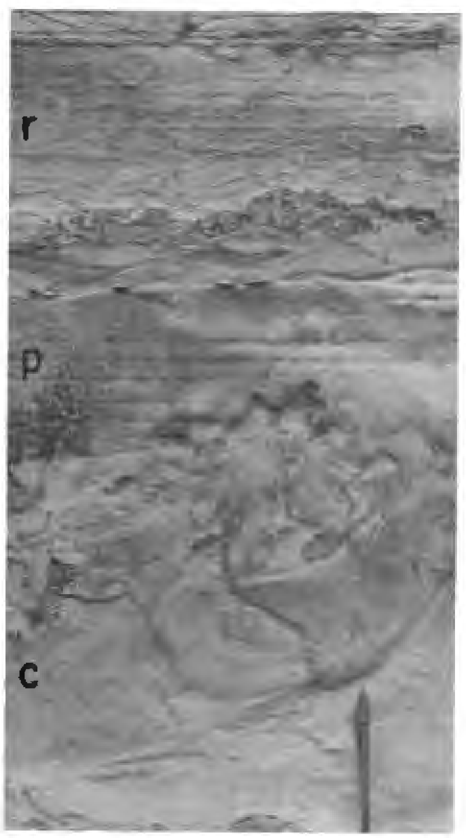


Figure 18. Sedimentary sequence and internal features of inlet-influenced barrier sand facies. See figure 17 for explanation. Pictured sedimentary features include: A. Rhythmic ridge (r) and swale (s) topography preserved on top of barrier sand sequence produced by spit accretion over the subjacent migrating tidal inlet. Basinward dipping, accretionary, planar stratification (p) was deposited in the beach and upper shoreface environment. Low-angle foresets grade laterally into highly-burrowed middle shoreface sand and silt (b) immediately below. B. Burrowed (crabs?) beach ridge (br) overlying planar laminated beach and upper shoreface sand (p). C. Intensely-burrowed (mud shrimp) middle shoreface sand. D. Medium- to large-scale, low-angle trough cross stratification typical of tidal inlet deposits. Ash-rich mud drapes (at top and base of hammer) commonly outline individual bedsets. E. Very large mud shrimp-type burrows (b) occur locally within cross-bedded tidal inlet-fill sands. Burrow systems were sporadically reworked, producing abundant, slightly indurated silt and sand pebbles (p).

A



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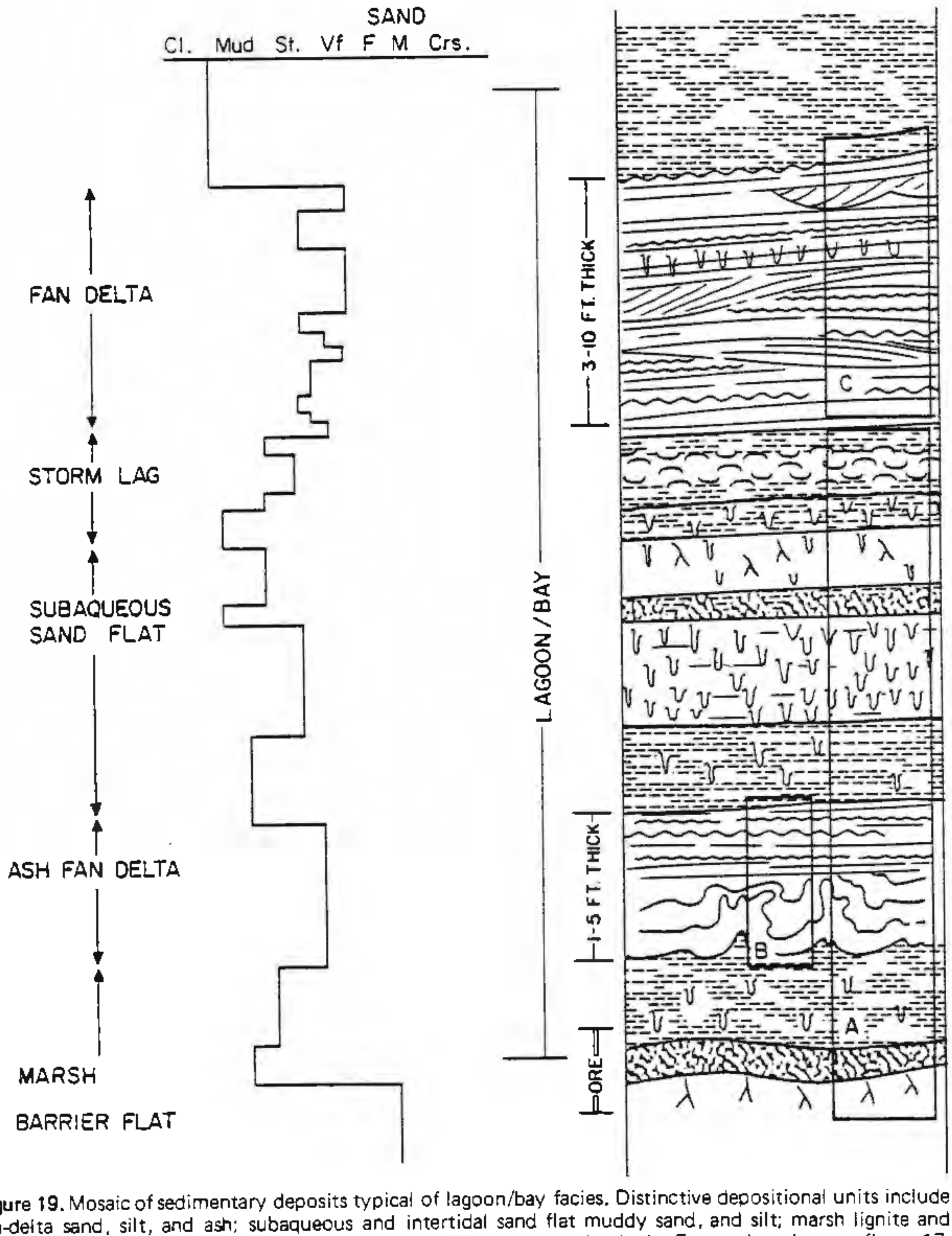

Figure 19. Mosaic of sedimentary deposits typical of lagoon/bay facies. Distinctive depositional units include fan-delta sand, silt, and ash; subaqueous and intertidal sand flat muddy sand, and silt; marsh lignite and lignitic mud; lagoon-fill mud; and thin, highly fossiliferous, storm-lag beds. For explanation see figure 17. Distinctive sedimentary features include the following: A. Laterally continuous, even bedding (l) typical of lagoonal deposits. White bed (a) is composed of volcanic ash. Uranium occurred in a lignite bed that directly overlays the hummocky upper surface (h) of a back barrier flat sand unit. B. Internal features of the ash bed (a) illustrated above include convolute bedding (c) at the base, a zone of planar lamination (p), and an overlying ripple-laminated zone (r). The sequence, which superficially resembles that of a turbidite bed, indicates rapid deposition of ash as a splay, or fan delta, in the lagoonal environment. C. Interbedded sand and ash sequence deposited by a relatively large fan delta. Lagoonal mud (l) is overlain by several interbedded zones of ripple and planar laminations (r and p). Sequence is capped by multiple, broad, shallow scour channels (ch) filled with small-scale trough cross-laminated sand.

posite of inlet fill capped by accretionary shoreface and beach, and may be as much as 100 feet (30 m) thick.

Lagoon/bay Facies (fig. 19)

Composition: Highly variable mixture of mud, sandy mud, silt, muddy sand, volcanic ash, and lignitic mud. Abundant plant debris; septarian zones and shell material in local bed. Prominent fan delta, ash-rich silt, and very-fine-sand sequences are up to 10 feet (3 m) thick.

Internal geometry: Thin to thick, laterally continuous beds; both transitional and sharp lithologic boundaries are common.

Sedimentary structures: Fan delta sequences display abundant fine-scale primary sedimentary structures, including planar, wavy, ripple, and small- to medium-scale, trough cross-laminations; broad, shallow scour-and-fill and convolute stratification are common; scattered burrows occur locally. Some beds are characterized by extensive bioturbation and ripple or wavy laminations.

Vertical sequence: No recurrent vertical sequence.

OCCURRENCE OF URANIUM

Uranium deposits occur in coastal barrier, inlet fill, cuspate delta, and distributary channel fill (fig. 13). Lagoonal facies are essentially unproductive, except for marsh lignite beds that directly overlie uraniferous barrier sands. Ore occurs at preferential positions within different genetic sand facies. Channel-fill deposits, including both tidal inlet and distributary sands, are mineralized near the base; coastal barrier and cuspate delta-margin sands contain ore at or near the top. Thus, ore distribution reflects coarsest and initially most permeable portions of the framework sand. In plan view, the geometry of mineralization fronts ranges from dip- to strike-oriented, and from linear to irregular, reflecting the geometry of the host sand body (fig. 13). This geometry, in turn, demonstrates the influence of facies geometry on patterns of groundwater flow.

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