

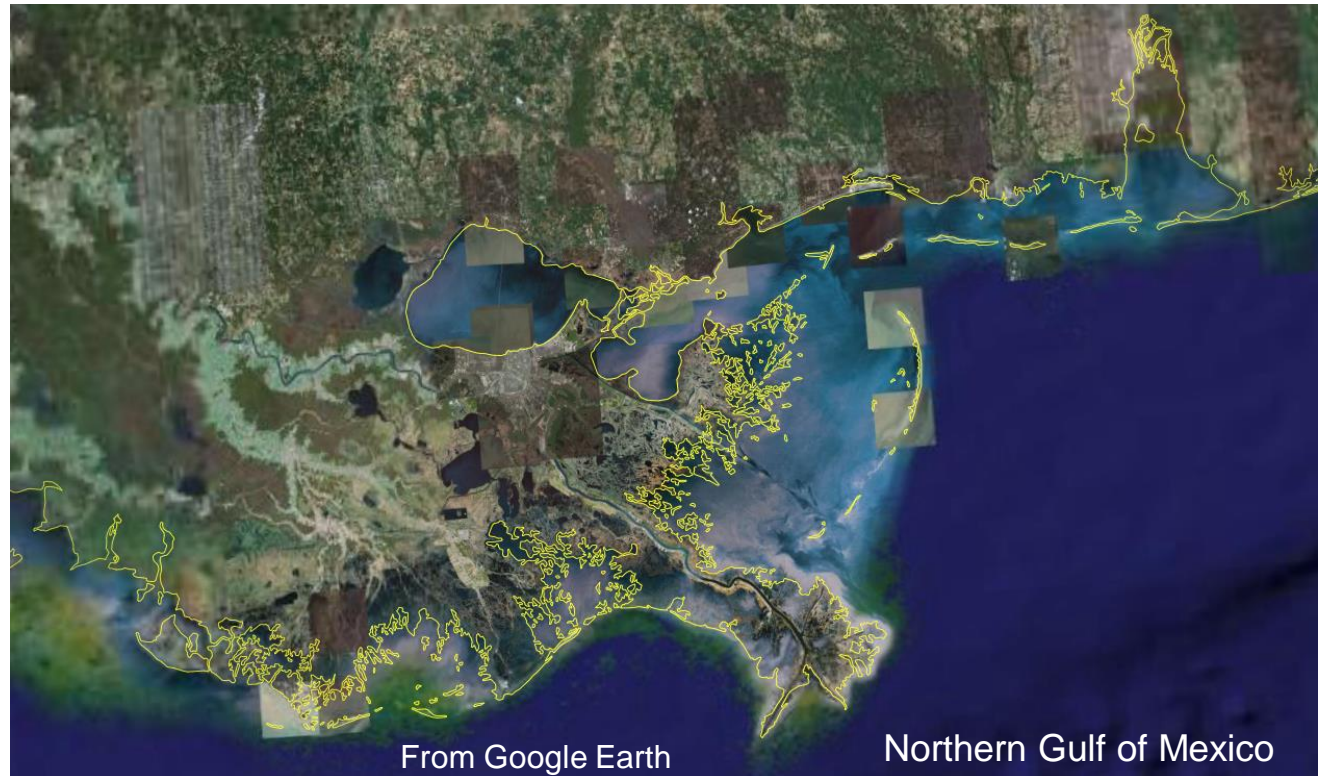
9. Marginal-Marine Environments

Principal depositional environments

- Deltas (三角洲)
- Beaches and barrier island systems: Beaches (海灘), Strandplains(海濱平原), barrier islands/bars (堰洲島 障壁島)
- Estuaries (河口灣 characteristic of transgressive coasts)
- Lagoons (潟湖) (characteristic of transgressive coasts)
- Tidal flats (潮汐平原)

Depositional characteristics for marginal-marine environments

- River, wave, and tidal processes are dominant sedimentary processes
- Salinity varies significantly
- Some environments are of intermittent to nearly constant subaerial exposure, others are continuously covered by shallow water.
- Wide variety of sediment types including conglomerates, sandstones, shales, carbonates, and evaporites.



Principal Coastal Environments

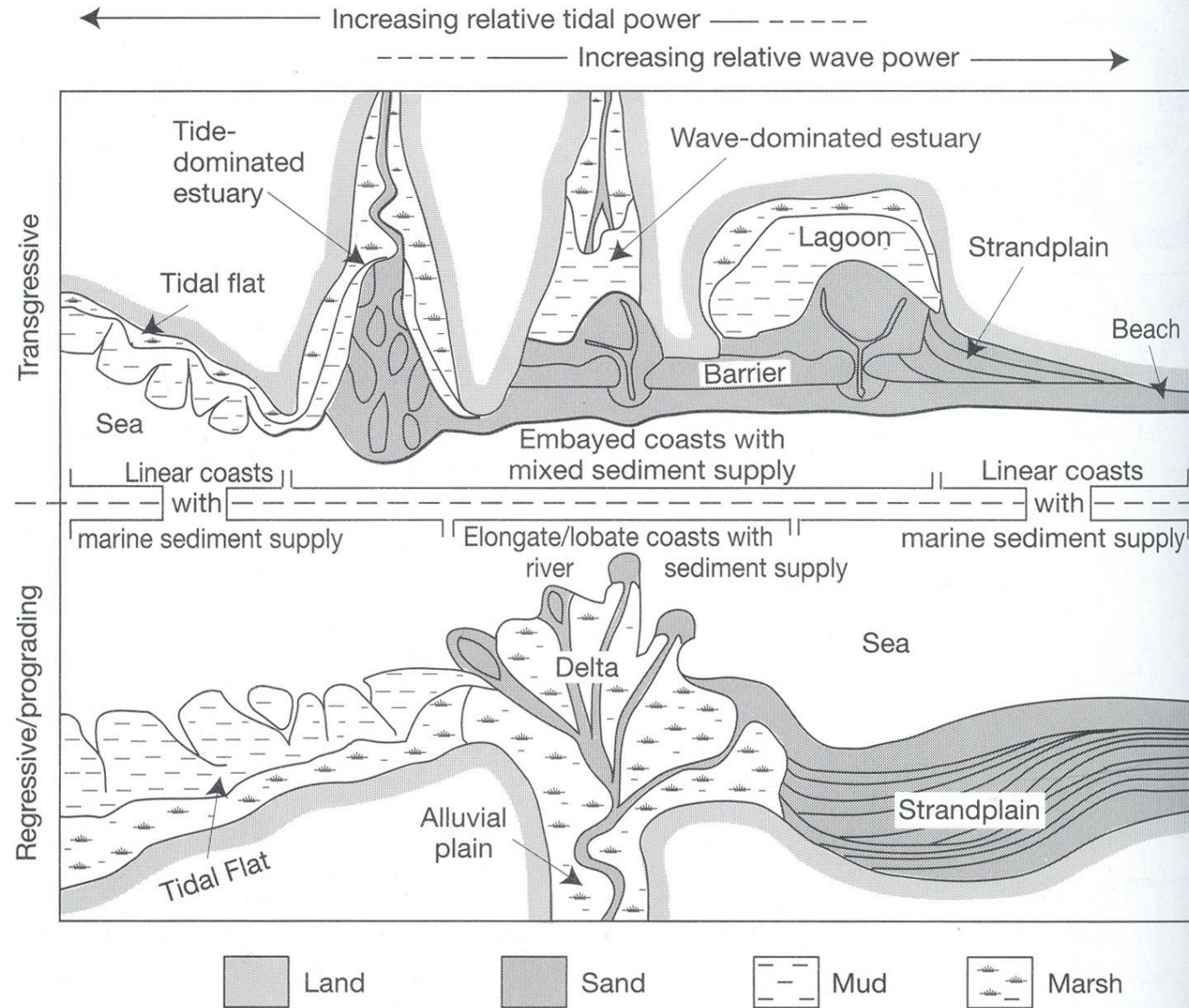


Figure 9.1
 The principal coastal environments of the marginal-marine depositional setting. The figure is organized to show the relative influence of tidal power (increasing to the left) and wave power (increasing to the right) on each environment. Note that deltas are features of prograding (regressive) coasts, whereas estuaries and lagoons are particularly characteristic of transgressive coasts. [From Boyd et al., 1992, Classification of clastic coastal depositional environments: Sed. Geology, v. 80, Fig. 2, p. 141, reproduced by permission.]

6.2 Deltaic Systems

Delta: Discrete shoreline protuberances formed where rivers enter oceans, semi-enclosed seas, lakes or lagoons and supply sediment more rapidly than it can be redistributed by basinal processes.

Delta form where large, active drainage systems with heavy sediment loads exists.

Economic importance for deltaic deposits: hydrocarbons, coal, and some minerals such as uranium.

Table 9.1 Characteristics of selected modern deltas

Delta	Location	Delta-plain area (km ²)	Annual water discharge (m ³ /sec)	Annual sediment discharge (tons × 10 ⁶)
Alta	Norway—Alta Fiord	10	?	?
Burdekin	Queensland, Aust.—Pacific	2112	475	?
Copper	U.S.—Gulf of Alaska	1920	1236	70
Ganges-Bramaputra	India & Pakistan—Bay of Bengal	105,641	30,769	1,670
Irrawaddy	Burma—Gulf of Martaban	20,571	13,562	265
Mackenzie	NW Terr., Canada—Beaufort Sea	13,000	9,100	126
Mahakam	Indonesia—Makassar Strait	5000	?	16
Mississippi	U.S.—Gulf of Mexico	28,568	15,631	349
Niger	Nigeria—Gulf of Guinea	19,135	8,769	40
Ord	Western Australia—Timor Sea	3,896	163	22
Punta Gorda	Belize—Gulf of Honduras	0.4	?	?
São Francisco	Brazil—Atlantic	734	3420	6
Skeidarar Sandur	Iceland—North Atlantic	600	400	?
Yallahs	Jamacia—Caribbean Sea	10.5	17.5	?

Data source: Orton and Reading, 1993

Boggs (2006), p.291

Delta Classification and Sedimentation Processes

Factors controlling the geometry, trend, and internal features of the progradational framework sand bodies of deltas:

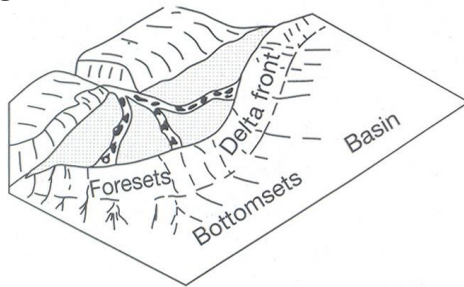
- river (sediment) input
- wave-energy flux
- tidal flux

Each of the above delta categories can be further distinguished on the basis of sediment grain size (mud/silt, fine sand, gravelly sand, or gravel).

Delta are classified on the basis of delta-front regimes:

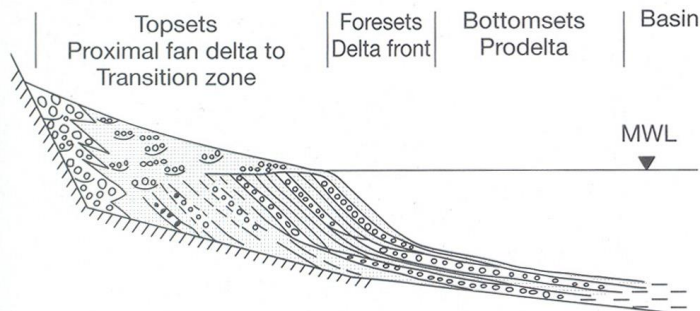
1. Fluvial-dominated deltas
2. Tide-dominated deltas
3. Wave-dominated deltas

Note:



Flocculation (凝聚作用): Aggregation of fine sediment into small lumps owing to the presence of positively charged ions in seawater that neutralize negative charges on clay particles.

Gilbert-type delta: coarse-grained delta with topset, foreset, and bottomset arrangement of beds, created as sediment deposition progrades basinward.



Boggs (2006), p.293

Figure 9.4

Schematic representation of a Gilbert-type delta. [From Reading, H. G., and J. D. Collinson, 1996, *Clastic coasts*, in Reading, H. G. (ed.), *Sedimentary environments: Processes, facies and stratigraphy*, 3rd ed., Blackwell Science, Oxford, Fig. 6.22, p. 174, Reproduced by permission.]

Delta Classification and Sedimentation Processes

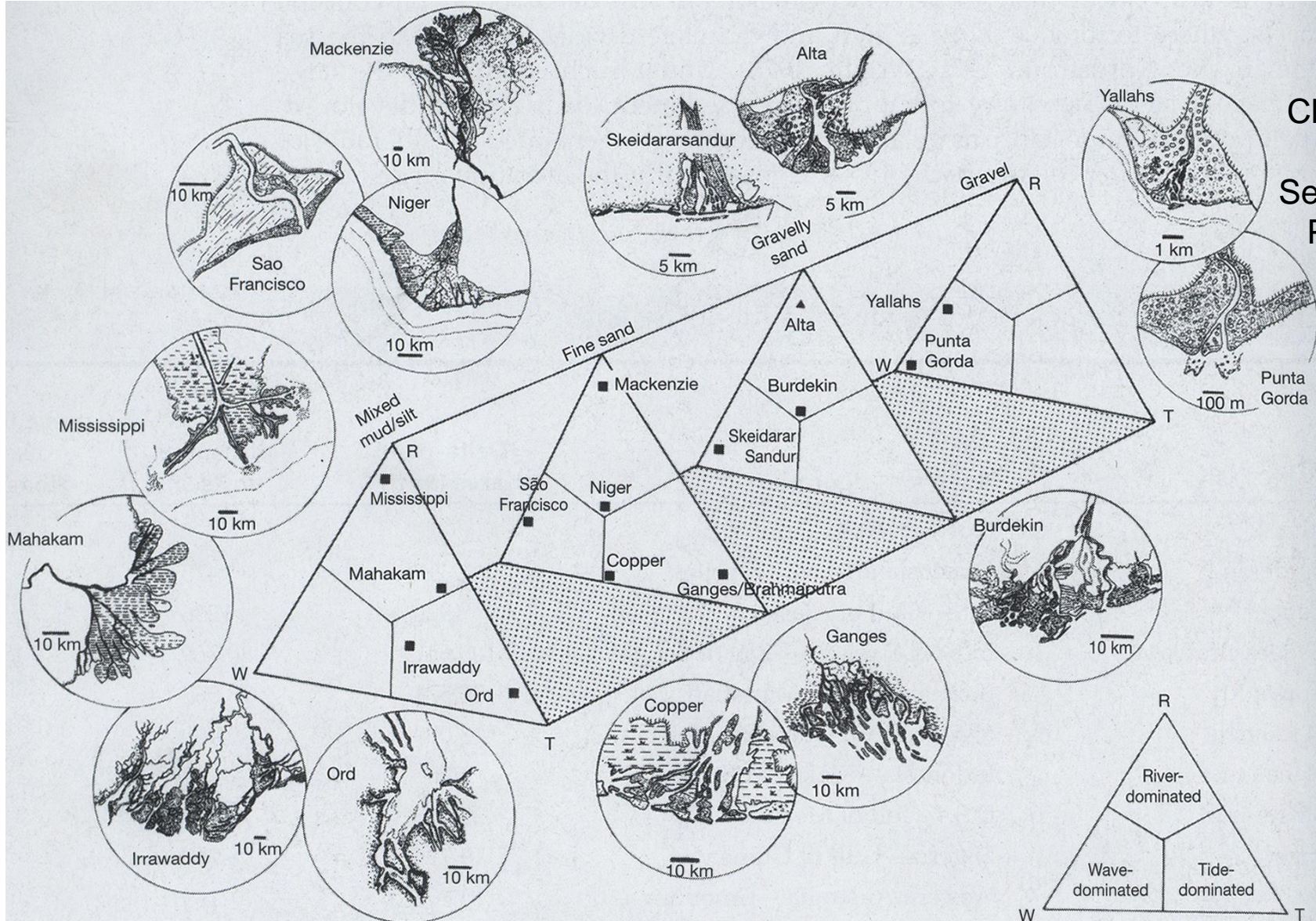


Figure 9.3

Boggs (2006), p.292

Classification of deltas on the basis of dominant process of sediment dispersal at the delta front, and the prevailing grain size of sediment delivered to the front. Dispersal processes: R, river; W, wave; T, tidal. The insets illustrate the shapes of selected modern deltas plotted in the classification diagram; see Table 9.1 for their locations. [After Orton, G. J., and H. G.

Fluvial-dominated Deltas

Three types of flow in the river mouths:

1. **Homopycnal flow**: almost equal density for river and basin water. This flow leads to rapid, thorough mixing and abrupt deposition of much of the sediment load in the river mouth. This type of flow is particularly common at the mouths of coarse-grained rivers and presumably causes the formation of Gilbert-type delta.
2. **Hyperpycnal flow**: River water has higher density than basin water, commonly formed during floods. This jet flow moves along the bottom as a density current that deposits its load along the more gentle slopes of the delta front to form turbidites.
3. **Hypopycnal flow** (most important in delta bordering marine basins): River water is less dense than basin water, as in rivers that flow into denser seawater or a saline lake. It flows outward on top of the basin water. Fine sediment may thus be carried in suspension some distance outward from the river mouth before it flocculates and settles from suspension. Hypopycnal flow tends to generate a large, active delta-front area, typically dipping at 1 degree or less, as contrasted with the 10-20 degree dip of most Gilbert-type deltas.

Dominant processes in river mouths

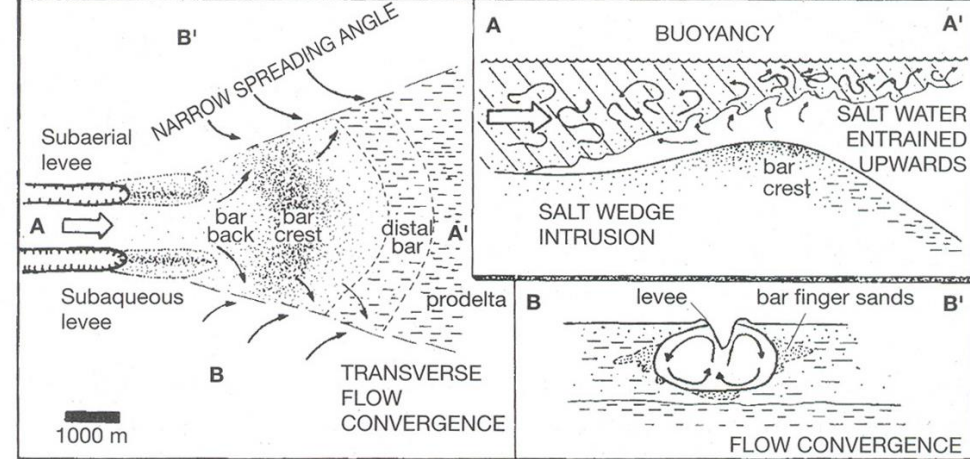
Buoyant dominated river mouths: hypopycnal flow detaches from the bed and is thus unable to move bedload beyond the detachment point. Turbulent mixing is intense near the river mouth, and much of the coarser suspended and bed load is deposited. This leads to the formation of elongate distributaries with parallel banks, called subaqueous levees; few channel bifurcations, and narrow distributary-mouth bars that grade seaward to fine-grained distal-bar deposits and prodelta (近三角洲) clays. Bar sands or bar-finger sands are typical components of such deltaic assemblages. Examples: Mississippi River delta.

Friction-dominated river mouths: occurs where rivers enter water so shallow that the inflow can expand only in a horizontal direction. This leads to generate triangular “middle-ground” bars and channel bifurcation.

Inertia-dominated river mouths: form where the slope is steep enough to allow expansion of the inflow in both horizontal and vertical direction. Occurs where high-velocity river flows enter fresh water and/or carry substantial quantities of coarse sediments. Through mixing of the axial jet of homopycnal flow may cause rapid deposition of the bed load, leading to formation of the Gilbert-type foresets. However, hyperpycnal flow may develop laterally to the axial jet and transport sediments as mass flows.

Buoyant-dominated river mouths

(A)
FINE-
GRAINED
SUSPENDED-
LOAD
CHANNELS



Friction-dominated river mouths

(B)
SANDY
MIXED-LOAD
CHANNELS

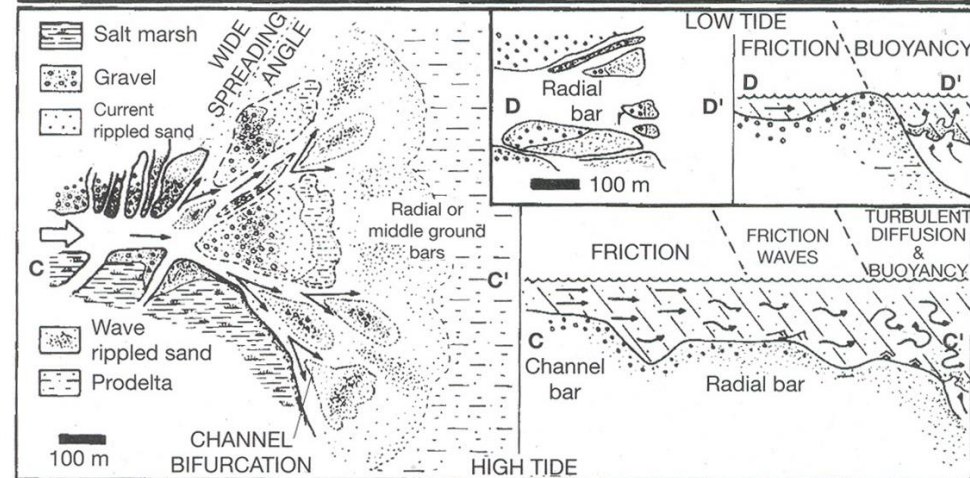
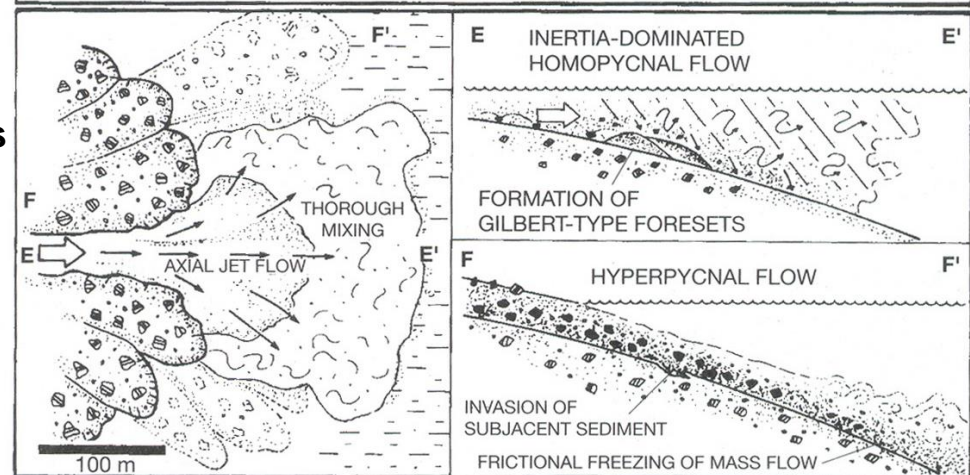


Figure 9.5

Schematic depiction of the complex relationship arising from sediment grain size, river outflow inertia (velocity), outflow friction with the bed, and outflow buoyancy—and its effect on delta formation. [After Orton, G. J., and H. G. Reading, 1993, Variability of deltaic processes in terms of sediment supply, with particular emphasis on grain size: Sedimentology, v. 40, Fig. 4, p. 487, reproduced by permission.]

Inertia-dominated river mouths

(C)
GRAVELLY
BEDLOAD
or
MASS-FLOW
DOMINATED
CHANNELS



increasing importance of friction between effluent and riverbed
increasing density of fluvial discharge relative to basin waters

Example Fluvial-dominated Deltas

Mississippi River delta:

Birdfoot-type, buoyancy-dominated delta. It consists of 7 sedimentary lobes that have been active during the past 5000-6000 years, indicating the periodic channel or distributary abandonment is a common process. Common sediment facies are marsh (草澤) and natural-levee deposits, delta-front silts and sands, and prodelta clays.

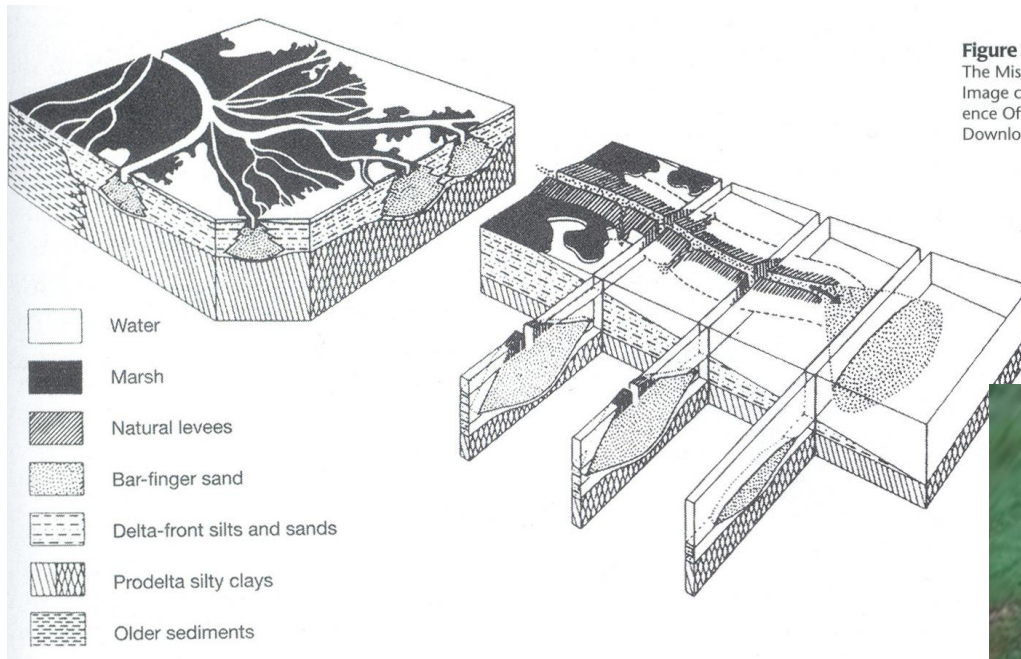


Figure 9.2

The Mississippi River Delta, Gulf of Mexico. Image courtesy of NASA Landsat Project Science Office and USGS EROS Data Center. Downloaded from the Internet 4/19/04.



Figure 9.6

The fluvial-dominated, Mississippi delta system. [From Reineck, H. E., 1970, Marine sandkörper, rezent und fossil: Geol. Rundschau v. 60, Fig. 2, p. 305]

Boggs (2006), p.290

Mackenzie Delta, Beaufort Sea, Canada



Tide-dominated Deltas

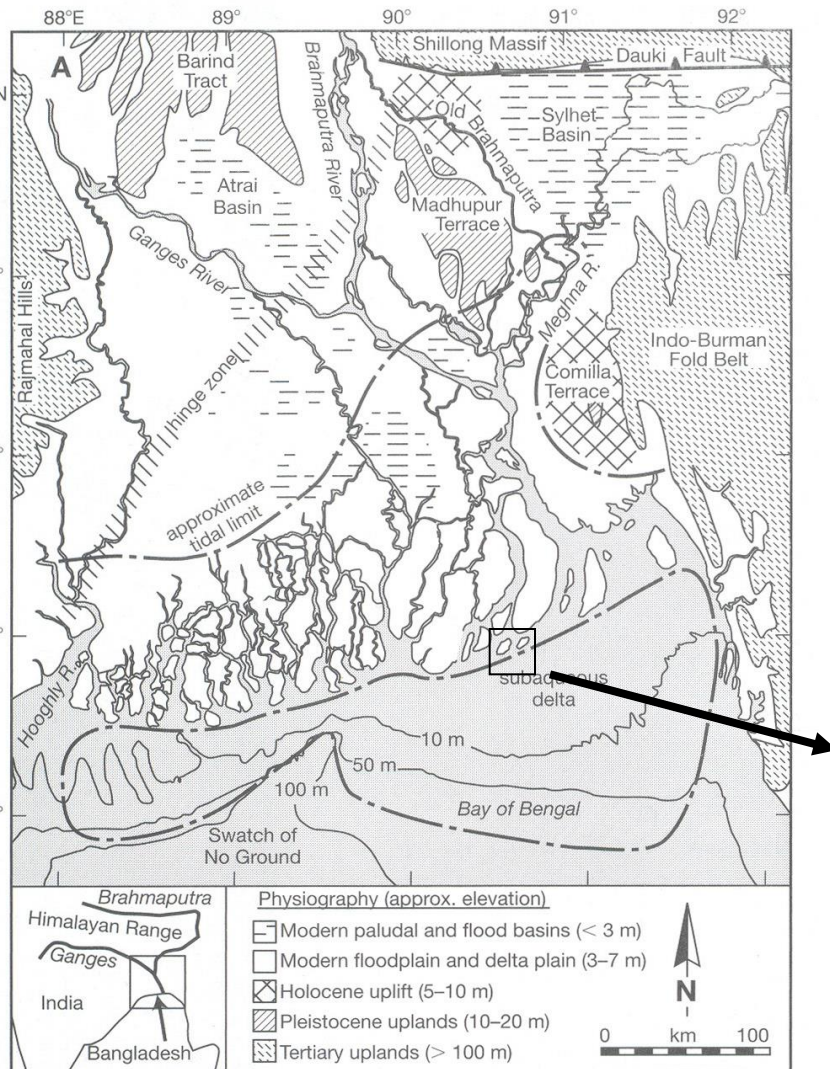
If tidal currents are stronger than river outflows, these bidirectional currents can redistribute river-mouth sediments, producing sand-filled, funnel-shaped distributaries. The distributary mouth bar may be reworked into a series of linear tidal sand ridges that replace the bar and extend from within the channel mouth out onto the subaqueous delta-front platform.



Ganges-Brahmaputra Delta

Image © 2006 TerraMetrics
© 2006 Europa Technologies

Ganges-Brahmaputra delta



- Mean tidal range: 4 m.
- Tidal currents: up to 3.5 m/s
- Relatively low wave energy
- Sand transport/deposition is intense during monsoon season.

Characterized by tidal flat, natural levees, and floodbasins, tidal sand ridges.

The strong tidal influence is manifested by a network of tidal sand bars and channels oriented roughly parallel to the direction of tidal current flow.



Fig. 9.7A of Boggs (2006), p.297.

Wave-dominated deltas

Strong waves cause rapid diffusion and deceleration of river outflow and produce constricted or deflected river mouths. Distributary-mouth deposits are reworked by waves and are redistributed along the delta front by longshore currents to form wave-built shoreline features such as beaches, barrier bars, and spits.

A smooth delta front, consisting of well-developed, coalescent beach ridges, may eventually be generated.

- ✓ Tidal range: mesotidal
- ✓ Wave energy: extremely high
- ✓ Sediment discharge: high with middle-ground bars

Sediments are dominated by amalgamated, sandy beach ridges while mud only accumulates locally in lagoons

Fig. 9.8A of Boggs (2006), p.298.

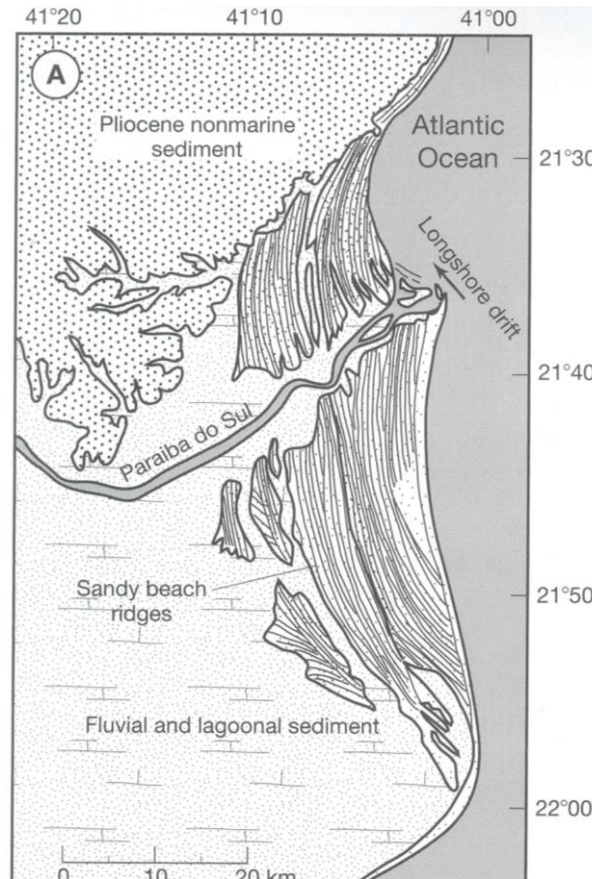
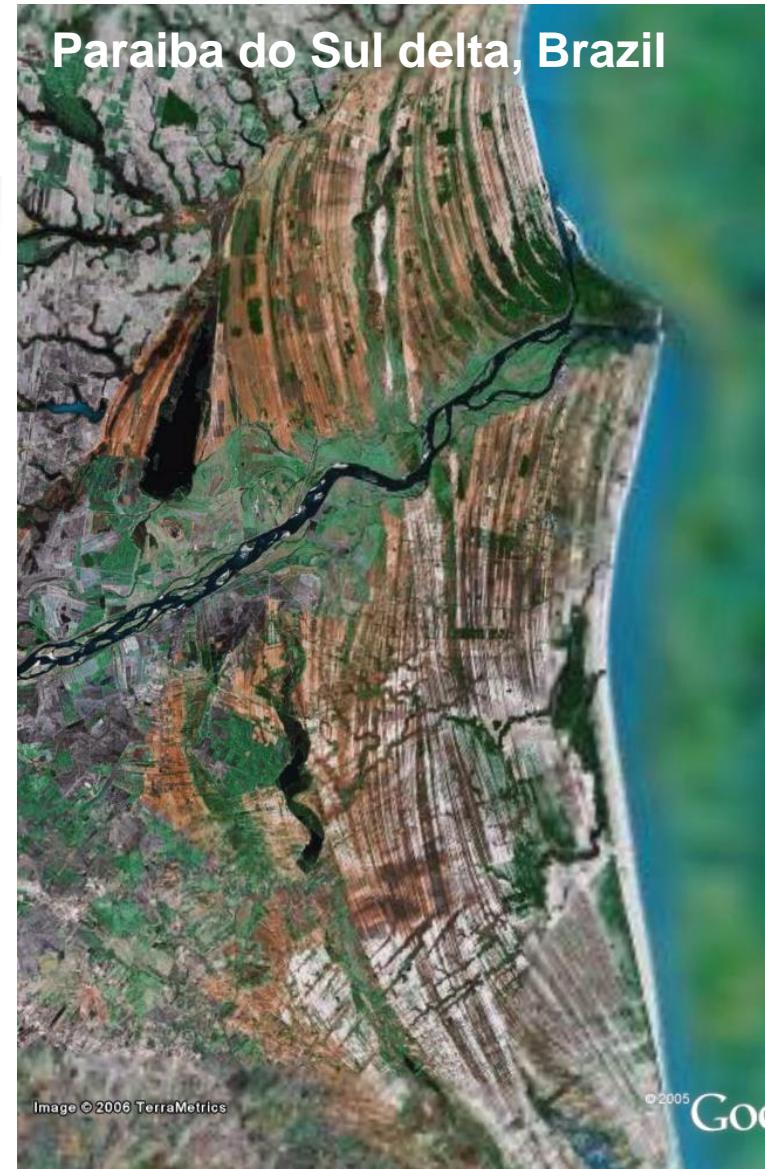


Figure 9.8

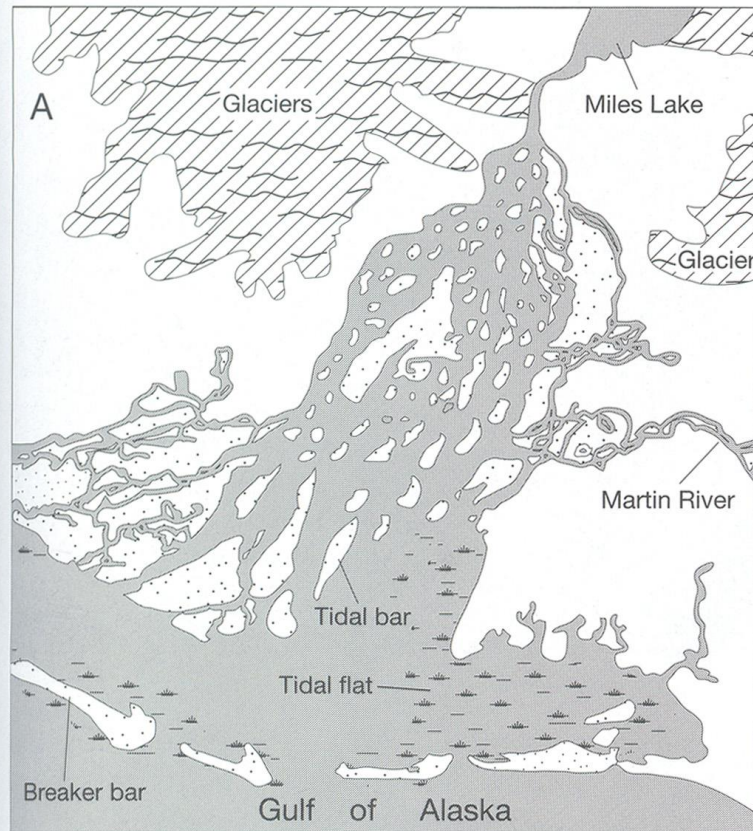
The Paraiba do Sul delta, Brazil, which is characterized by sandy beach ridges oriented roughly parallel to the shoreline. A. Map of the Rio Paraiba do Sul coastal plain. [Redrawn



Mixed-process deltas

Many deltas are shaped by a combination of fluvial-, tidal-, and wave-related processes.

Copper River delta, Canada: influenced by tide as well as high wave power.



- Tidal range: 3 m.
- Tidal currents: up to 2 m/s
- Waves: strong swells coupled with westerly marine currents, set up a net westward longshore drift.

Major delta environments:

1. Subaerial deltaic plain, consisting of marsh deposits;
2. Tidal lagoons, composed of tidal sands and mudflat deposits interlaced with a complex of tidal channel fills;
3. The wind-influenced shoreface, consisting of marginal island, breaker bar, and middle shoreface sands, lower shoreface sand and mud, and prodelta/shelf mud.

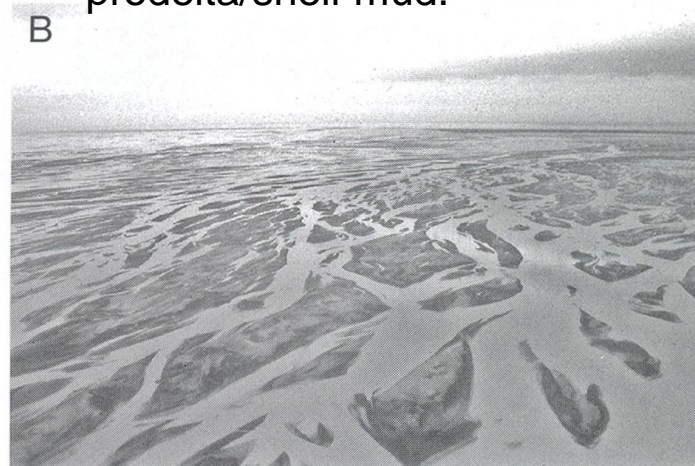


Figure 9.9

The Copper River delta, Gulf of Alaska. A. Physiographic map of the delta, showing tide-influenced channels and bars and wave-influenced breaker bars; based on U.S. Dept. of Agriculture map, "The Copper River," Alaska Region R110-RG-100. B. Tidal channels and tidal sand bars on the delta; photograph by Allan Cline.

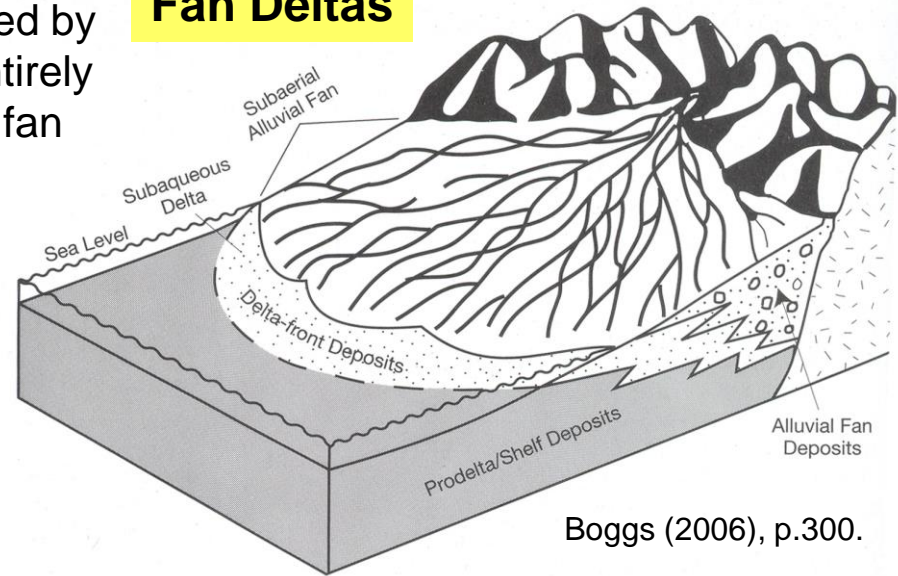
Boggs (2006), p.299.

Fan Deltas

A fan delta is a coastal prism of sediments delivered by an alluvial-fan system and deposited, mainly or entirely subaqueously, at the interface between the active fan and a standing body of water.

The subaqueous portion of fan deltas may be fluvial dominated, wave dominated, or tide dominated. Sediments are deposited downslope in the subaqueous part of fan deltas by processes such as slumping and debris avalanching, turbidity-current flow, and hyperpycnal flows that takes place particularly during flood stages.

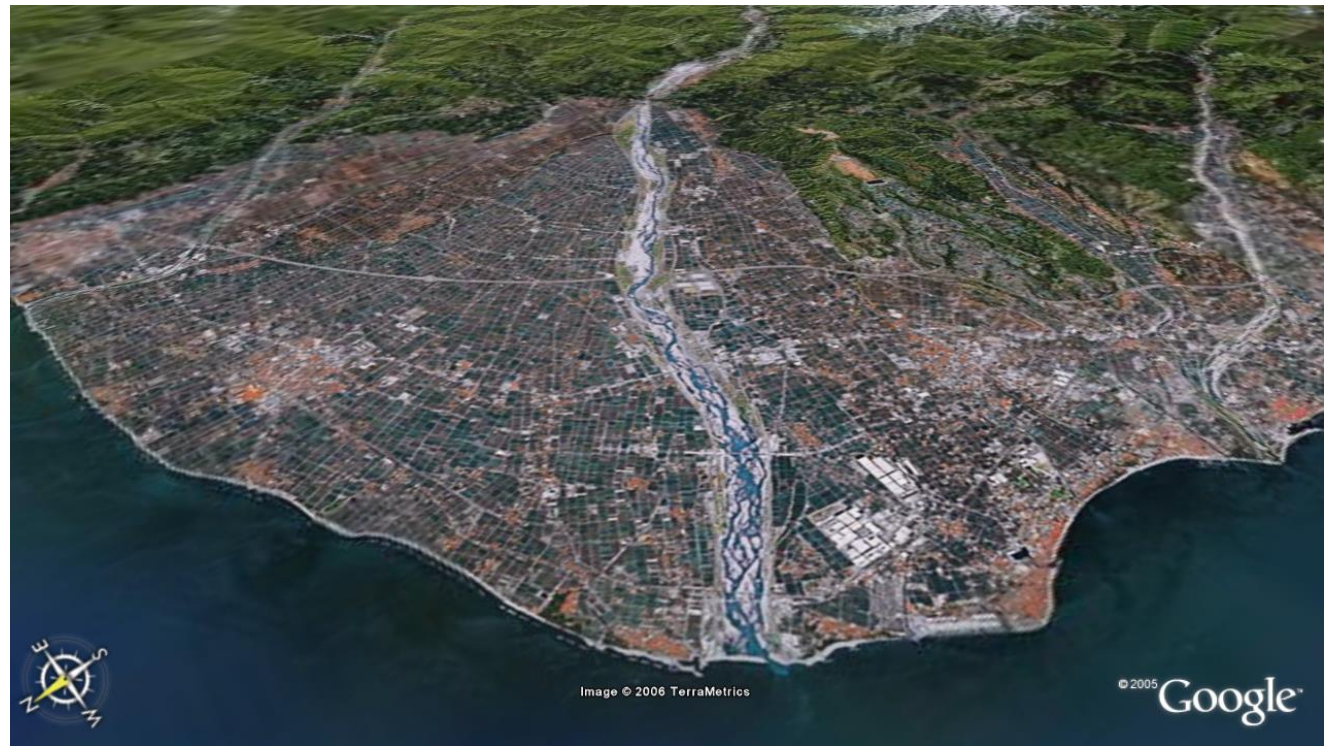
Figure 9.11
Schematic diagram of a fan delta, showing the subaerial alluvial fan and subaqueous delta. [After Nemec, W., and R. J. Steel, 1988, What is a delta and how do we recognize it? in Nemec, W., and R. J. Steel (eds.), Fan deltas: Sedimentology and tectonic setting: Blackie, Glasgow, Fig. 1A, p. 6.]



Boggs (2006), p.300.

Figure 9.10

→
Kurobegawa fan, a large fan delta at the mouth of the Kurobe River, Toyama Bay, Japan Sea, off central Japan. [From Fujii, S., and N. Nasu, 1988, Kaiteirin (submerged forest; text in Japanese), Tokyo University Press, Color plate of Kurobegawa fan. Photograph courtesy of S. Fujii; reproduced by permission of University of Tokyo Press.]

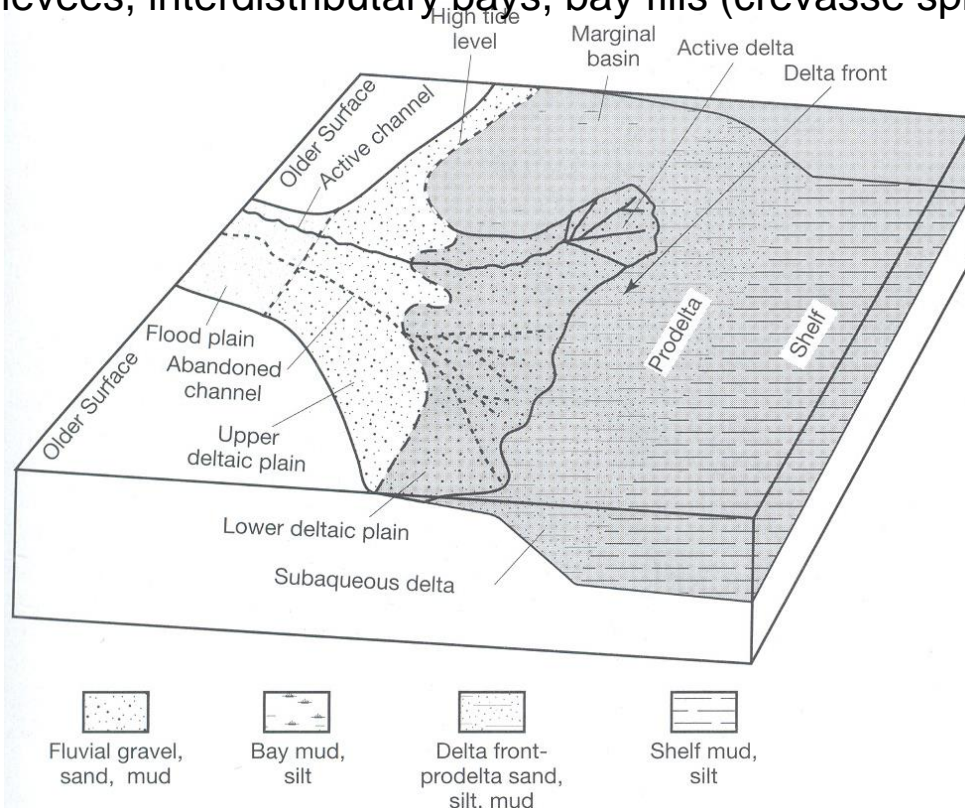


Physiographic and sediment characteristics of deltas

Subaerial deltaic plain

A. **Upper delta plain:** lies above high-tide level, dominated by fluvial processes such as distributary-channel migration, channel and point-bar deposition, overbank flooding, and crevassing into lake basins. Principle environments: braided channels, meandering channels, back swamps, and floodplain (swamps, marshes, freshwater lakes)

B. **Lower delta plain:** lying between low-tide and high-tide level, subjected to fluvial and marine influences. Principle environments: active distributary systems, abandoned distributary-fill deposits, and it may be flanked by marginal-basin or bay-fill deposits; tidal channels, natural levees, interdistributary bays, bay fills (crevasse splays), marshes, and swamps.



Subaqueous delta plain: lies seaward of the lower deltaic plain below low-tide level.

Delta front: the uppermost part of the subaqueous delta, lying at water depths down to 10 m or so.

Prodelta (or prodelta slope): The remaining seaward part of the delta which may reach water depth as much as 200-300 m and it may extend outward for distances of a few km to tens of km.

Figure 9.12

Principal components of a fluvial-dominated delta system. The physiographic subdivisions of tide- and wave-dominated deltas are similar; however, sediments on the delta front and the lowermost deltaic plain are reworked by tides and waves. [Based in part on Coleman and Prior, 1982.]

Delta Cycles

Idealized fluvial-dominated (Mississippi) delta sequence

Growth of delta tends to be cyclic.

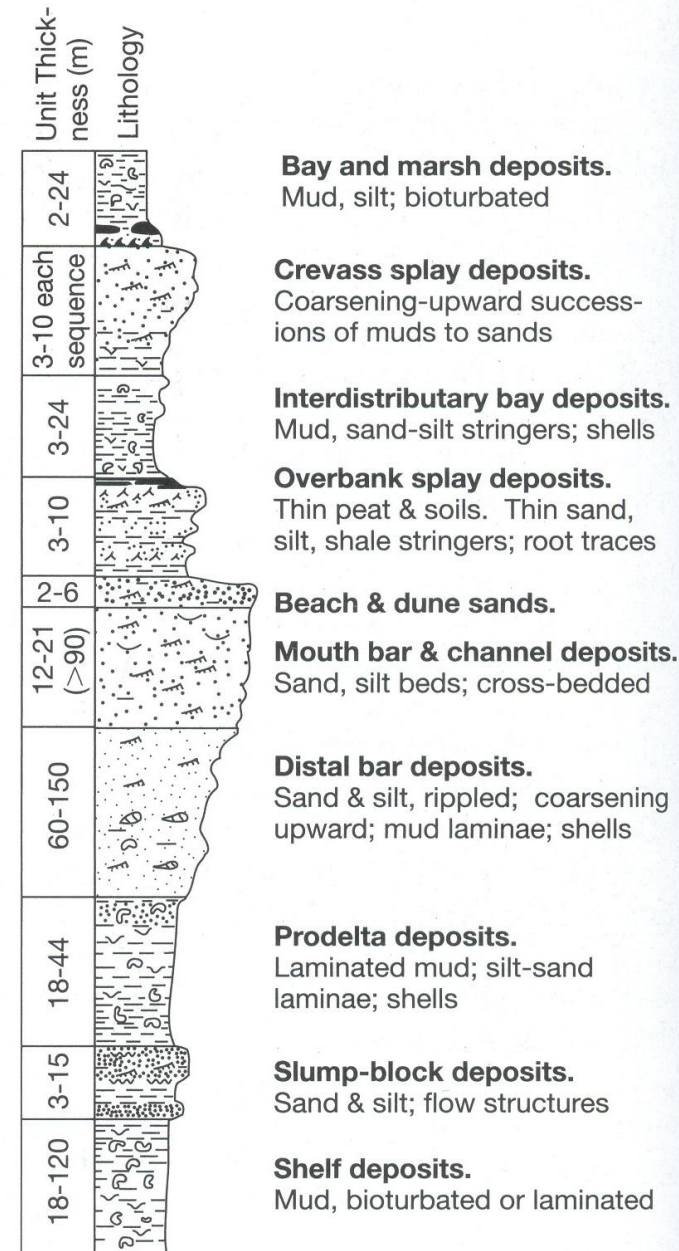
- (1) During active **prograding phases**, prodelta fine silts and clays are progressively overlain by delta-front silts and sands, distributary-mouth sands, and finally marsh, fluvial, as possibly eolian deposits as the delta builds seaward, producing a coarsening-upward regressive succession.
- (2) Interruption of progradation by delta-lobe abandonment or marine transgression brings on a **destructive phase** in which erosion and redistribution of river-mouth deposits predominates.

A complete delta cycle may range in thickness from 50 to 150 m. Smaller scale cycles representing progradation of individual distributaries range from only about 2 to 15 m.

Boggs (2006), p.302.

Figure 9.13

Idealized vertical succession of facies in a fluvial-dominated (Mississippi) delta. Note the thickness of individual units shown in the column. [From Coleman, J. M., 1981, *Deltas: Processes of deposition and models for exploration*, 2nd ed., Fig. 4.3, p. 91, reprinted by permission of IHRDC Publications, Boston.]

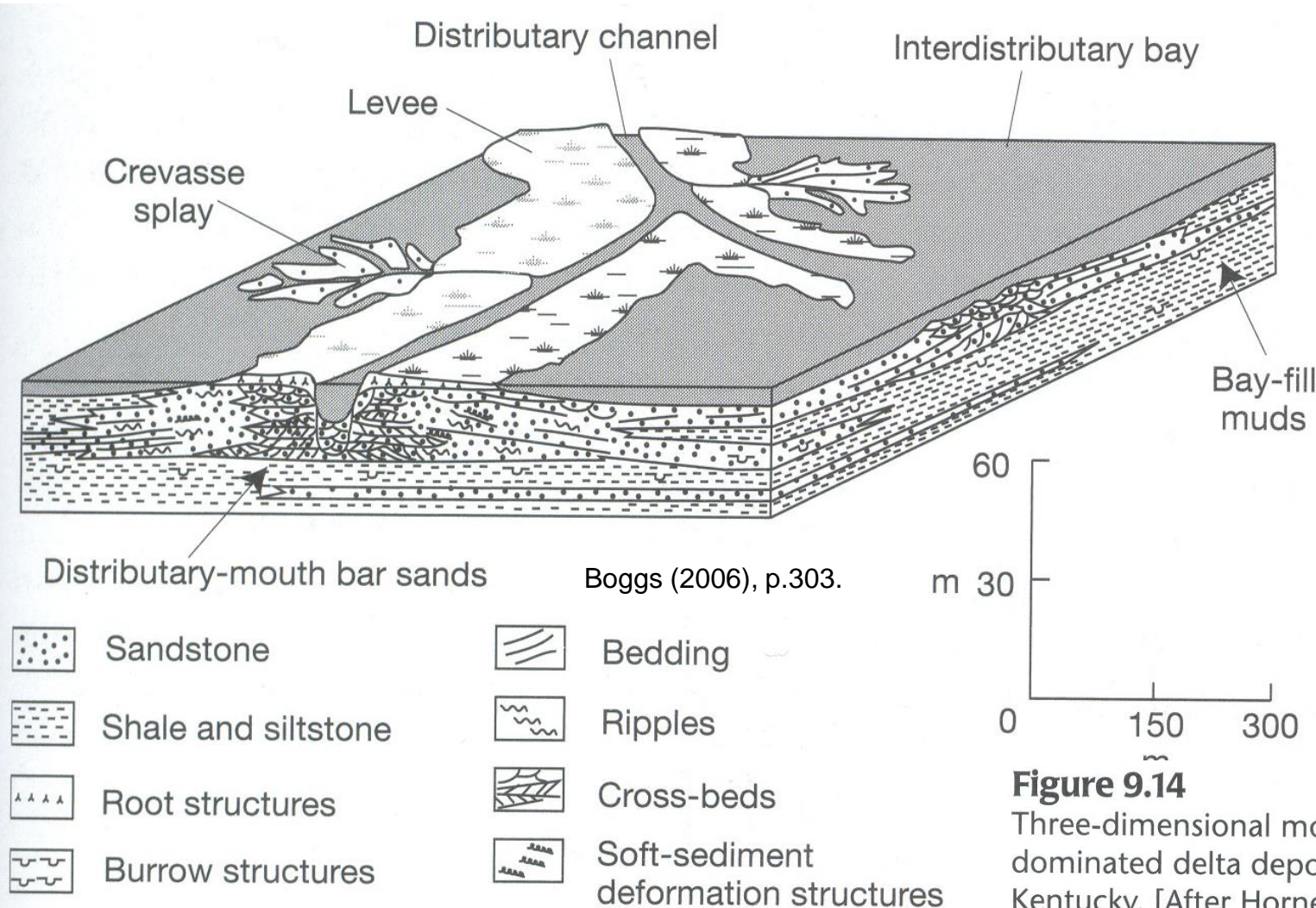


Ancient Deltaic Systems

Fluvial-dominated delta

An example from the Carboniferous delta in the Appalachians

Distributary-mouth-bar sandstones grade laterally into bay-fill muds. The sand bodies are 1.5-5 km wide and 15-25 m thick. They are widest at the base and have gradational lower and upper contacts. Grain size increases upward in the succession and toward the center of the bars.



Fining-upward, graded beds are common on the flanks of the bars, as are oscillation- and current-rippled surfaces. Pebble-lag conglomerates are present at the bases of the channel deposits.

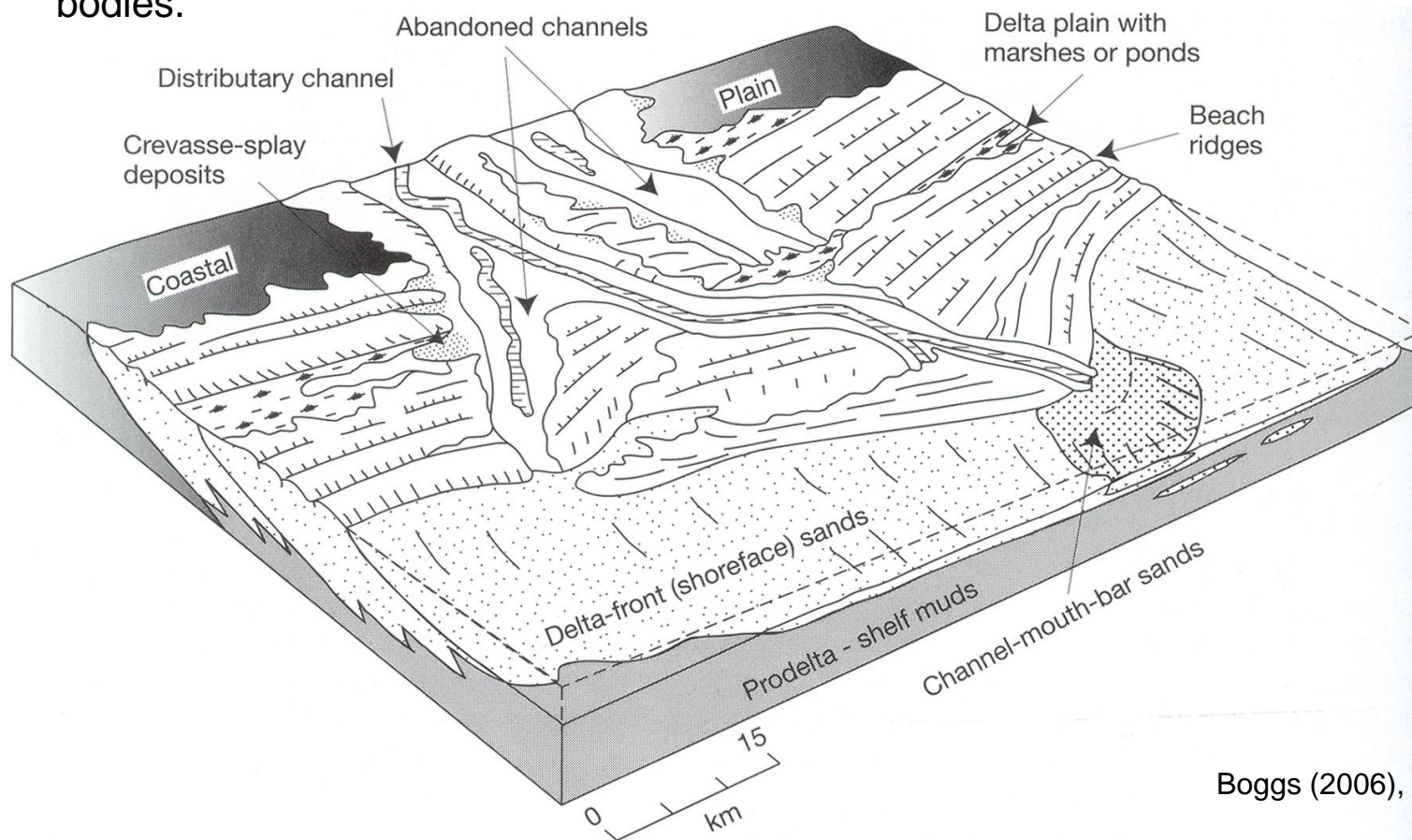
Figure 9.14

Three-dimensional model of fluvial-dominated delta deposits from eastern Kentucky. [After Horne, J. C., et al., De-

Upper Cretaceous (Texas)

Wave-dominated delta

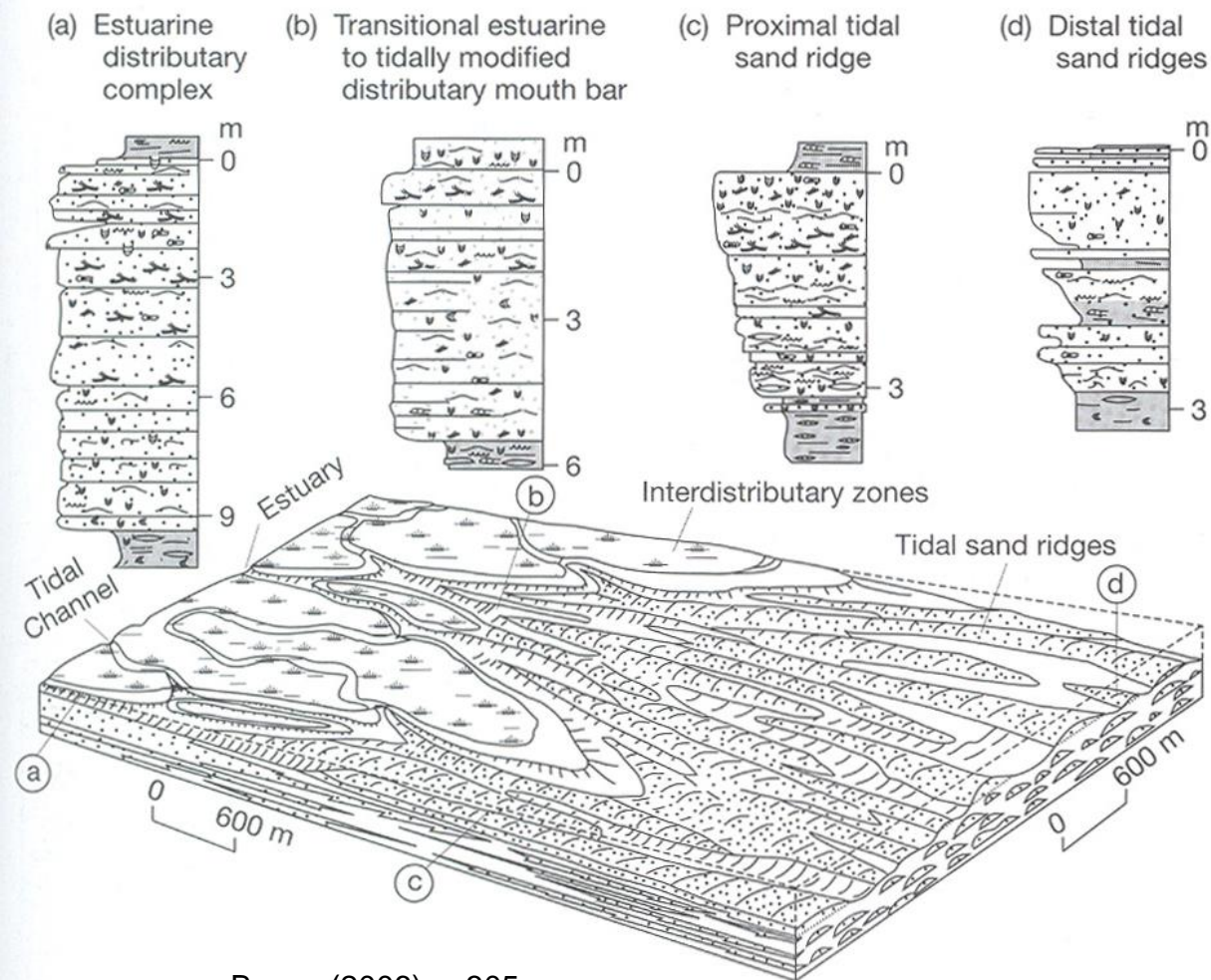
Sediments was extensively reworked by waves to form elongate, strike-aligned sandstone bodies.



Boggs (2006), p.304.

Figure 9.15

Three-dimensional model illustrating the sand-body geometry and facies of a wave-dominated delta system in the San Miguel Formation (Cretaceous), South Texas. [After Weise, B. R., 1980, Wave-dominated delta systems of the Upper Cretaceous San Miguel Formation, Maverick Basin, South Texas: Bureau of Economic Geology, University of Texas at Austin, Report of Investigations 107, Fig. 26, p. 20, reproduced by permission.]



Boggs (2006), p.305.

Figure 9.16

Three-dimensional model of the delta front and lower delta plain of the tide-dominated delta in the Misoa Formation (Eocene), Maracaibo Basin, Venezuela. A typical estuarine distributary complex is shown in (a). A transitional lithofacies occurs farther seaward (b), where greater influence of shallow-marine conditions and a high degree of reworking by tidal currents modify the typical estuarine distributary-channel complex. Proximal tidal sand-ridge facies (c) are present in areas of high sediment discharge near the ends of the estuaries (c). Distal sand-ridge facies lie farther from the estuaries, where the sediment supply is limited and tidal currents are weaker (d). Note that both the sand facies (dot pattern) and mud facies (dark shade) are extensively bioturbated. [After Maguregui, J., and N. Tyler,

Tide-dominated delta

Eocene delta in Venezuela

Typical delta sequence is characterised by:

- Tidal sands arranged in perpendicular to the shoreline.
- Interdistributary zone is characterised by muddy tidal flats.
- Sands accumulated in the estuarine channels to form estuarine distributary-channel complexes; in the tidally-influenced, distributary-mouth-bars area and further seaward.

Fan-delta

Example from the Late Carboniferous-Permian in Spitsbergen

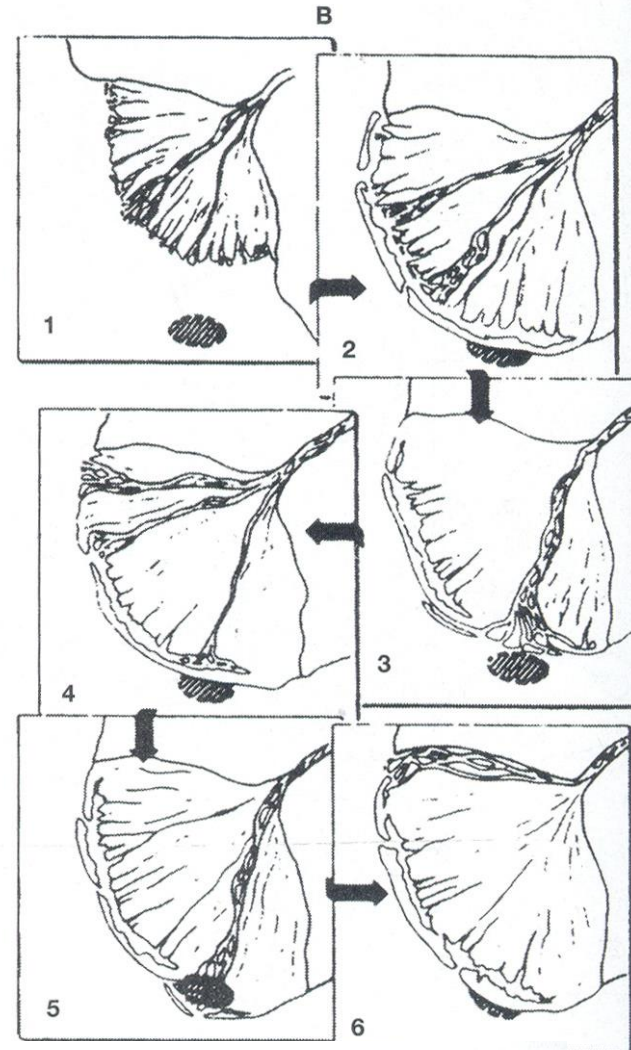
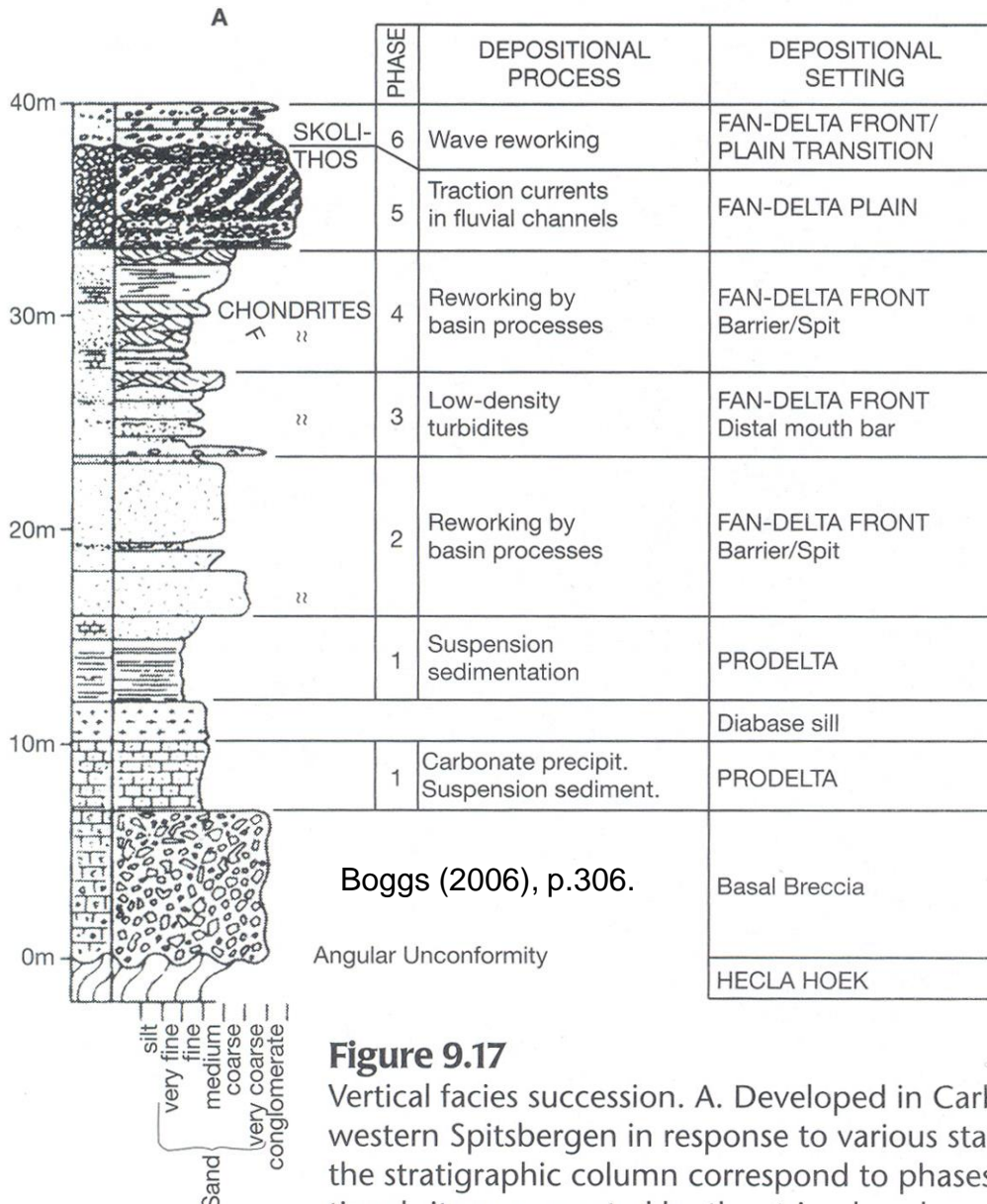
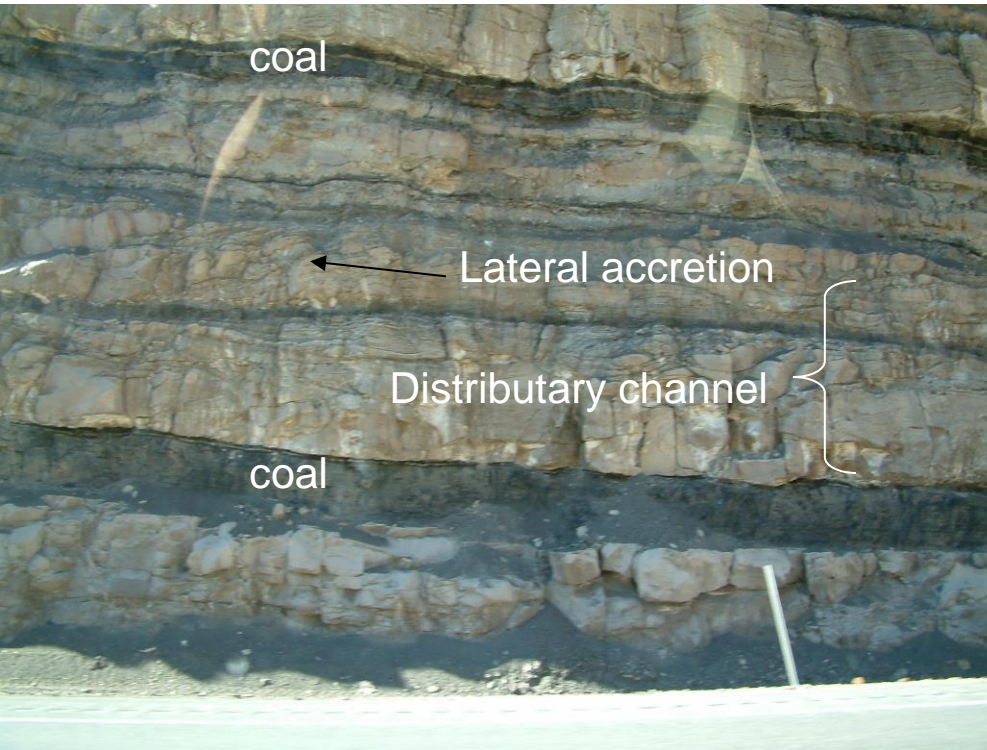


Figure 9.17

Vertical facies succession. A. Developed in Carboniferous-Permian fan-delta deposits of western Spitsbergen in response to various stages of fan progradation. B. Phases 1–6 in the stratigraphic column correspond to phases 1–6 in the plan-view sketches. The depositional site, represented by the striped oval area, remained fixed in space while the fan-delta geometry changed relative to that area. [From Kleinspehn, K. L., et al., 1984,

Delta coastal plain facies



Photos by Andrew Lin

Cretaceous (Campanian) Blackhawk Formation of SE Utah. Example delta/coastal plain facies. Sandstones are mostly singly storey, distributary channels a few meters in thickness. Thinner, more discontinuous sandstones are a variety of overbank and crevasse splay facies. Coals bound the major channels and are commonly split by sandstones.



Blackhawk Formation SE Utah