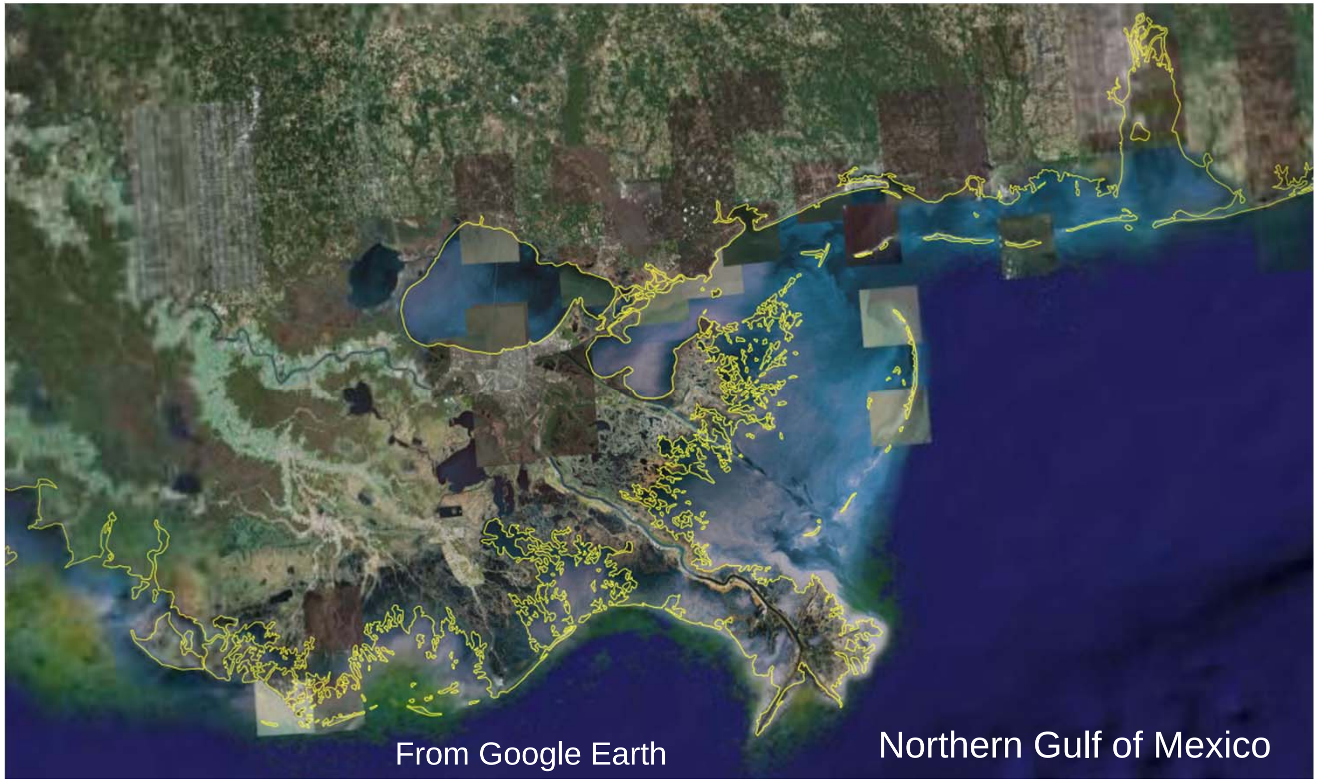
# 6. Marginal-Marine Environments

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 (瀉湖) (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

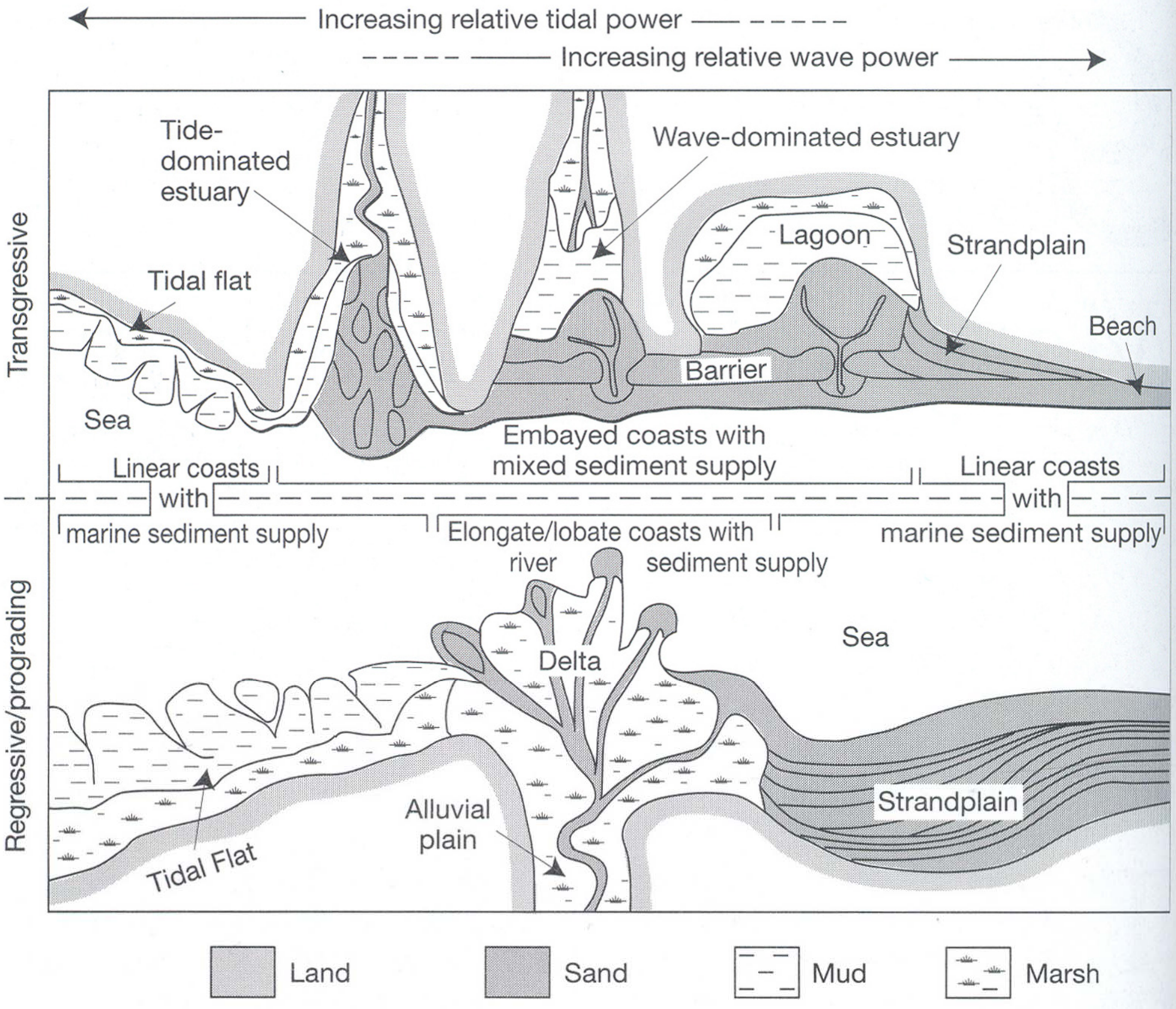



**Figure 9.1**
The principal coastal environments of the marginal-marine depositional setting. The figure is organized to show the relative influence of tidal power (increasing to the left) and wave power (increasing to the right) on each environment. Note that deltas are features of prograding (regressive) 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.]

Boggs (2006), p.290

# 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 $\times 10^6$) |
|---|---|---|---|---|
| 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:

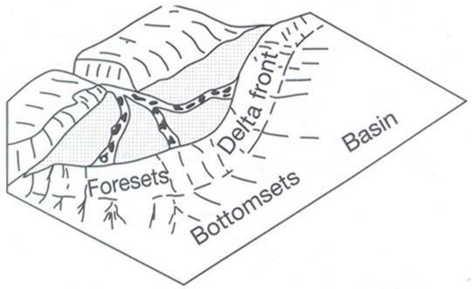
- river (sediment) input
- wave-energy flux
- tidal flux

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

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

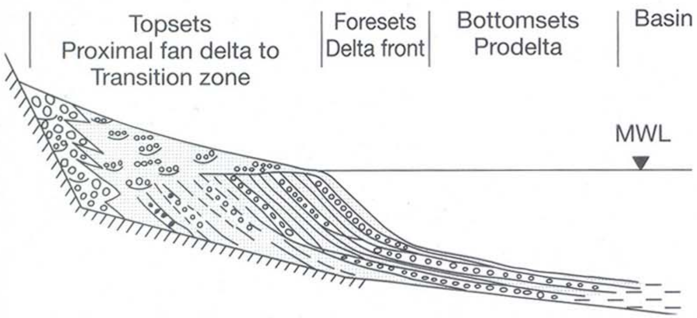
Each of the above delta categories can be further distinguished on the basis of sediment grain size (mud/silt, fine sand, gravelly sand, or gravel).

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.

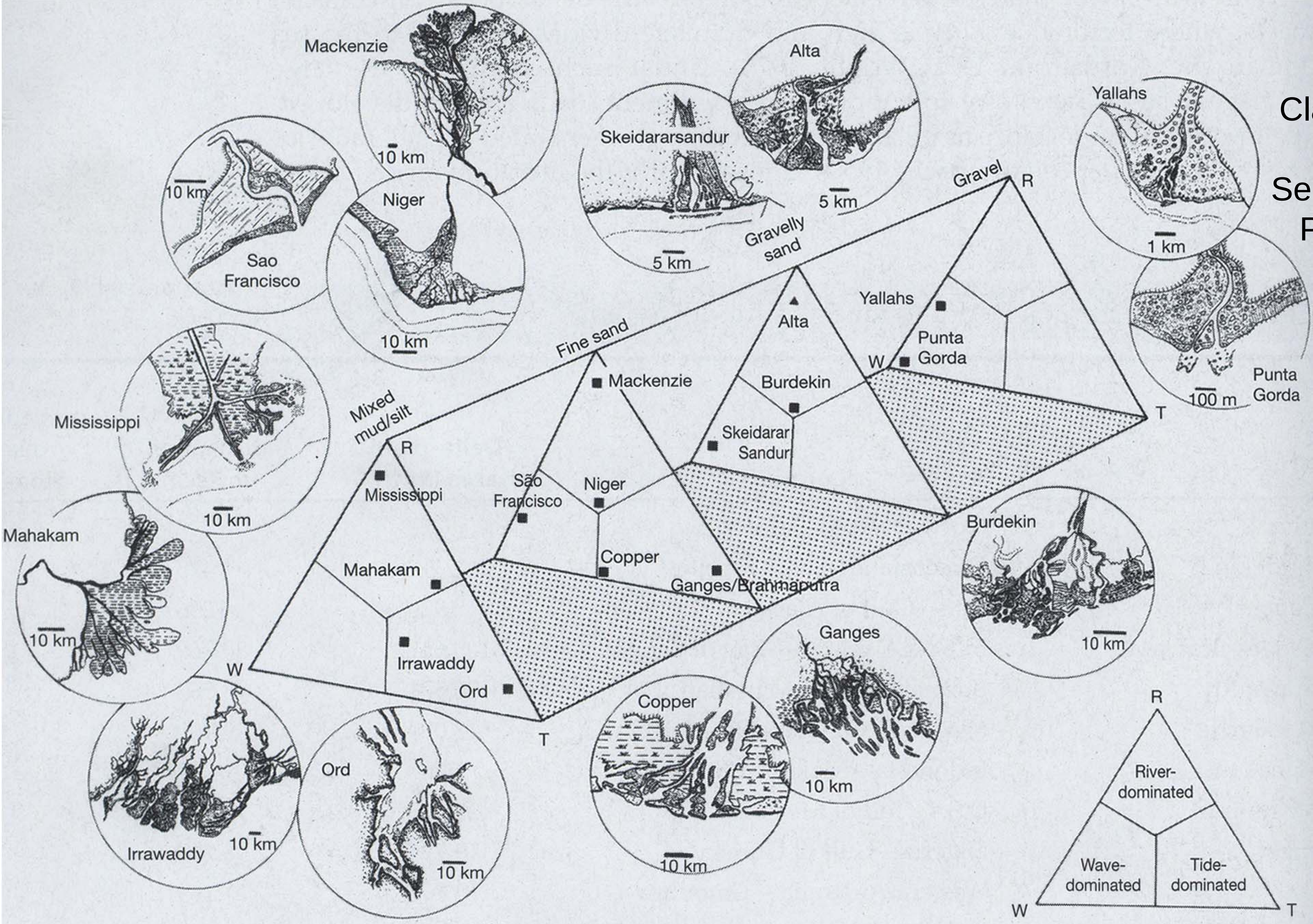
Gilbert-type delta: coarse-grained delta with topset, foreset, and bottomset arrangement of beds, created as sediment deposition progrades basinward.




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




Boggs (2006), p.292

**Figure 9.3**
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 plottec 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 lead 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

**Inertia-dominated river mouths**

(C) GRAVELLY BEDLOAD or MASS-FLOW DOMINATED CHANNELS

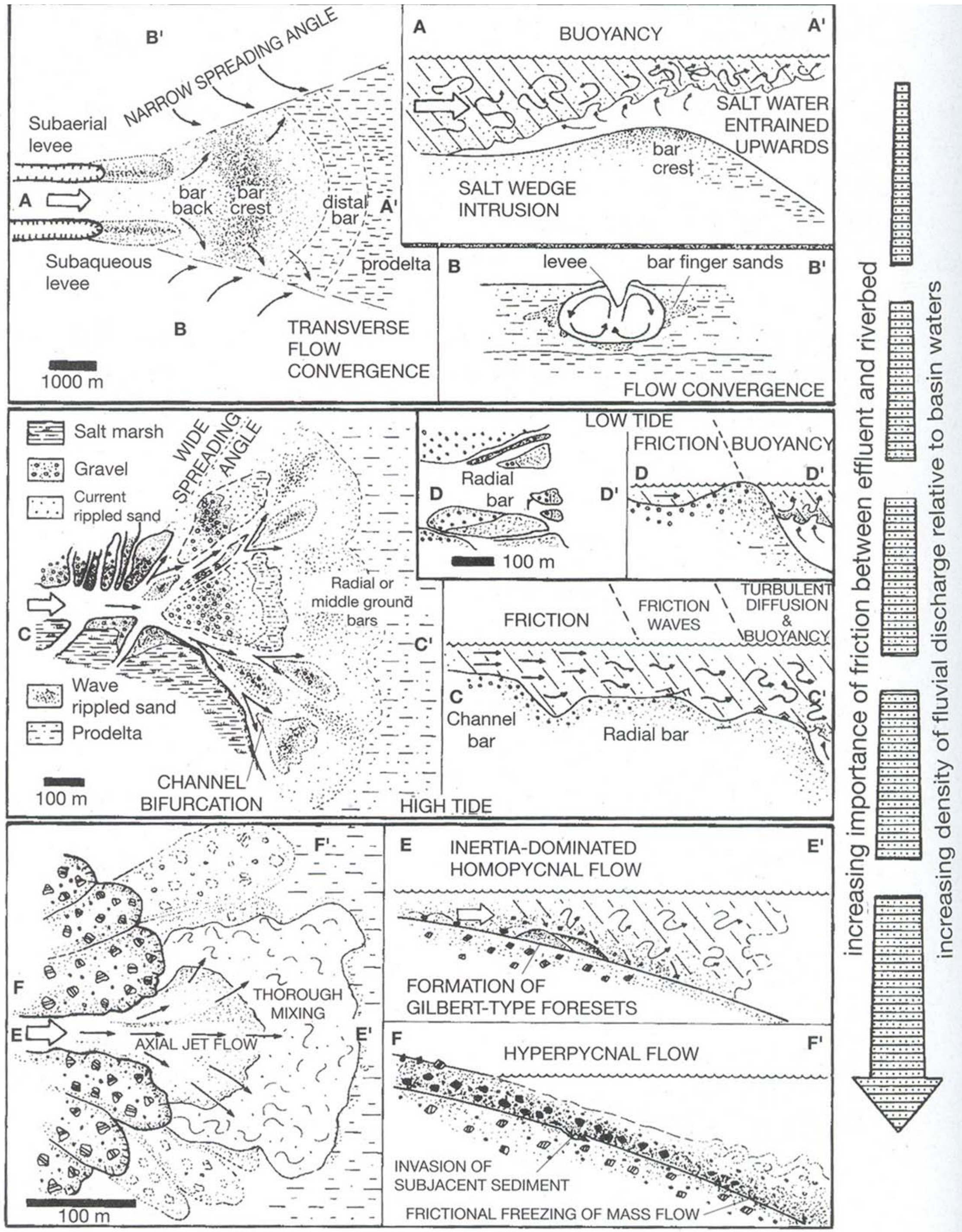



**Figure 9.5**
Schematic depiction of the complex relationship arising from sediment grain size, river outflow inertia (velocity), outflow friction with the bed, and outflow buoyancy—and its effect on delta formation. [After Orton, G. J., and H. G. Reading, 1993, Variability of deltaic processes in terms of sediment supply, with particular emphasis on grain size: Sedimentology, v. 40, Fig. 4, p. 487, reproduced by permission.]

Boggs (2006), p.294

# 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 Missisippi 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.

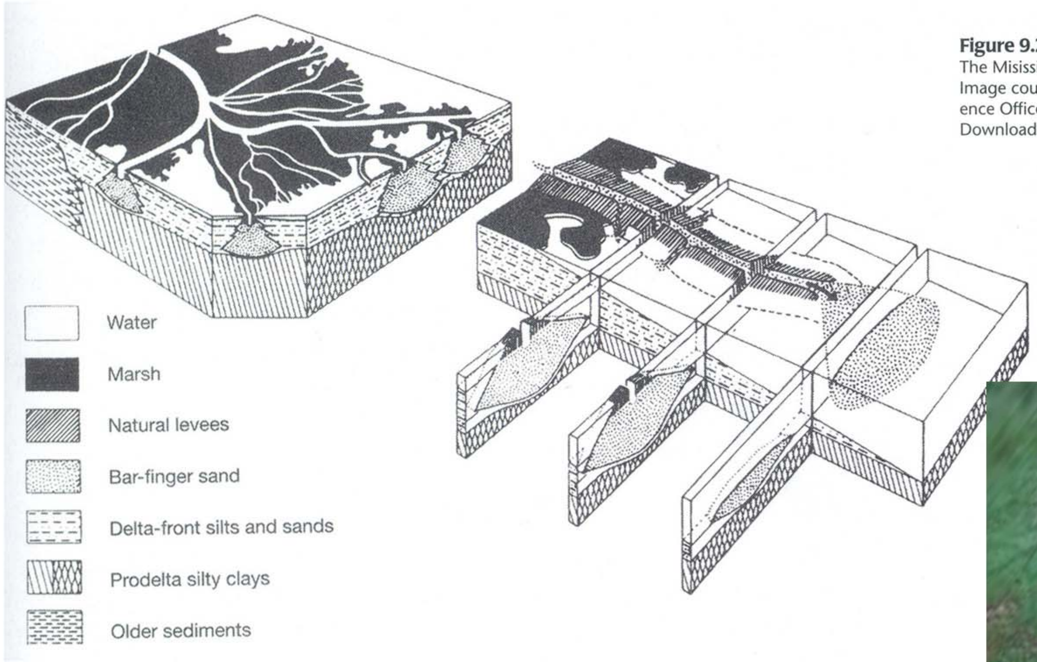
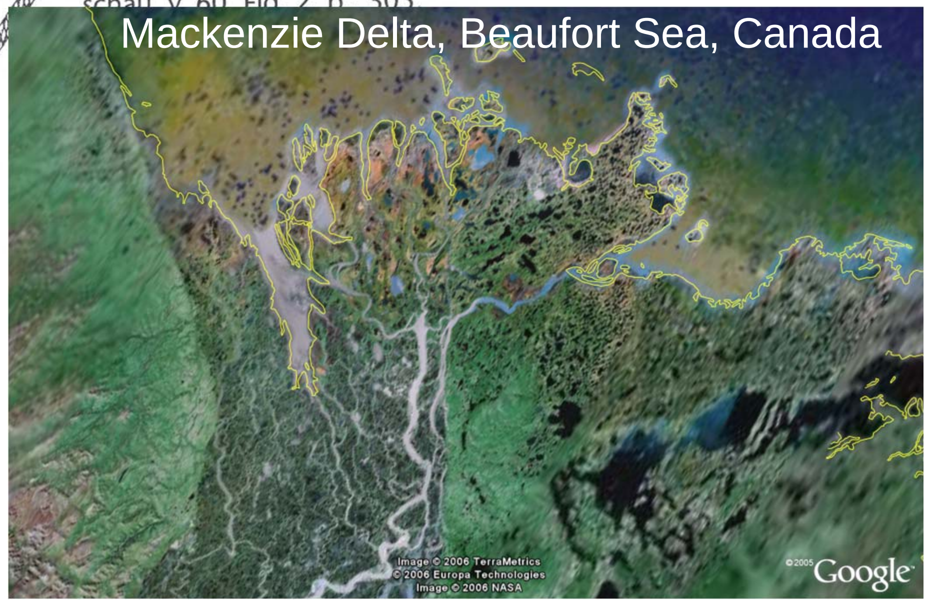



**Figure 9.6**
The fluvial-dominated, Mississippi delta system. [From Reineck, H. E., 1970, Marine sandkörper, rezent und fossil: Geol. Rundschau, v. 60, Fig. 2, p. 305.

Boggs (2006), p.290



# 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

# Ganges-Brahmaputra delta

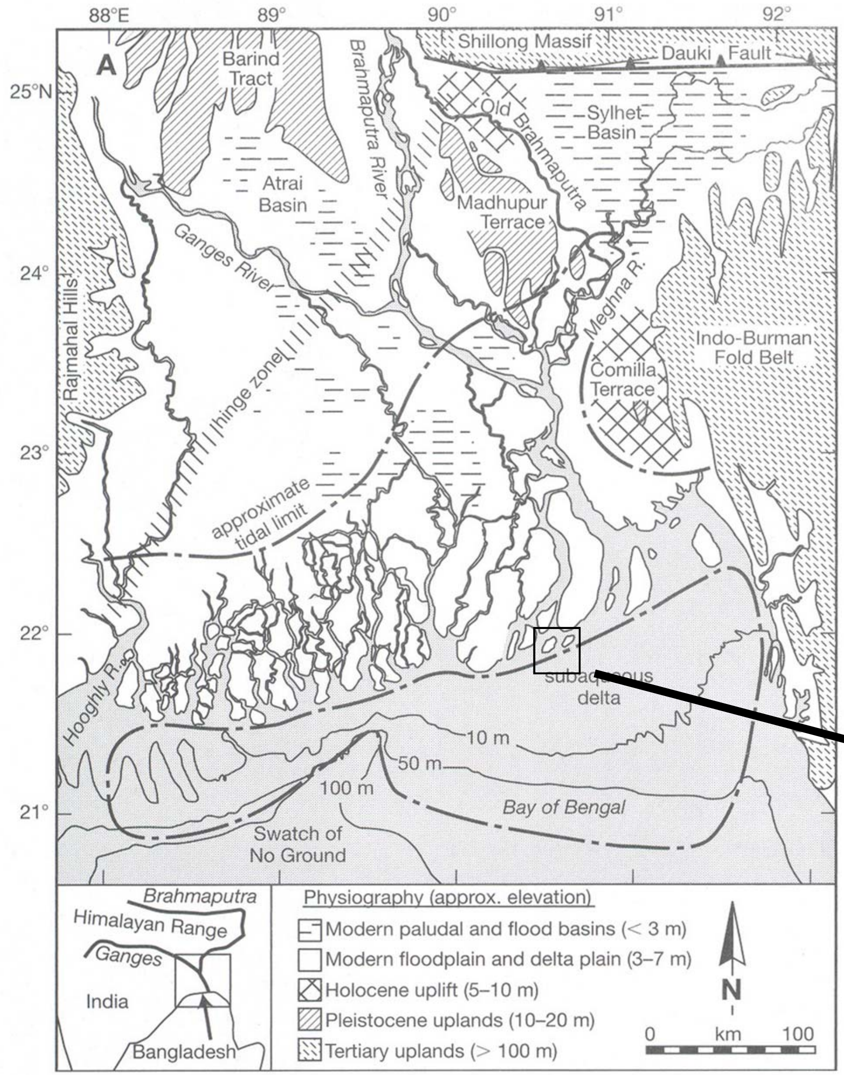



Fig. 9.7A of Boggs (2006), p.297.

- 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.

# Wave-dominated deltas

Strong waves cause rapid diffusion and deceleration of river outflow and produce constricted or deflected river mouths. Distributary-mouth deposits are reworded 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

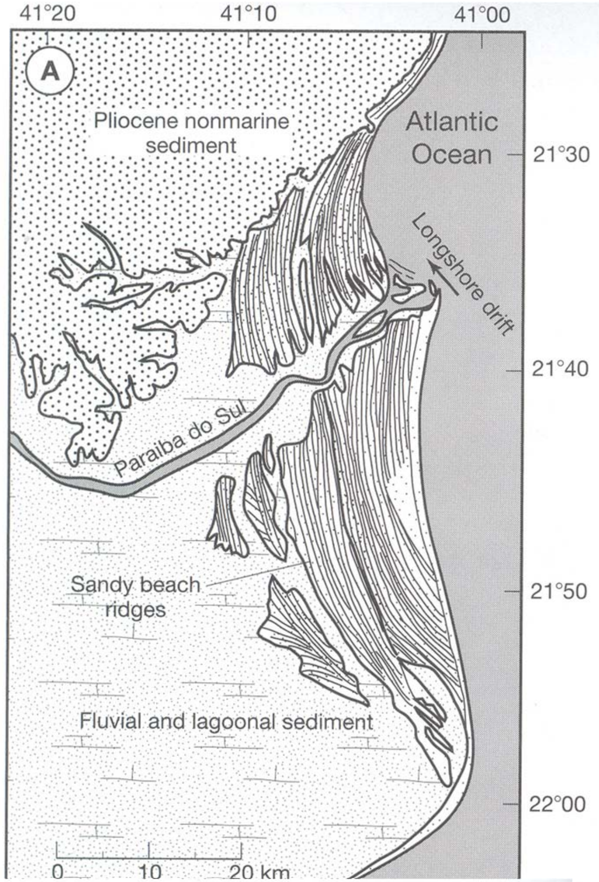
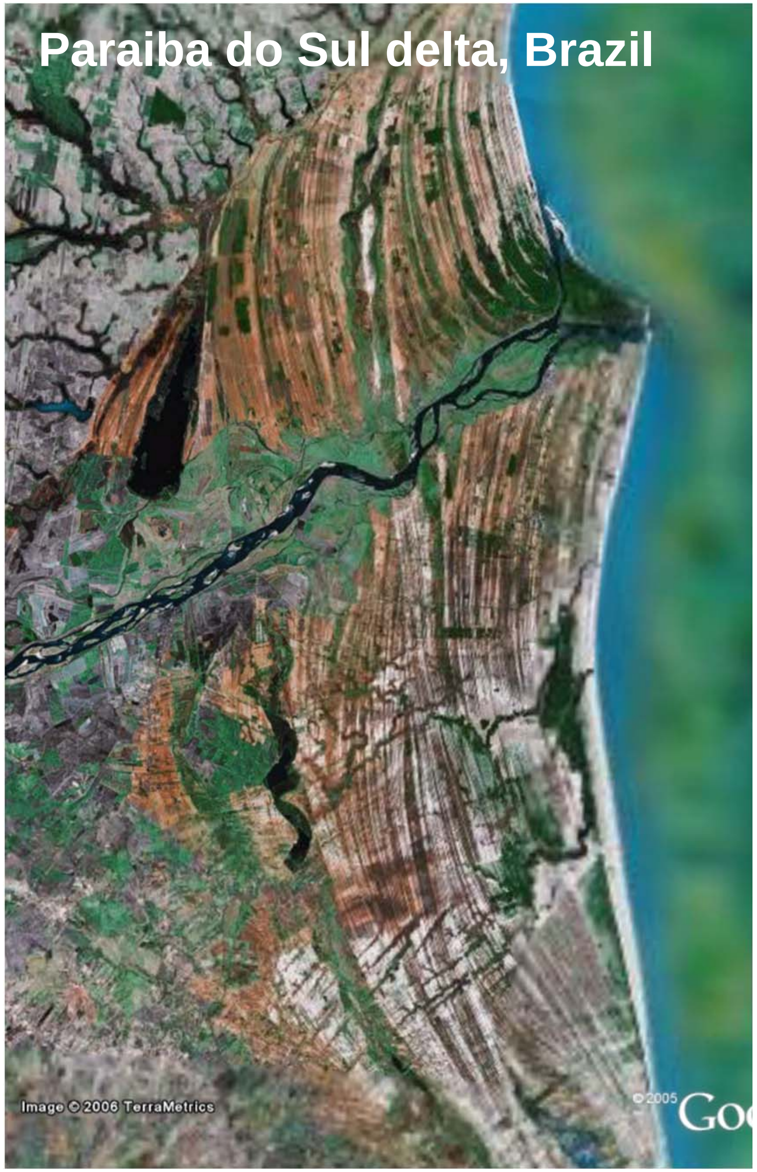



Fig. 9.8A of Boggs (2006), p.298.

**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

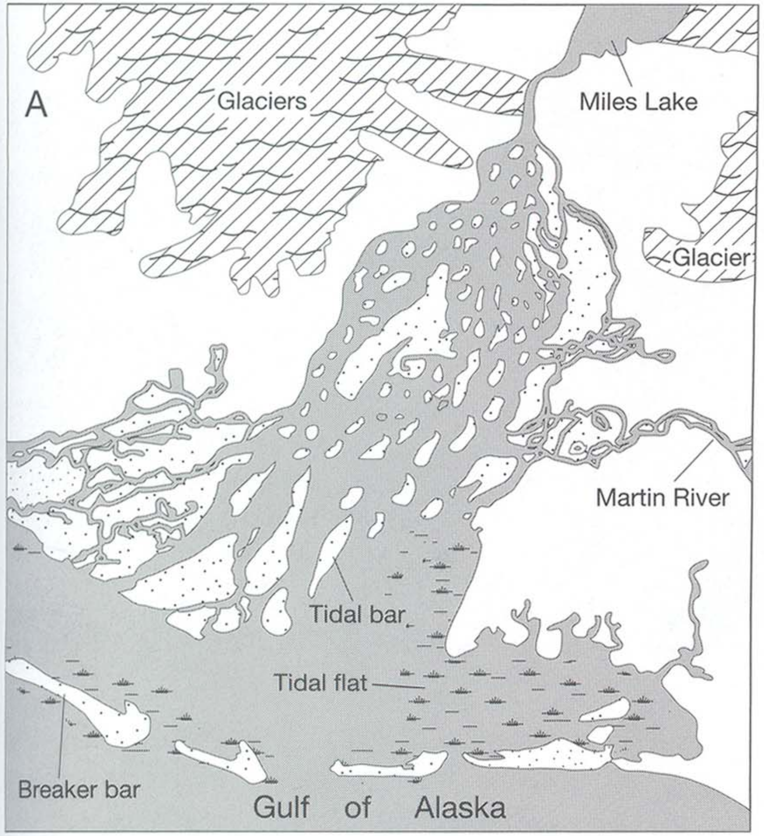
Many deltas are shaped by a combination of fluvial-, tidal-, and wave-related processes.

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.



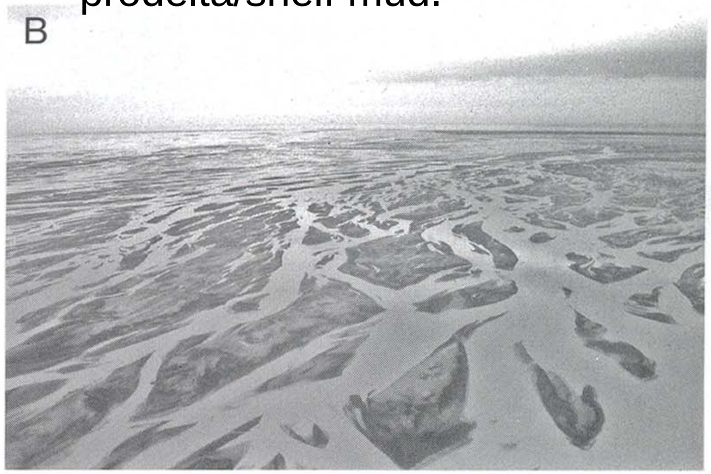




**Figure 9.9**
The Copper River delta, Gulf of Alaska. A. Physiographic map of the delta, showing tide-influenced channels and bars and wave-influenced breaker bars; based on U.S. Dept. of Agriculture map, "The Copper River," Alaska Region R110-RG-100. B. Tidal channels and tidal sand bars on the delta; 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.

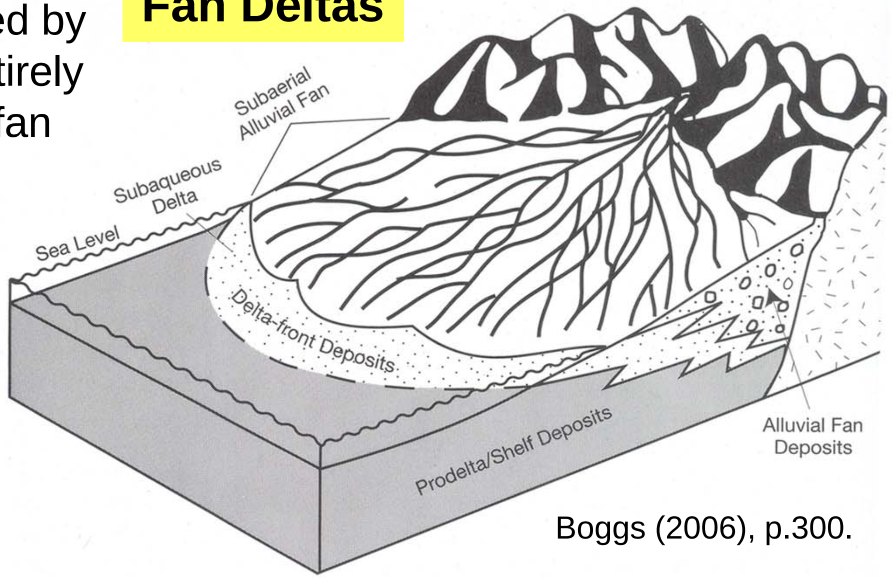



**Figure 9.11**
Schematic diagram of a fan delta, showing the subaerial alluvial fan and subaqueous delta. [After Nemec, W., and R. J. Steel, 1988, What is a delta and how do we recognize it? *in* Nemec, W., and R. J. Steel (eds.), Fan deltas: Sedimentology and tectonic setting: Blackie, Glasgow, Fig.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

Boggs (2006), p.300.

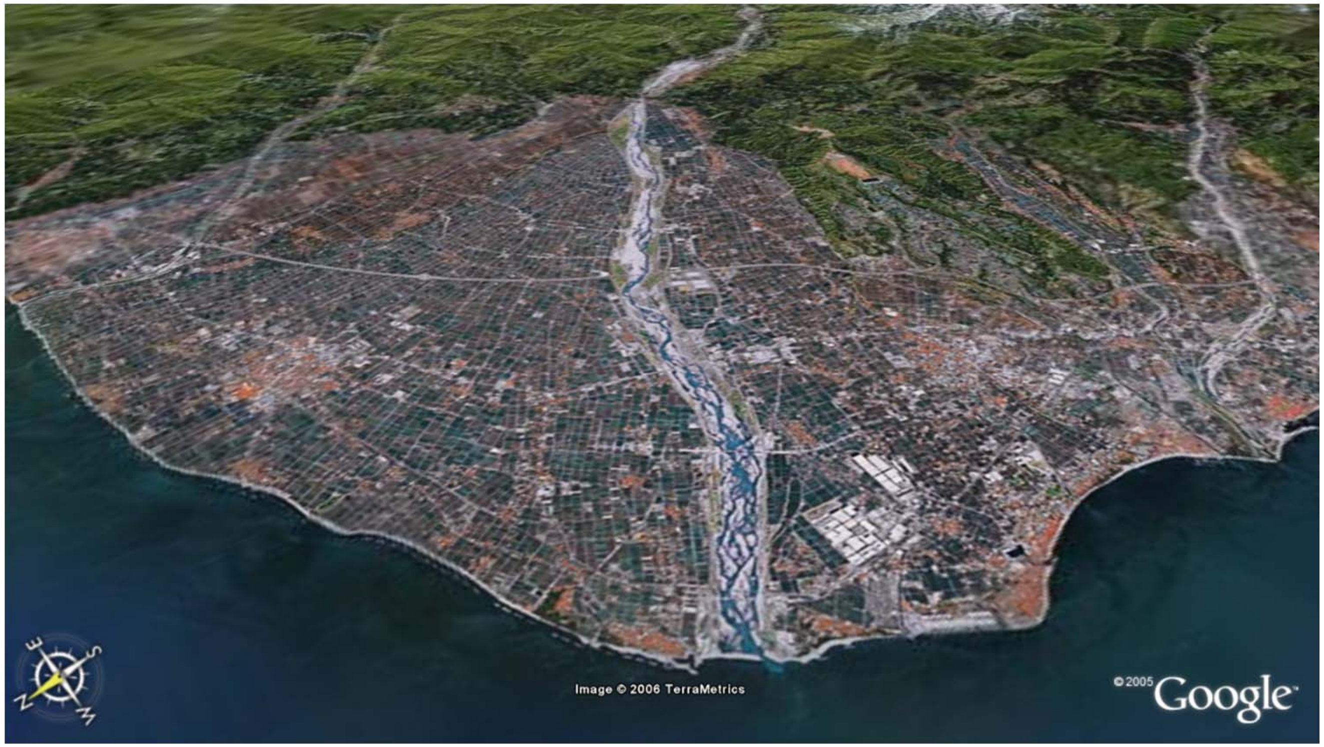


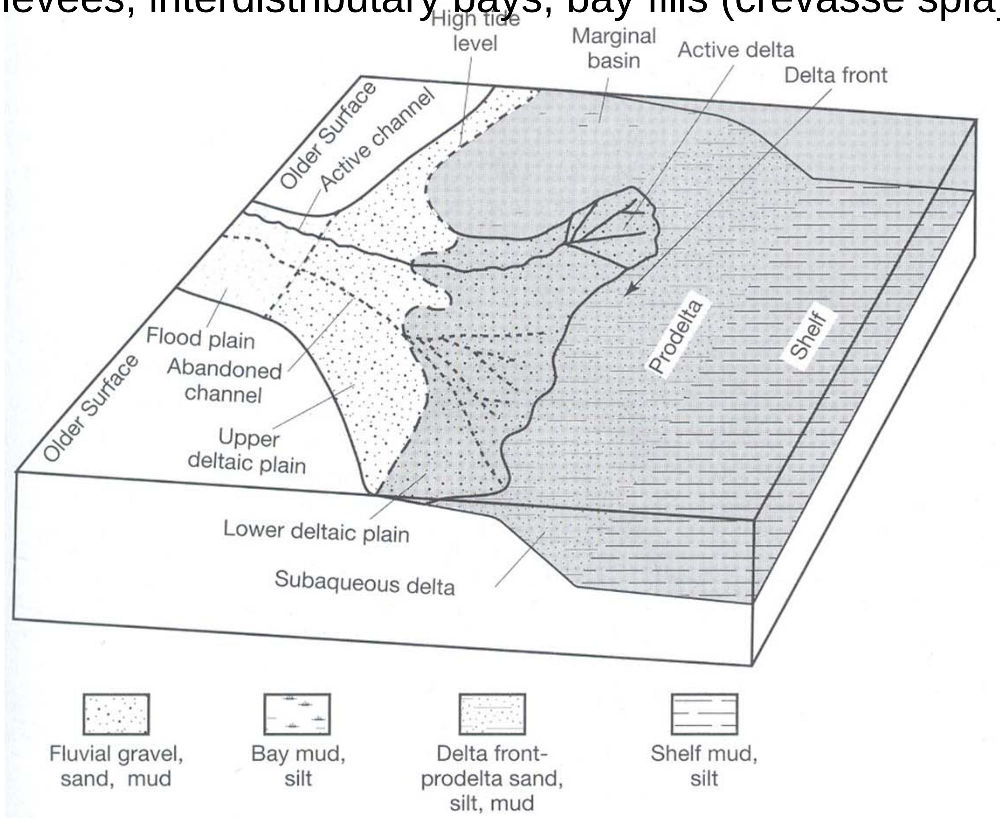

**Figure 9.10** →
Kurobegawa fan, a large fan delta at the mouth of the Kurobe River, Toyama Bay, Japan Sea, off central Japan. [From Fujii, S., and N. Nasu, 1988, Kaiteirin (submerged forest; text in Japanese), Tokyo University Press, Color plate of Kurobegawa fan. Photograph courtesy of S. Fujii; reproduced 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.]

Boggs (2006), p.301.

# 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.

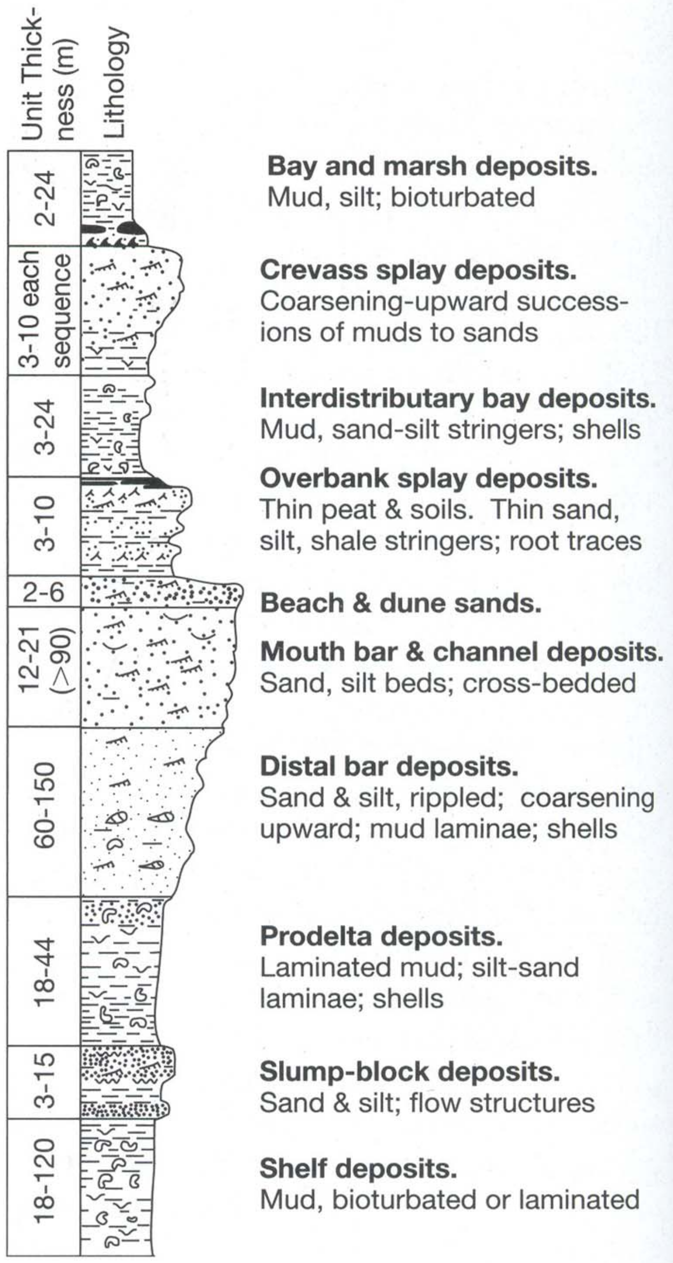


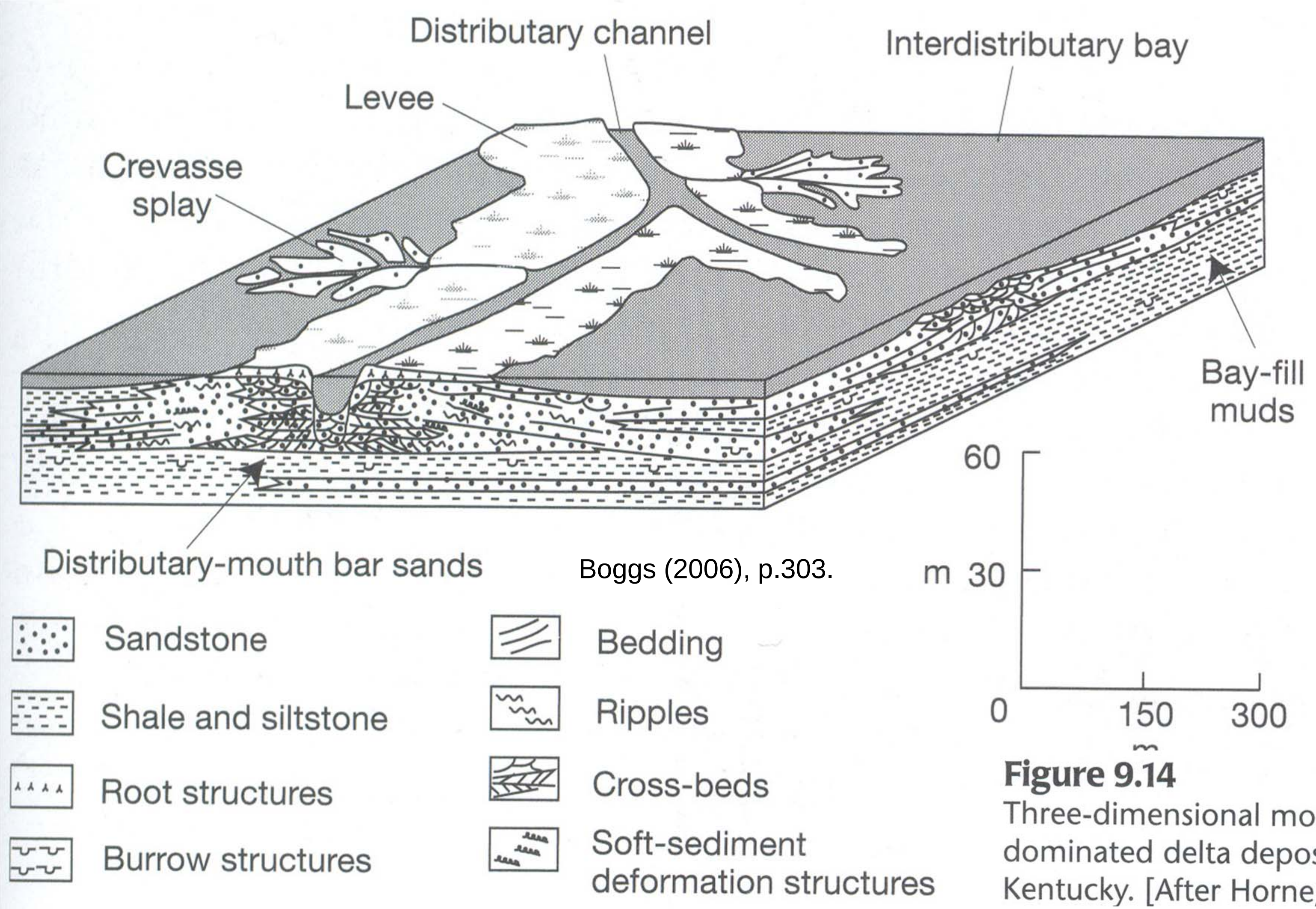

**Figure 9.13**
Idealized vertical succession of facies in a fluvial-dominated (Mississippi) delta. Note the thickness of individual units shown in the column. [From Coleman, J. M., 1981, Deltas: Processes of deposition and models for exploration, 2nd ed., Fig. 4.3, p. 91, reprinted by permission of 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.




Boggs (2006), p.303.

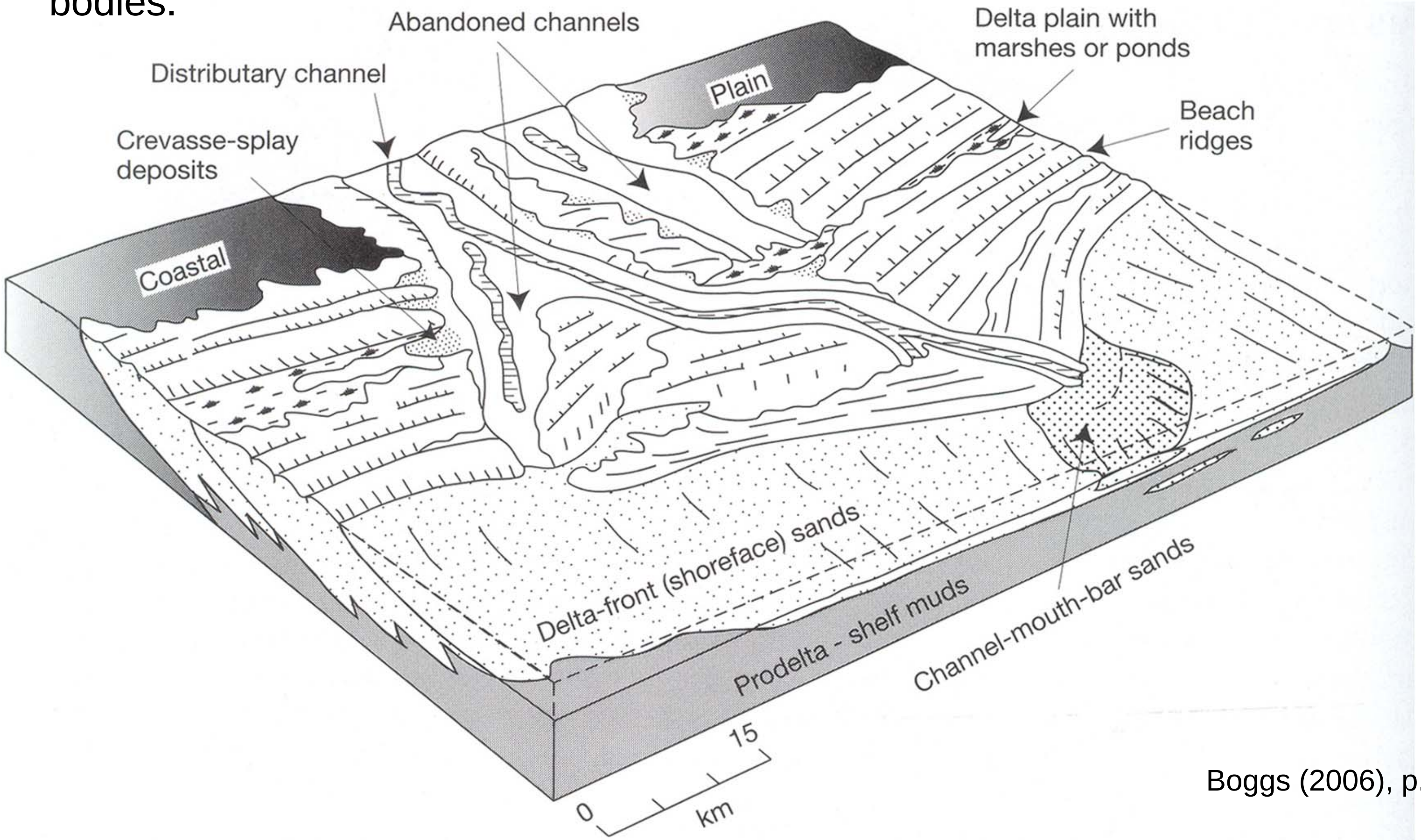
**Figure 9.14**
Three-dimensional model of fluvial-dominated delta deposits from eastern Kentucky. [After Horne, J. C., et al., De-

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.

# Wave-dominated delta

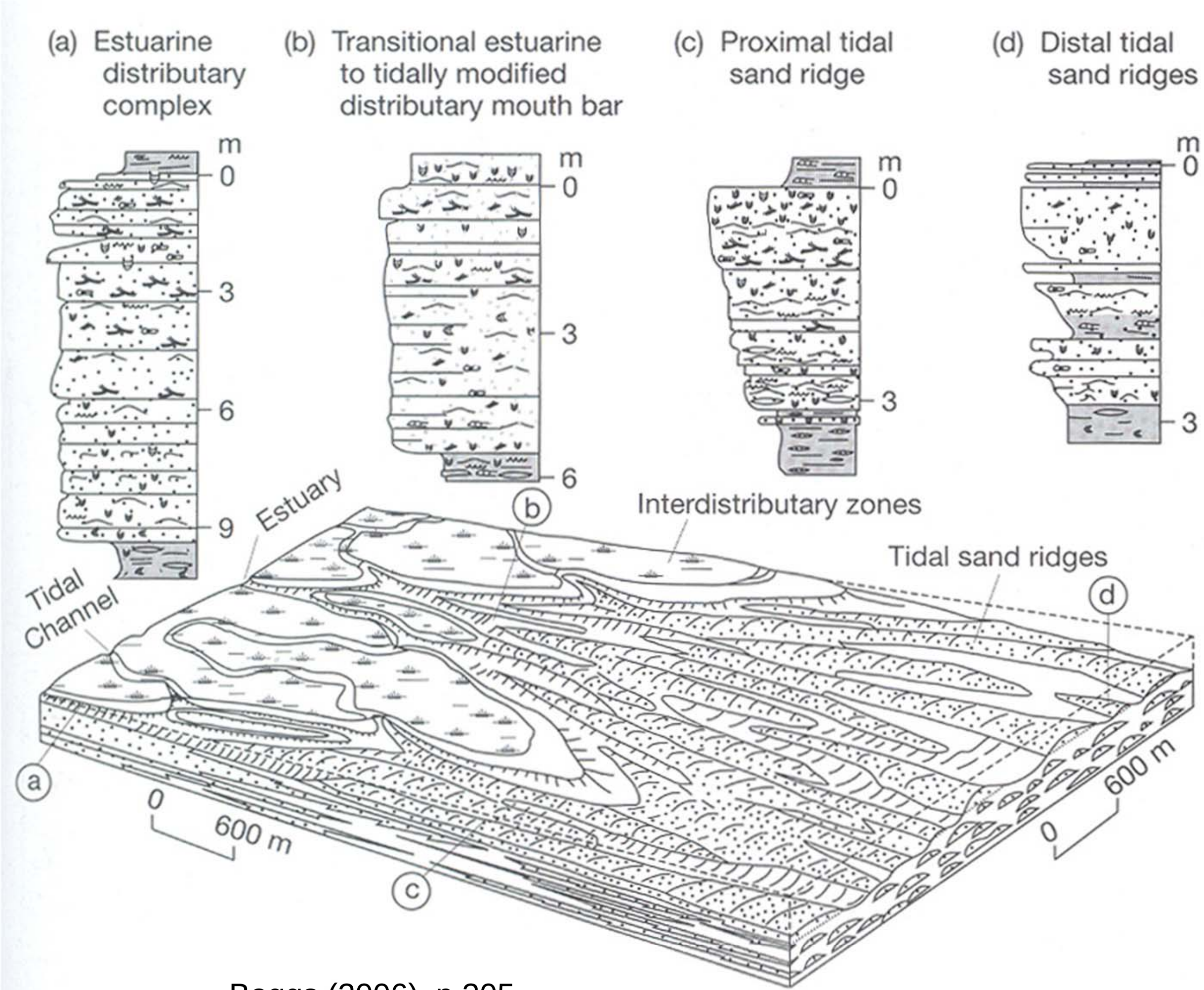
Upper Cretaceous (Texas)

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

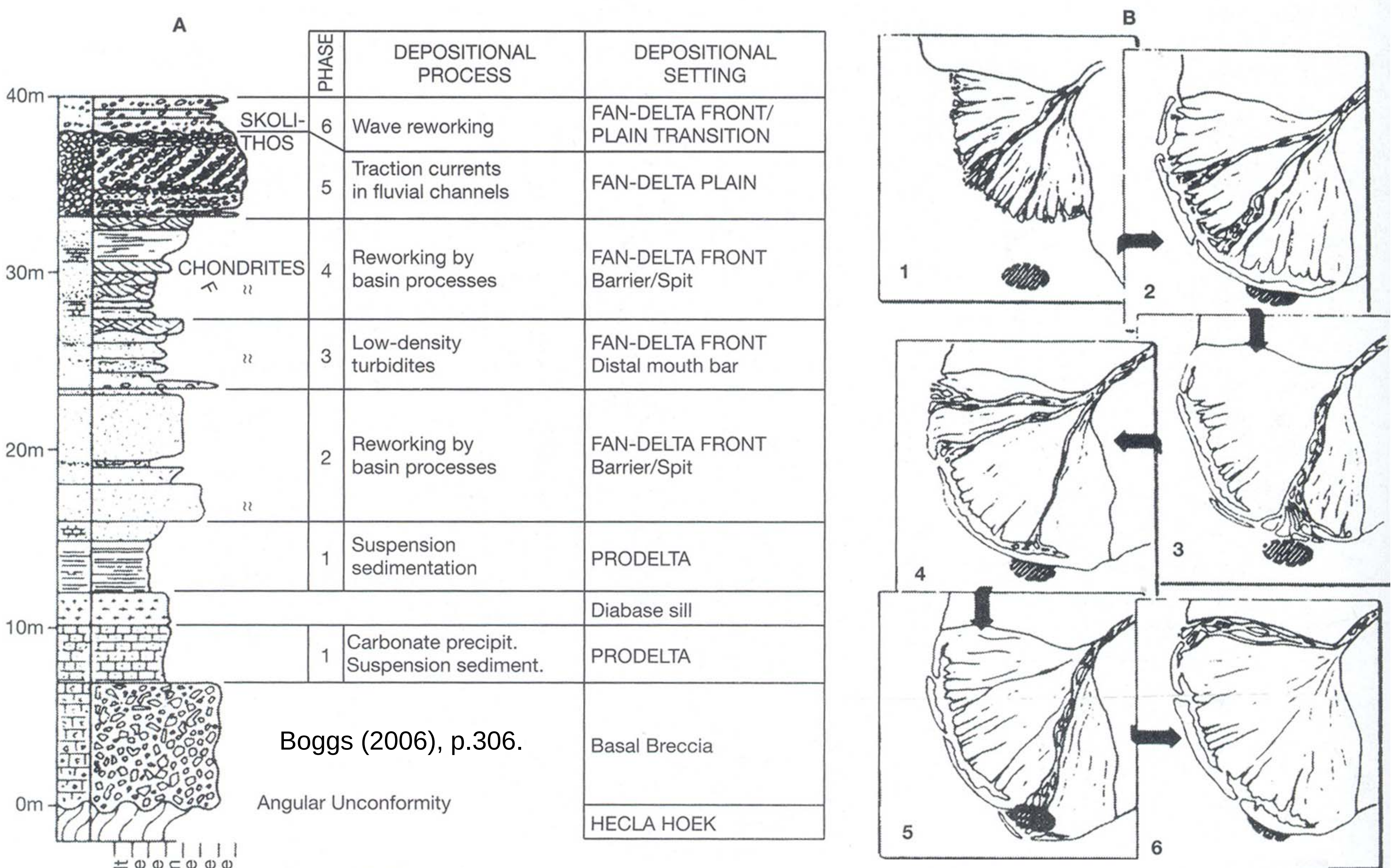
Eocene delta in Venezuela

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**

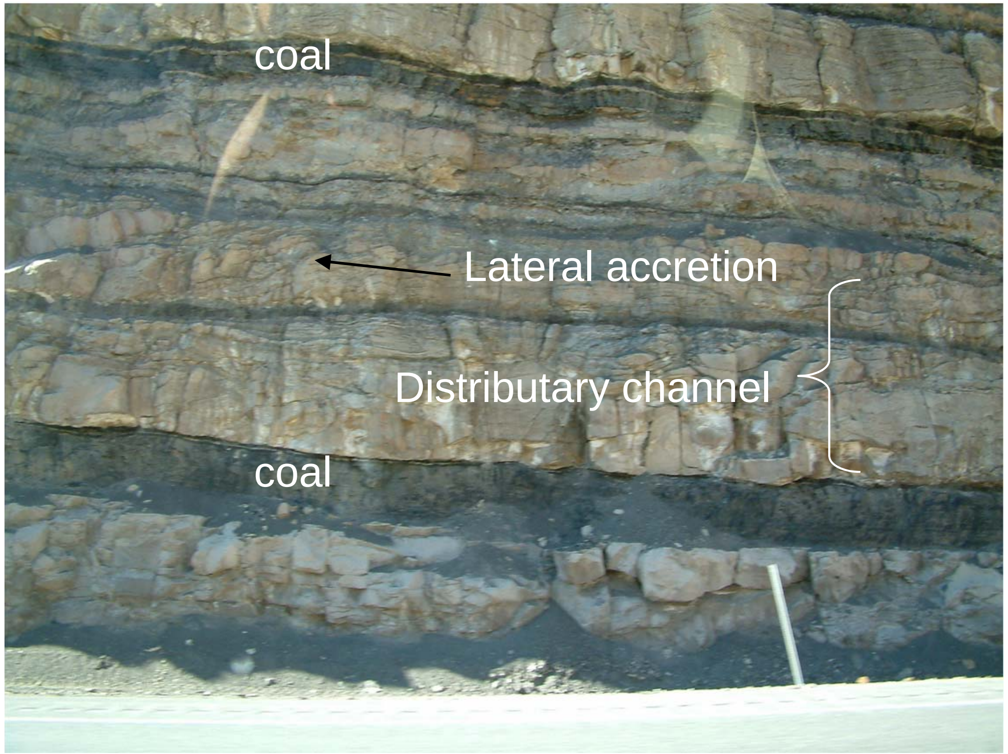
Example from the Late Carboniferous-Permian in Spitsbergen




Boggs (2006), p.306.

**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

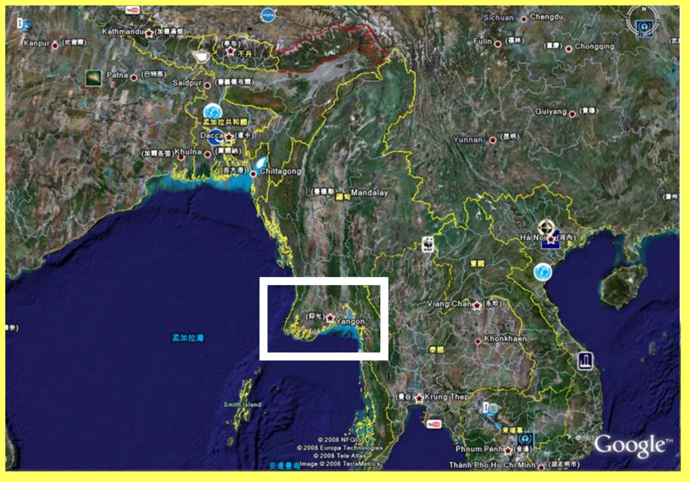
Cretaceous (Campanian) Blackhawk Formation of SE Utah. Example delta/coastal plain facies. Sandstones are mostly singly storey, distributary channels a few meters in thickness. Thinner, more discontinuous sandstones are a variety of overbank and crevasse splay facies. Coals bound the major channels and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

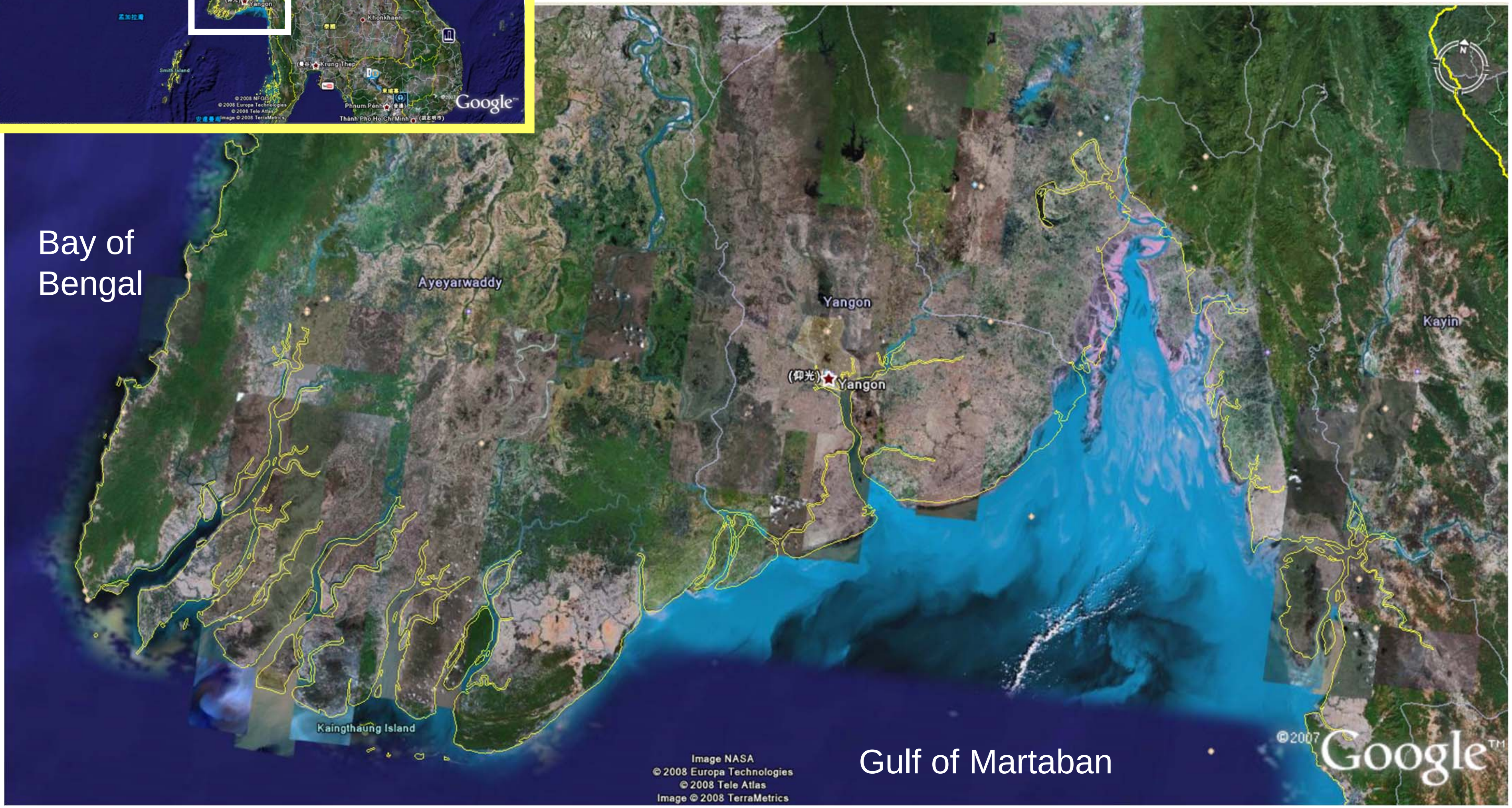
Blackhawk Formation SE Utah

What if a typhoon swept through a delta region

The example of Cyclone Nargis that hit Myanmar in May 2008

Myanmar in its coastal region lies in a delta



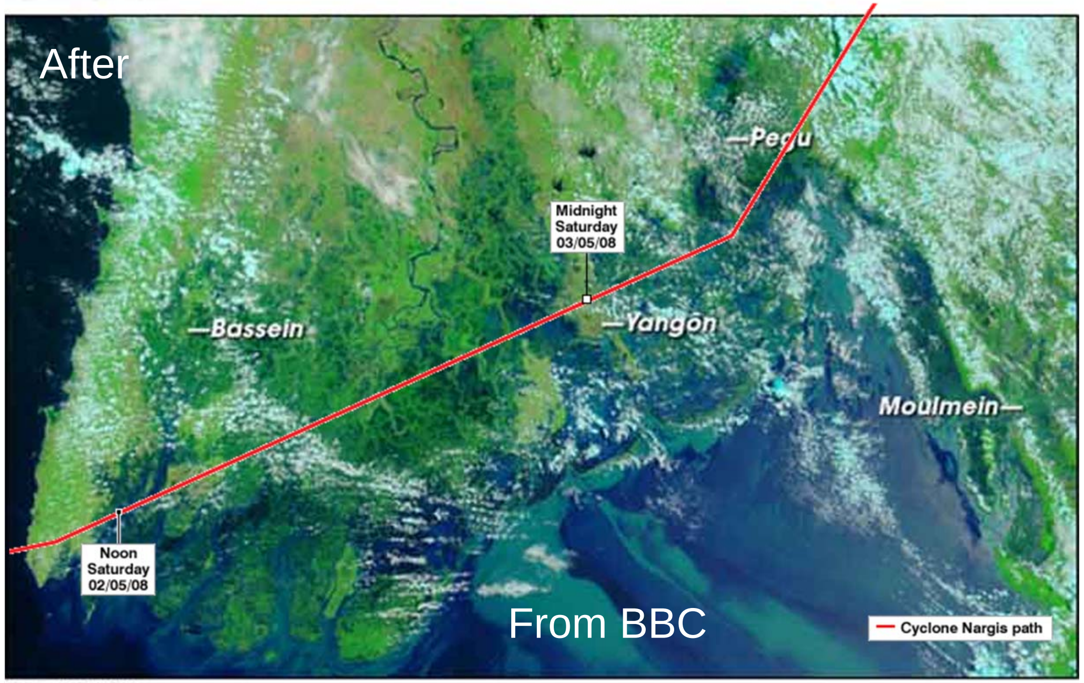



Typhoons (known in western Pacific) = Hurricanes (Atlantic and eastern Pacific) = Cyclones (Bay of Bengal and Indian Ocean)

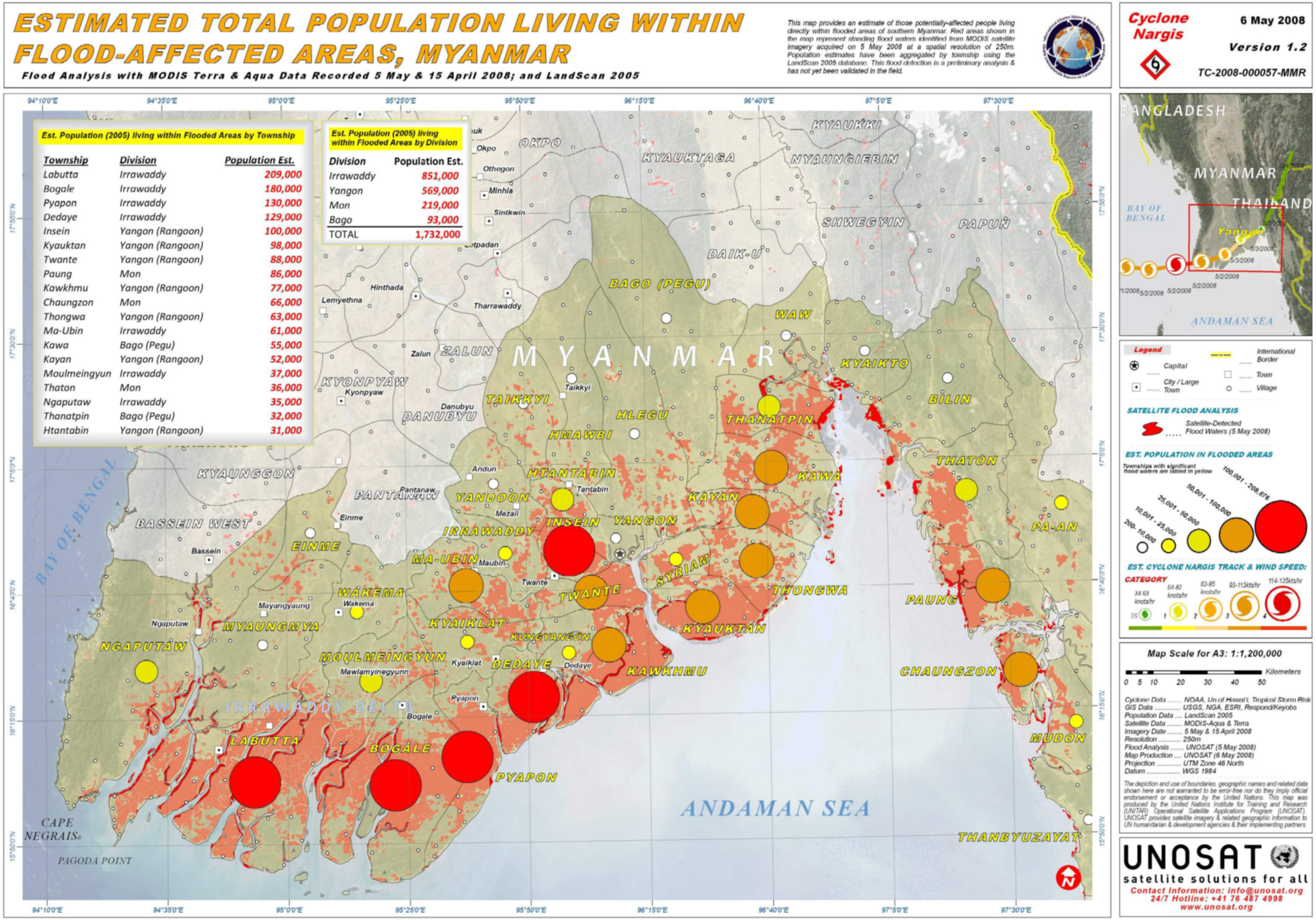
Cyclone Nargis hit Myamar’s delta region in May 2008, causing floods, and killing ~60,000 people.

April 15, 2008

Much of the Irrawaddy river delta region flooded!



May 5, 2008




From United Nation

The city of Yangôn (also called Rangoon) in Burma (Myanmar), is tucked into a "V" between two rivers that empty into the Gulf of Martaban through a large estuary. When Cyclone Nargis passed over the city in the first week of May 2008, the entire coastal plain flooded, surrounding Yangôn with water.

This pair of images from NASA's Landsat satellite shows the city and surrounding agricultural land before and after the storm. On March 18, 2008, the built up part of the city and its suburbs appear bluish purple, fallow cropland is pinkish-tan, and vegetation is dark green. The wide rivers are a muddy green.

After Nargis inundated the area with heavy rains and storm surge, standing water covered almost the entire area. As of May 5, flooding in the heart of the city appeared to be less than in the surrounding areas. (Flooding probably exists, but it may be at a smaller scale than Landsat is able to detect.) However, all the land to the west and southwest and most of the area to the east and southeast are still submerged. Across the river to the southeast of the city, a swath of relatively dry land perhaps higher in elevation, or protected by a levee extends toward the lower right corner of the image. Across the rest of the scene, standing water varies in shades from muddy brown, to green, to purplish blue.

May 5, 2008

March 18, 2008

From Reuters at: http://www.alertnet.org/thefacts/satelliteimages/121059647825.htm

# Typhoon Category

| Category | Wind speed | Effects |
|---|---|---|
| 1 | 74-95 mph | Minor flooding, little damage, storm surge 1.2-1.5 m |
| 2 | 96-110 mph | Roofs damaged, Some trees damaged, storm surge 1.8-2.4 m |
| 3 | 111-130 mph | Houses damaged, severe flooding, storm surge 2.7-3.4 m |
| 4 | 131-154 mph | Some roof destroyed, major structural damage to houses, storm surge 4-5.5 m |
| 5 | 155 mph upwards | Serious damage to buildings, severe flooding further inland, storm surge more than 5.5 m |

Nargis {

From BBC at: http://news.bbc.co.uk/2/hi/science/nature/4588149.stm

Laid waste: Missing roofs and buckled trees show the devastation in a delta town


Only the roofs stand about the water in flooded villages around Rangoon

Harrowing: Bodies lie bloated in the water still covering areas of the Irrawaddy delta

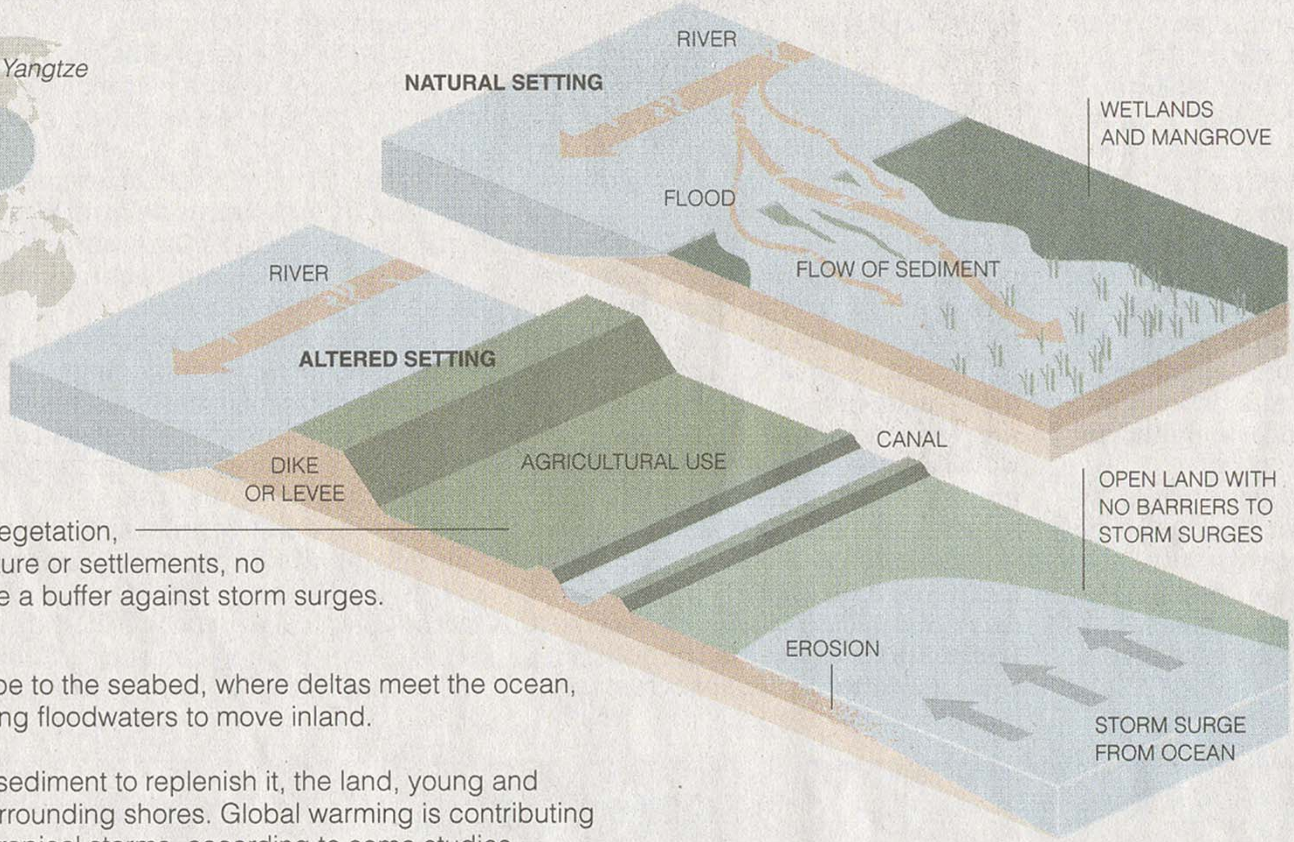
# Five Reasons Storms at Deltas Are Especially Deadly

**1. POPULATION GROWTH** Because deltas are particularly fertile, they often become hubs for commerce and attract large populations.

Low-lying settlements there are vulnerable to storm surges and flooding. The Irrawaddy delta was home to more than one-third of Myanmar's population.

**Regions at risk** Major delta areas that are vulnerable to hurricanes and cyclones. Circle sizes indicate regional population.


**2. EPHEMERAL LANDSCAPES** Deltas are continually reshaped by nature and, increasingly, people. Under natural conditions, river flooding washes land with fresh water, sediment and nutrients, building up delta lands. But dikes, levees and canals channel rivers and their sediments out to sea.




**3. LOSS OF VEGETATION**
Mangroves and other delta vegetation, cleared for farming, aquaculture or settlements, no longer anchor soils or provide a buffer against storm surges.

**4. CLEAR PATH FOR SURGES** The shallow slope to the seabed, where deltas meet the ocean, offers less resistance to storm surges, allowing floodwaters to move inland.

**5. LAND SINKING, SEAS RISING** Without new sediment to replenish it, the land, young and waterlogged, tends to subside more than surrounding shores. Global warming is contributing to a rise in sea levels and could strengthen tropical storms, according to some studies.

BILL MARSH/THE NEW YORK TIMES

From The New York Times May 19 2008