Depositional Environments
Lec. 4 (part 1) Deltas

DSRG

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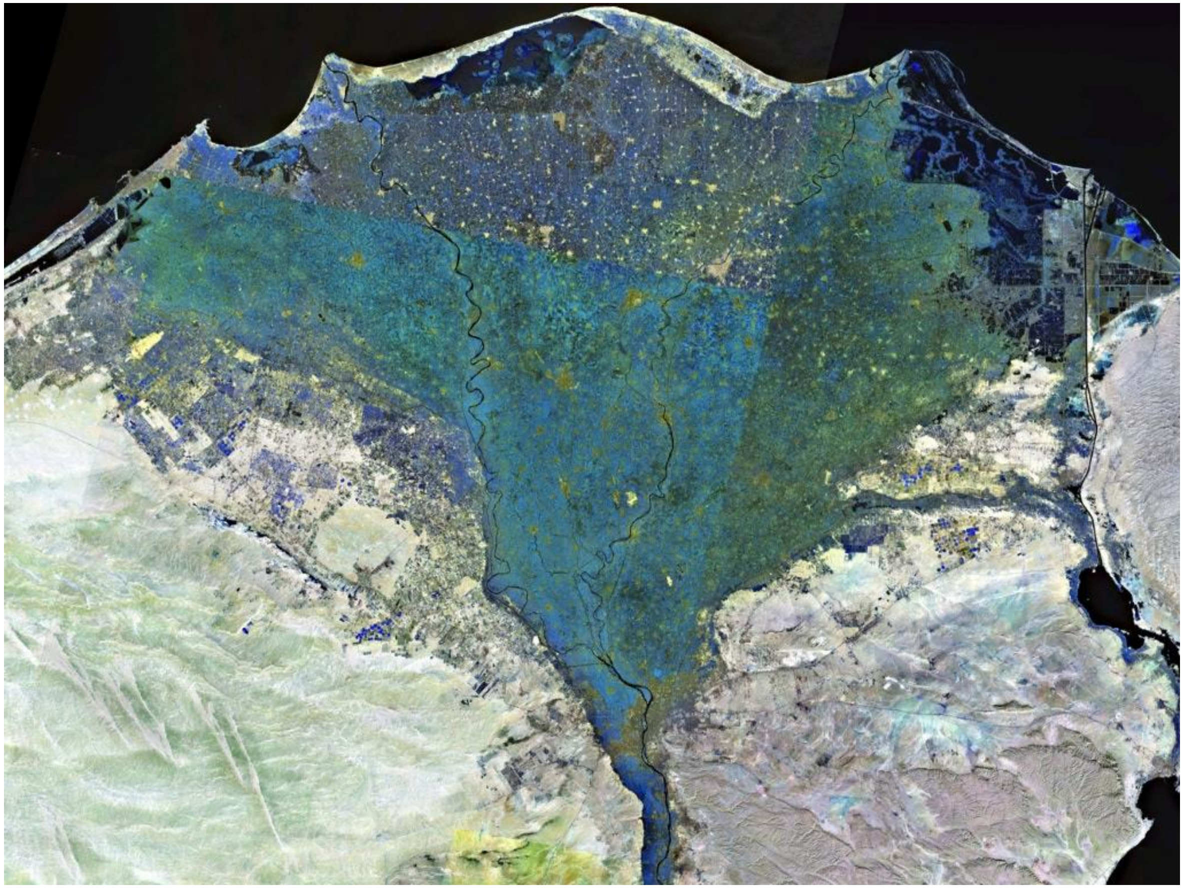
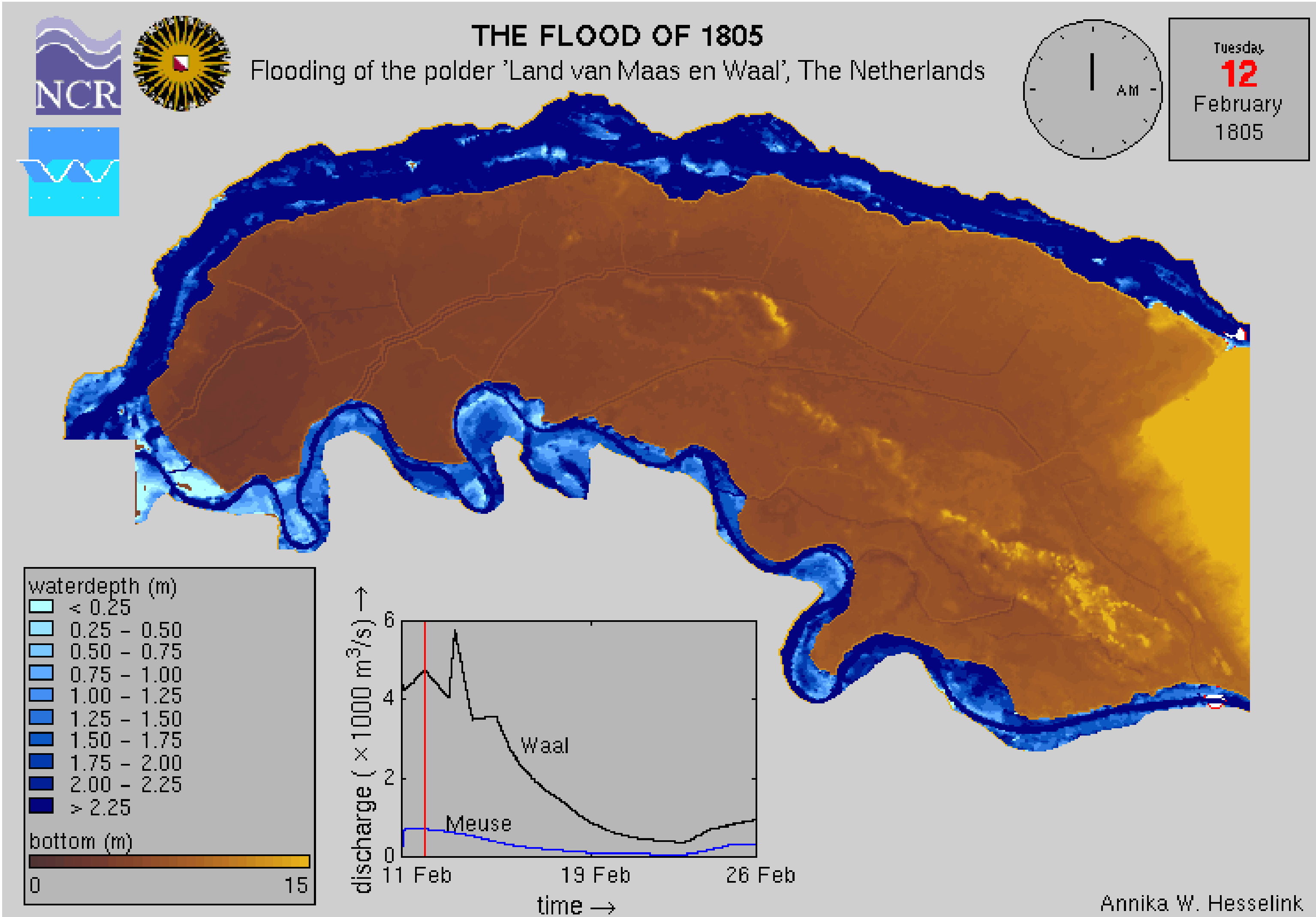
Deltas



The Nile Delta


THE FLOOD OF 1805
Flooding of the polder 'Land van Maas en Waal', The Netherlands
NCR
AM
Tuesday
12
February
1805
waterdepth (m)
< 0.25
0.25 – 0.50
0.50 – 0.75
0.75 – 1.00
1.00 – 1.25
1.25 – 1.50
1.50 – 1.75
1.75 – 2.00
2.00 – 2.25
> 2.25
bottom (m)
0
15
discharge (× 1000 m³/s) →
6
4
2
0
Waal
Meuse
11 Feb
19 Feb
26 Feb
time →
Annika W. Hesselink

Introduction

What are deltas and why they are important?

- Much of the sediment transferred from land to sea is carried by rivers and deposited at the shoreline in the form of deltas.
- About 25% of the world’s population live on deltaic coastlines and wetlands (Syvitski et al., 2005).
- Diverse and prolific ecosystems (Immense decrease in of freshwater discharge, resulting in enormous stresses to these coastal ecosystems).
- deltas have been estimated to host close to 30% of all of the world’s oil, coal, and gas deposits (Tyler and Finley, 1991).
- Significant fresh-water resources also occur in delta deposits, and exploitation of these aquifers requires robust facies models for deltas.

Outline

1. Definitions
2. River mouth processes
3. Delta environments
4. Classification of deltas
5. Controls on delta morphology

1. Definitions

- **Deltas are "discrete shorline 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"** (Elliott, 1986, p.113)

- Sediment supply must be able to overcome:
  - slow rise in sea level
  - tectonic subsidence
  - erosion by tides, waves, currents
  - consolidation of sediment accumulating

2. River mouth processes

The internal facies distribution and external morphology of a deltaic deposit depends upon

1. whether the river outflow is more dense (hyperpycnal), equally dense (homopycnal), or less dense(hypopycnal) than the standing body of water.

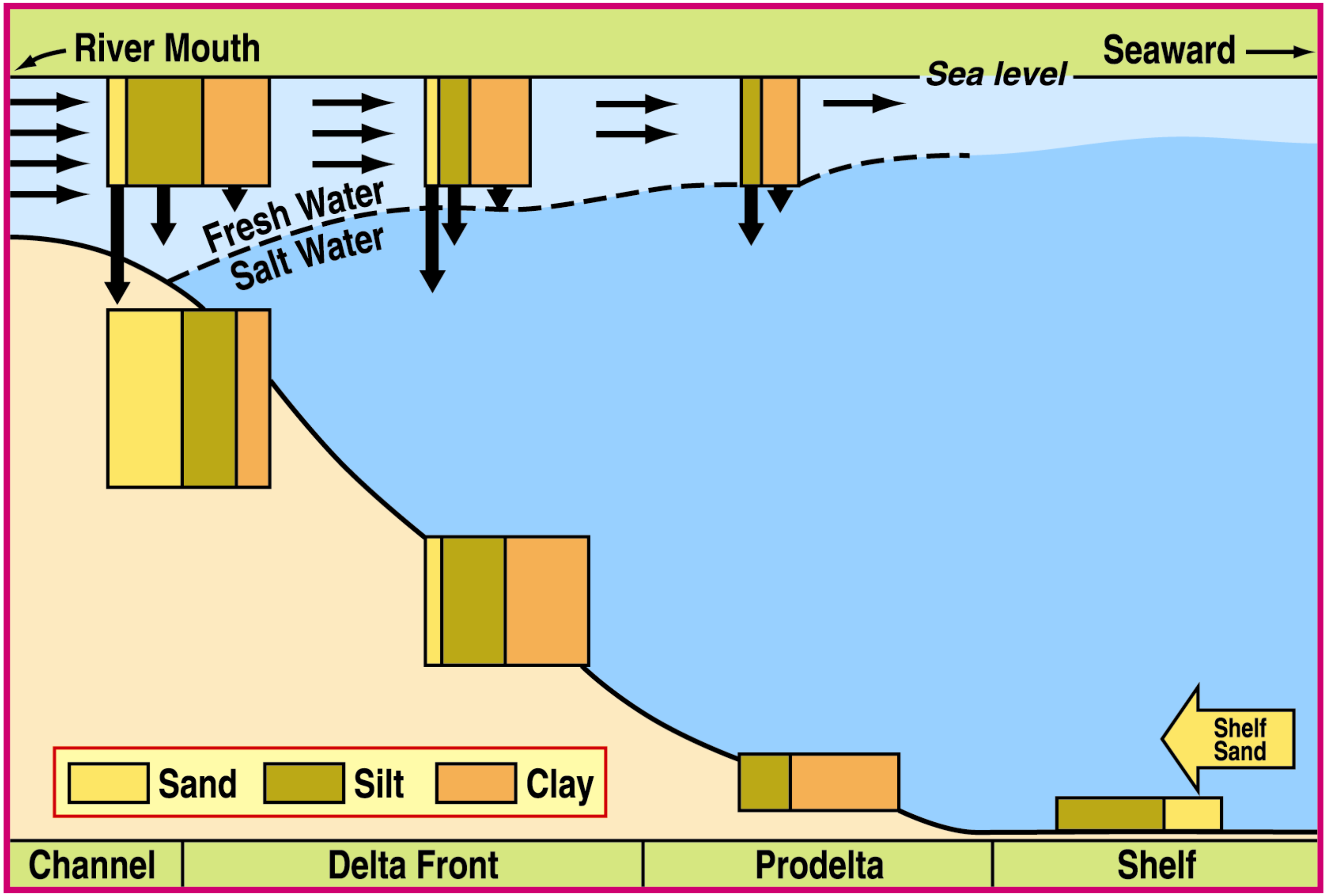
2. the interaction of the river plume with marine processes, which can include waves, tides, storms, and ocean currents, and biogenic reworking

3. the physical position of the delta in the basin, such as the shelf edge

3. the degree to which river derived sediments are reworked by marine processes

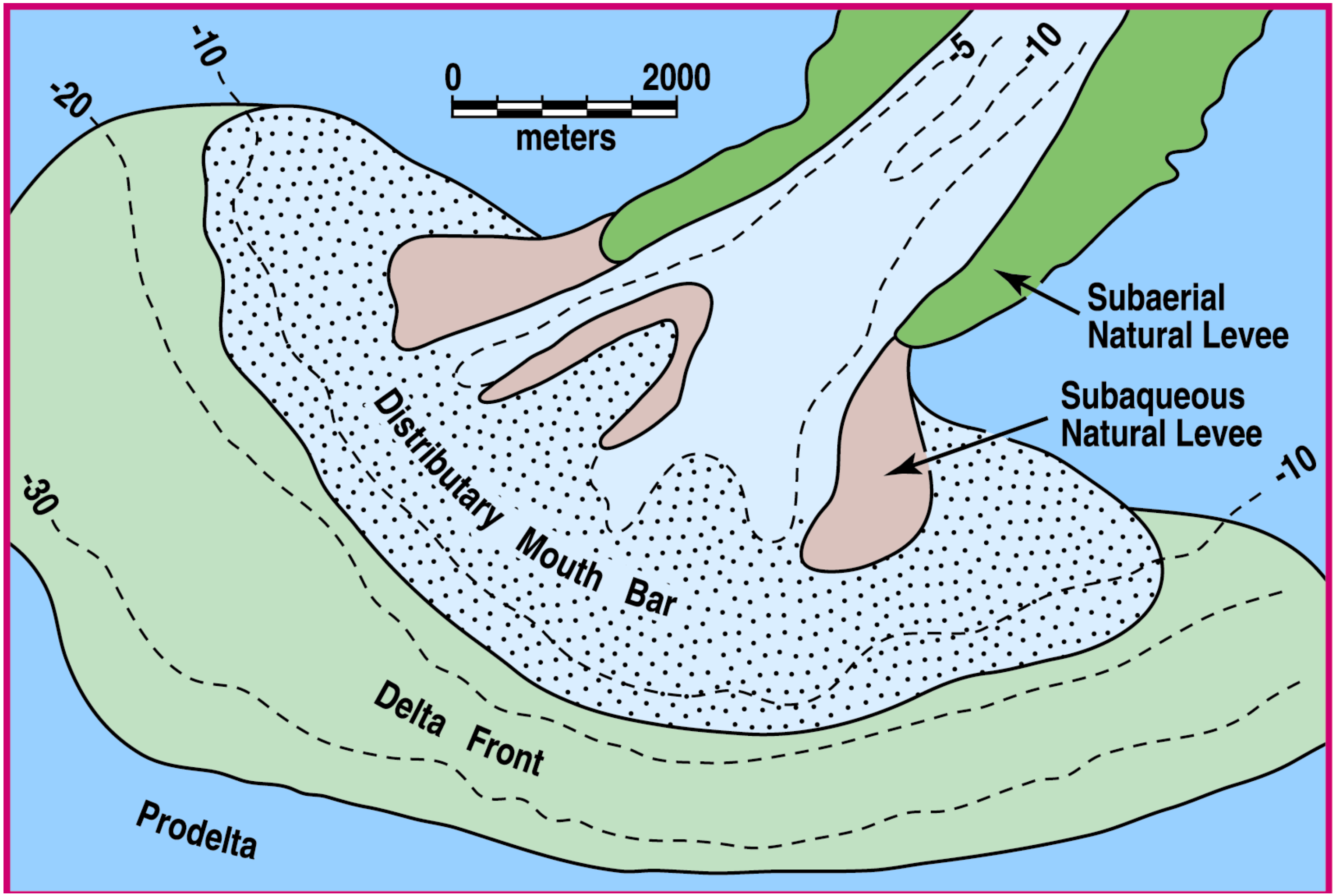
2. River mouth processes

Deposition of Sediment at a River Mouth



2. River mouth processes

Depositional Environments at a River Mouth



2. River mouth processes

- **A delta forms when a river of sediment-laden freshwater enters a standing body of water, loses its competence to carry sediment, and deposits it. The theory of jets has been widely applied to explain the dynamics of how river plumes interact.**

- **The river flows could be:**

Hypopycnal	homopycnal	hyperpycnal
• **The density of the fresh river water plus suspended sediment load may be less than that of the sea water, causing hypopycnal flow**	• **In fresh-water deltas greater degree of mixing between the river and standing body of water.** • **In marine settings where the amount of bed load is high.**	• **In freshwater lakes, sediment concentrations <1 kg/m3 produce hyperpycnal conditions.** • **Sediment concentrations >35 to 45 kg/m3) may be required to generate hyperpycnal flows in marine settings**

2. River mouth processes

Distributary mouth bar geometry and distribution controlled by three major forces

Force A

Inertial
Is a narrow linear sand bodies.

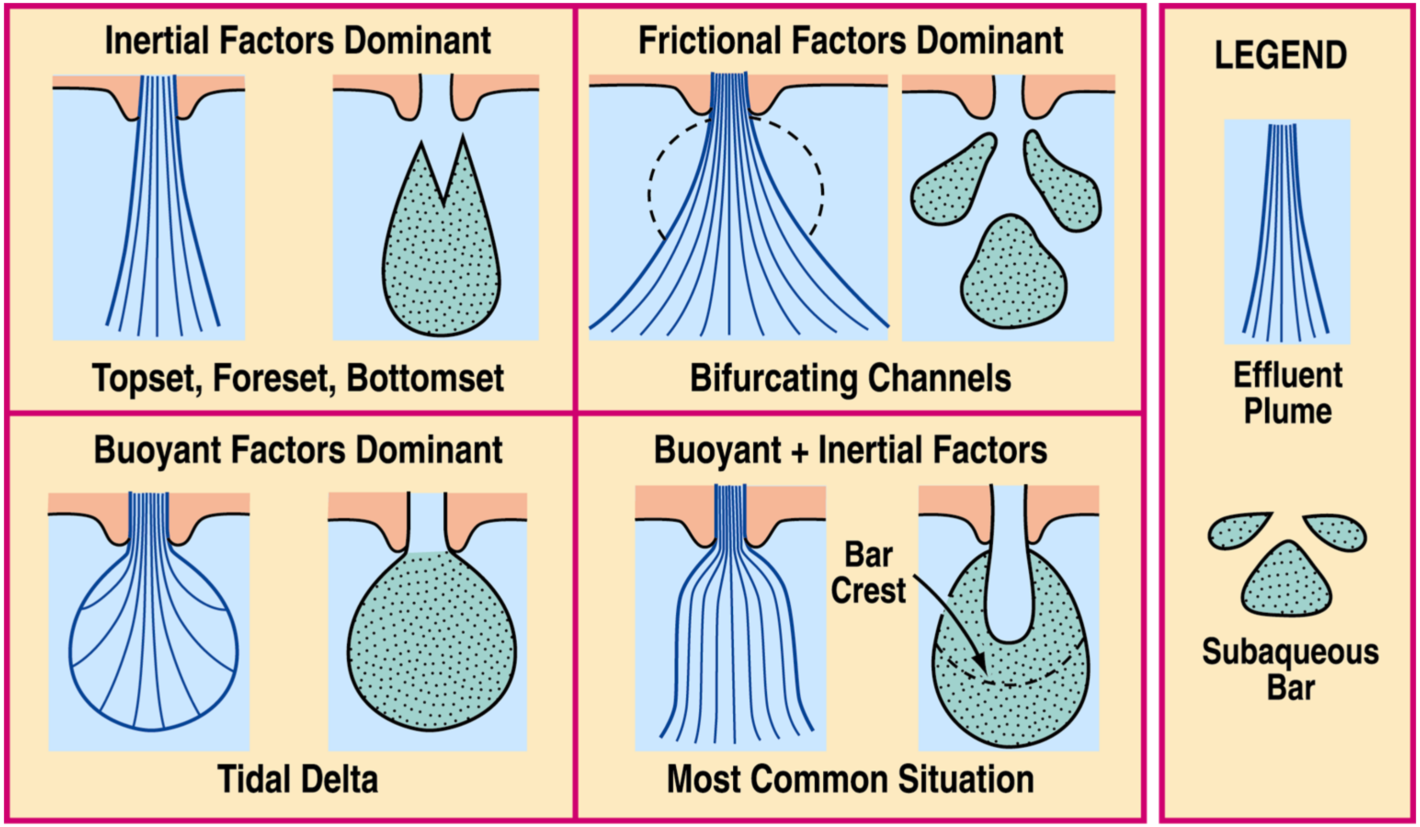
Force B

Buoyant
is thin, widespread coalescing sand bodies.

Force C

Frictional
is bifurcated channels capped by natural levee deposits.

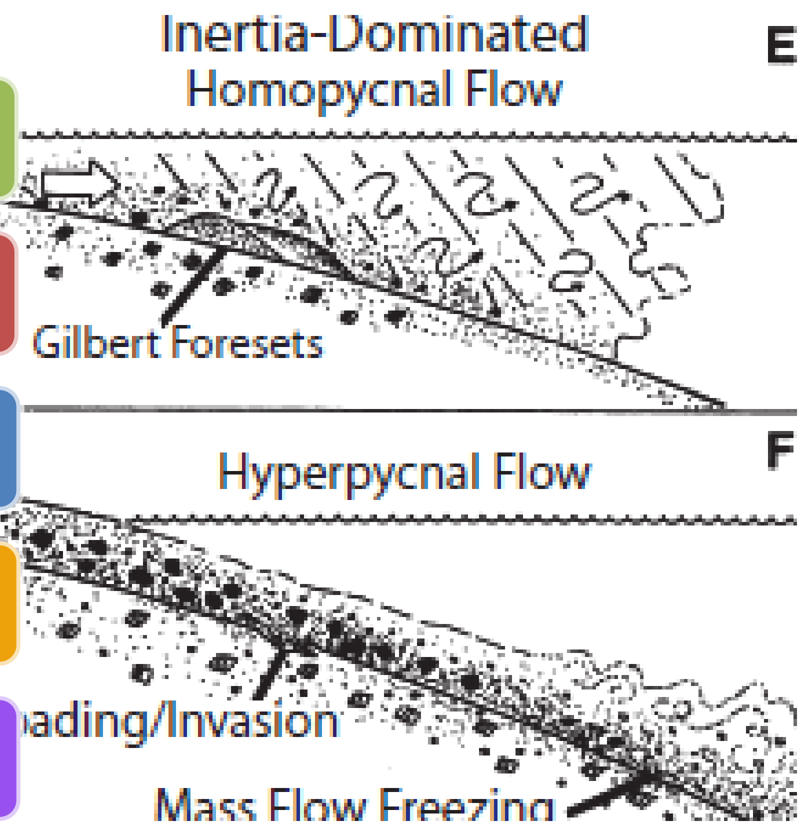
2. River mouth processes



2. River mouth processes

Inertial

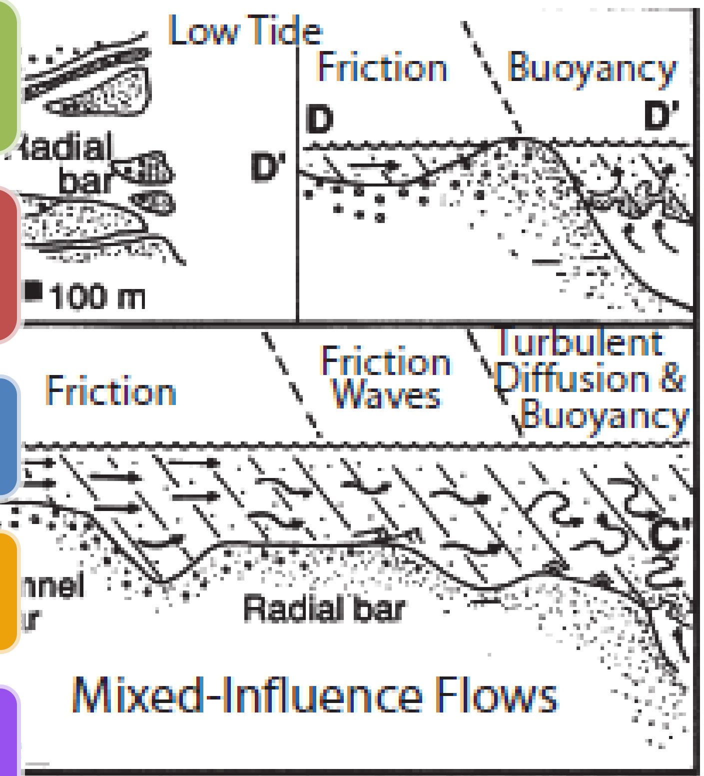
- **High flow velocity**
- **Small density contrasts**
- **Effluent spreads as turbulent jet**
- **Distributary bars are linear**
- **Very common in most major river deltas**



2. River mouth processes

Frictional

- Occurs when H_2O depths decrease/shallow seaward of river mouth
- Effluence decelerates causing bar expansion
- Formation of a broad arcuate radial bar
- Subaqueous levees form
- Bifurcating channels develop



2. River mouth processes

Buoyant

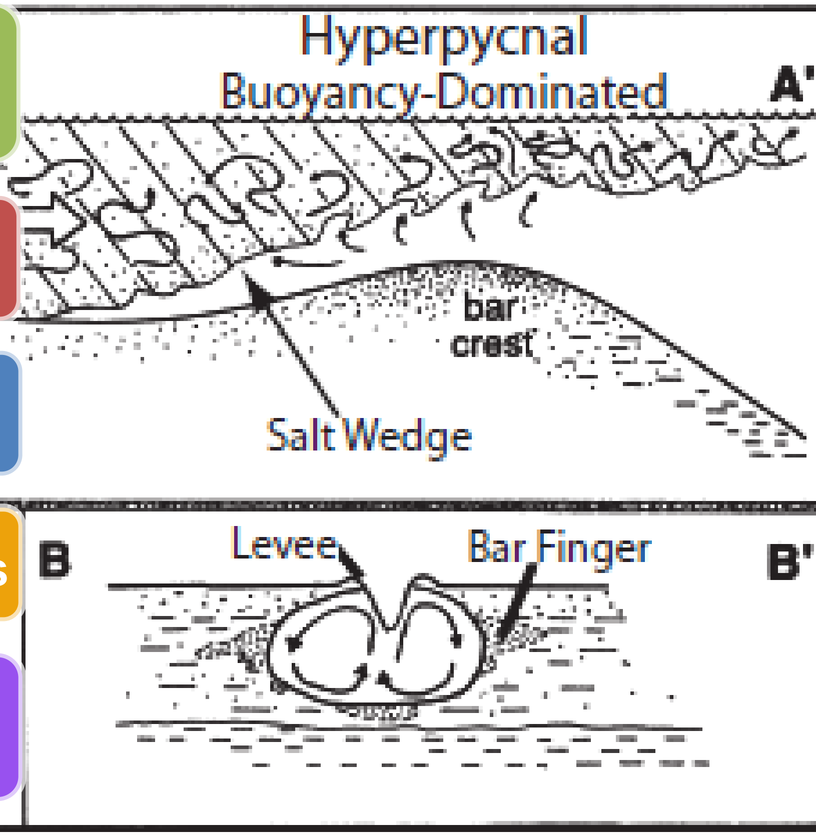
Fresh H_2O density = 1 m/cm^3
Salt H_2O density = 1.028 gm/cm^3

Reduction in turbulent diffusion

Fresh H_2O spreads as buoyant layer

Decrease in velocity as spreading occurs

Coarsest sediment deposited first, finer materials transported farther from mouth



3. Delta environments

Deltas comprise three main geomorphic environments of deposition:

3.1 *Subaerial delta plain*,

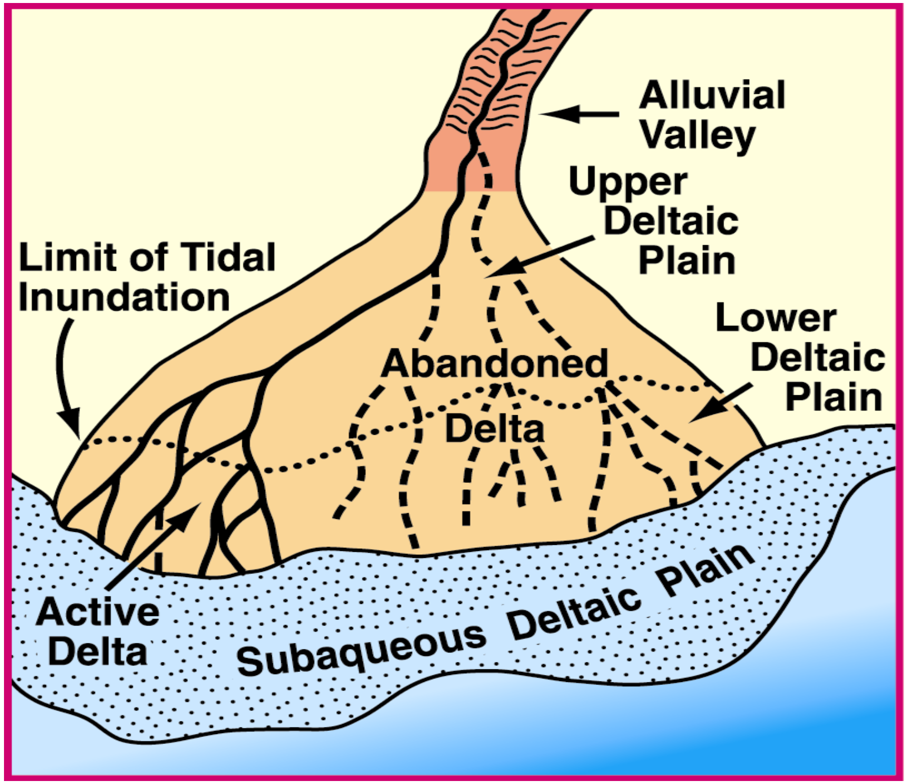
3.2 *Delta front (the coarser-grained area)*,

3.3 *Prodelta*

Delta Plain — Where river processes dominate

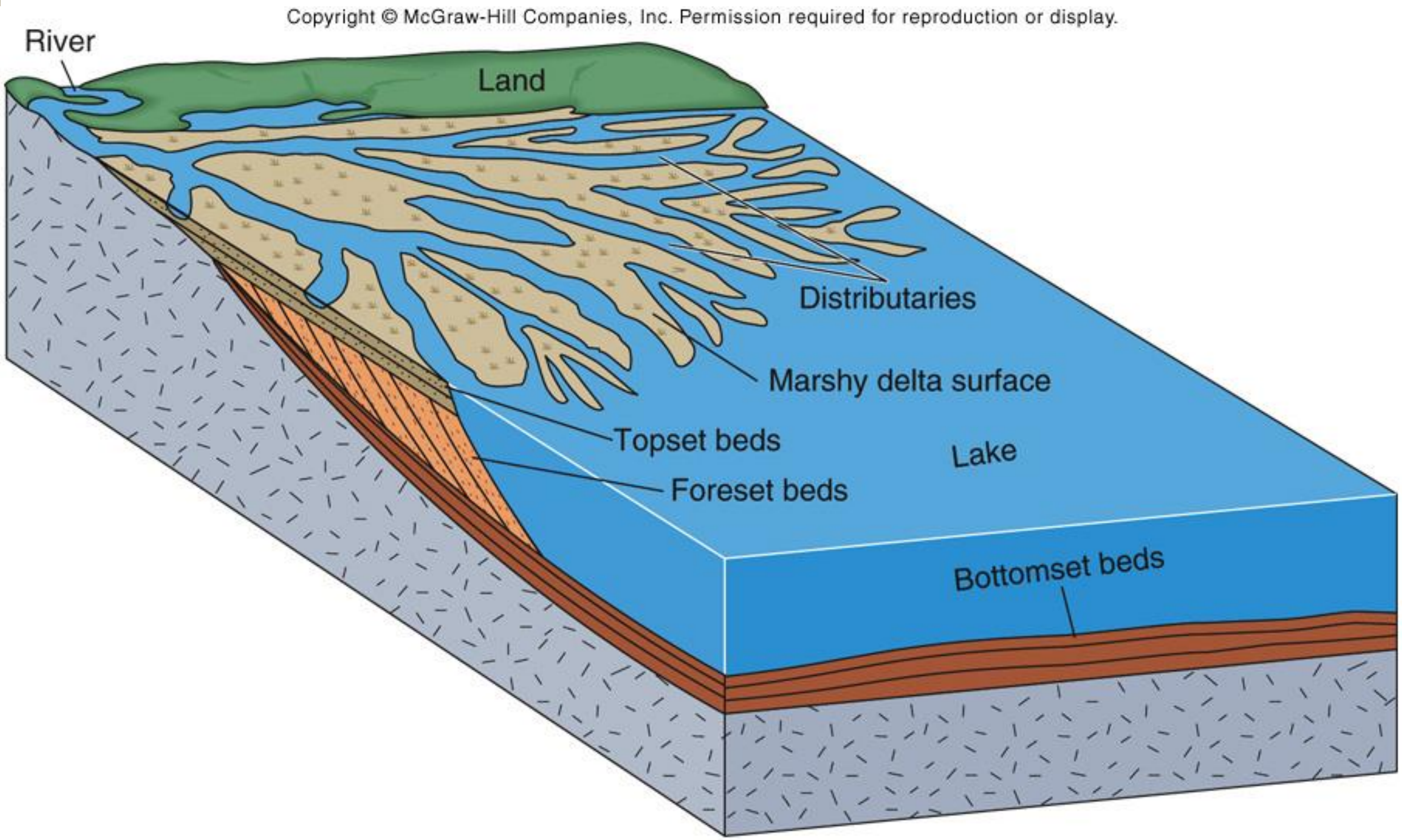
Delta Front — Where river and basinal processes interact

Prodelta — Primarily muddy



3. Delta environments

Internal Delta Morphology



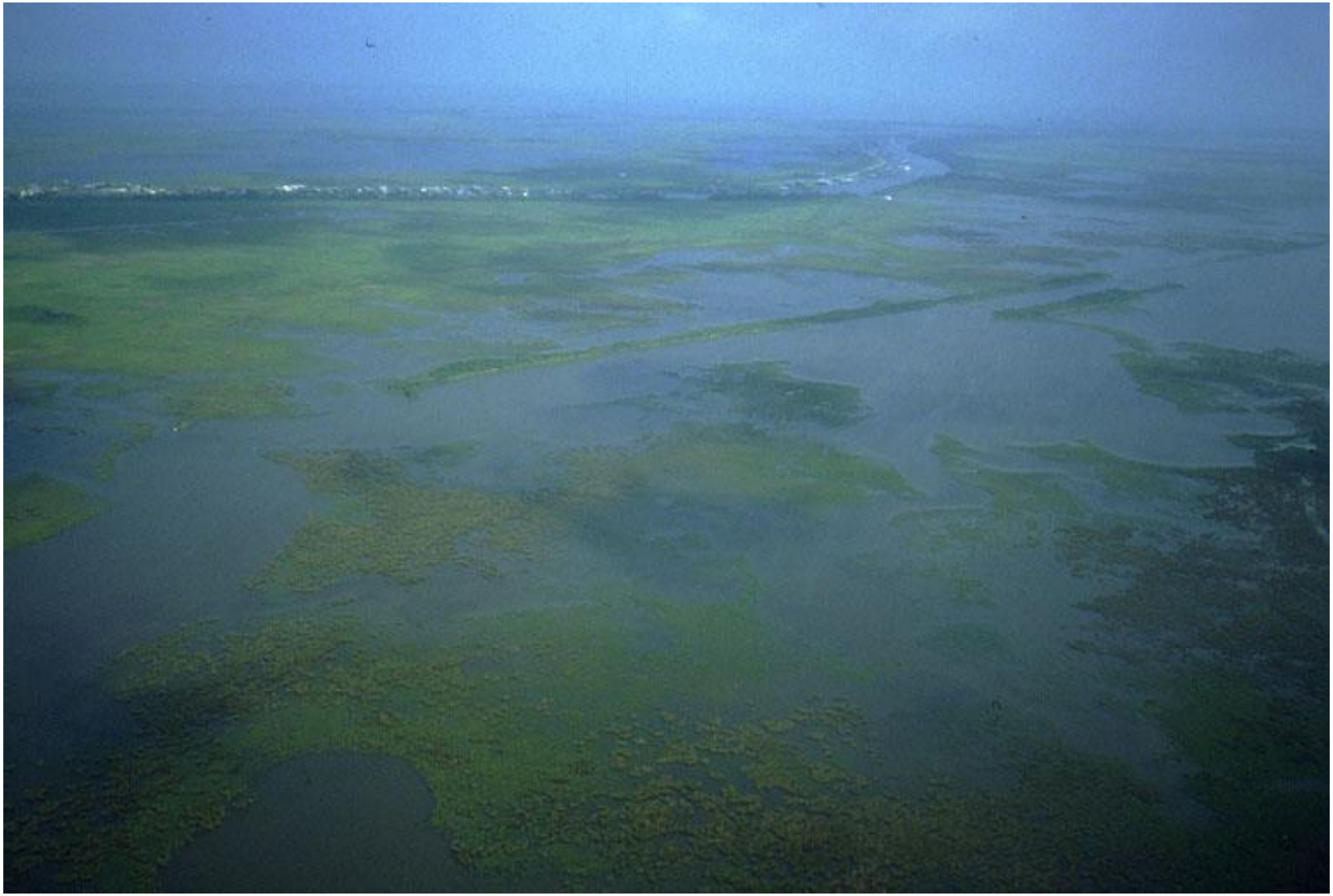
3. Delta environments

Delta Plain

Delta Plain

- Delta plains are commonly characterized by **distributaries** and **interdistributary areas**
  - The **upper delta plain** is gradational with floodplains, lacks marine influence and typically has large flood basins, commonly with freshwater peats and lacustrine deposits
  - The **lower delta plain** is marine influenced (e.g., tides, salt-water intrusion) and contains brackish to saline interdistributary bays (e.g., shallow lagoons, salt marshes, mangroves, tidal flats)
- Interdistributary areas commonly change from freshwater through brackish to saline environments in a downdip direction (e.g., transition from swamps to marshes)
- Minor (secondary) deltas commonly form when distributaries enter lakes or lagoons.

3. Delta environments



3. Delta environments

3. Delta environments

3. Delta environments

Delta Front

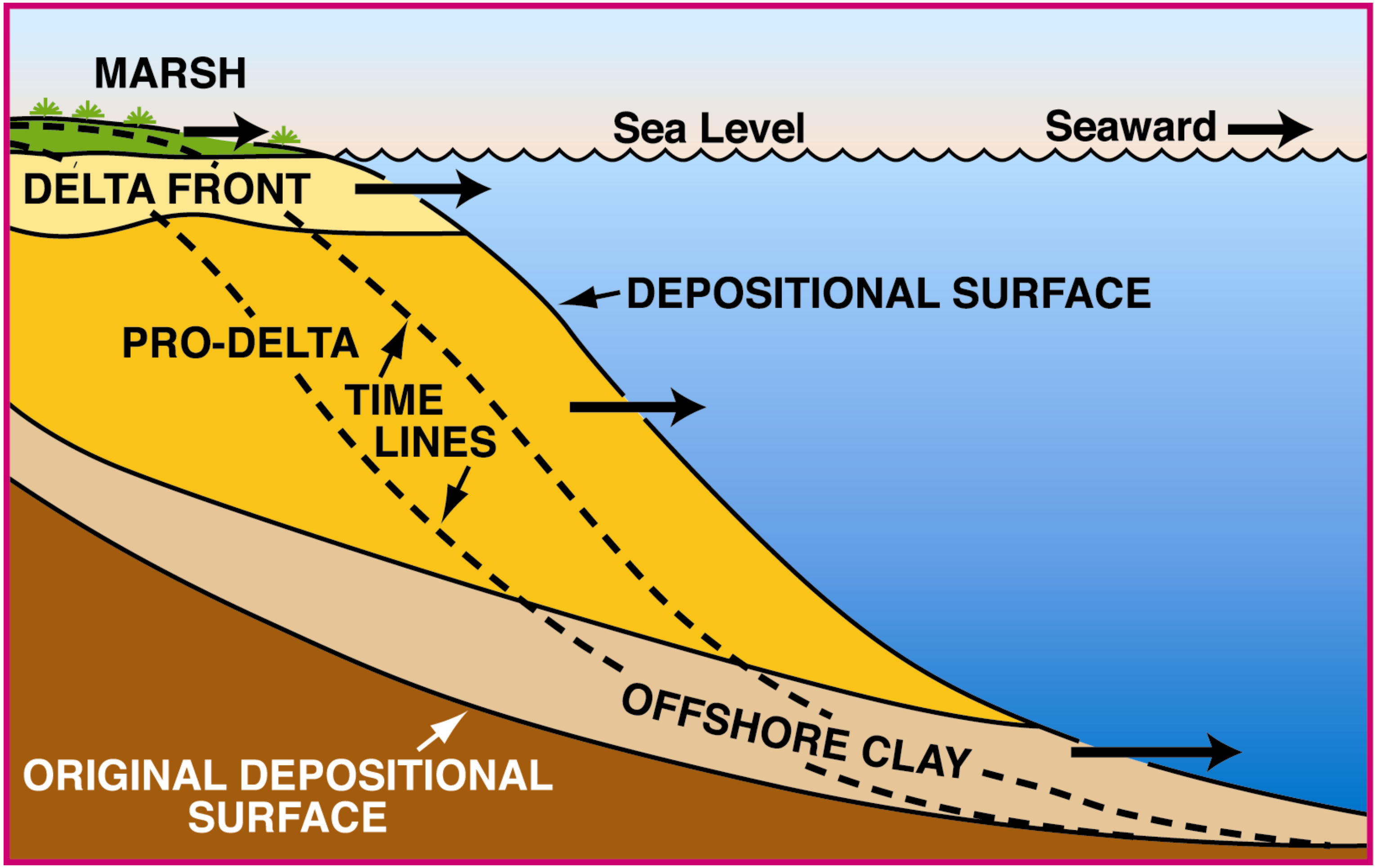
Delta Front

- **Delta Front** is defined as the area dominated by coarser sediment (sand and gravel) that includes subaqueous topset and foreset beds.

- **Mouth bars** form at the upper edge of the delta front, at the mouth of distributaries (particularly in hypopycnal flows); they are mostly sandy and tend to coarsen upwards
- Wave action can play an important role in winnowing and reworking of mouth-bar deposits; this may lead to merging with prograding beach ridges and if wave action is very important mouth bars are entirely transformed

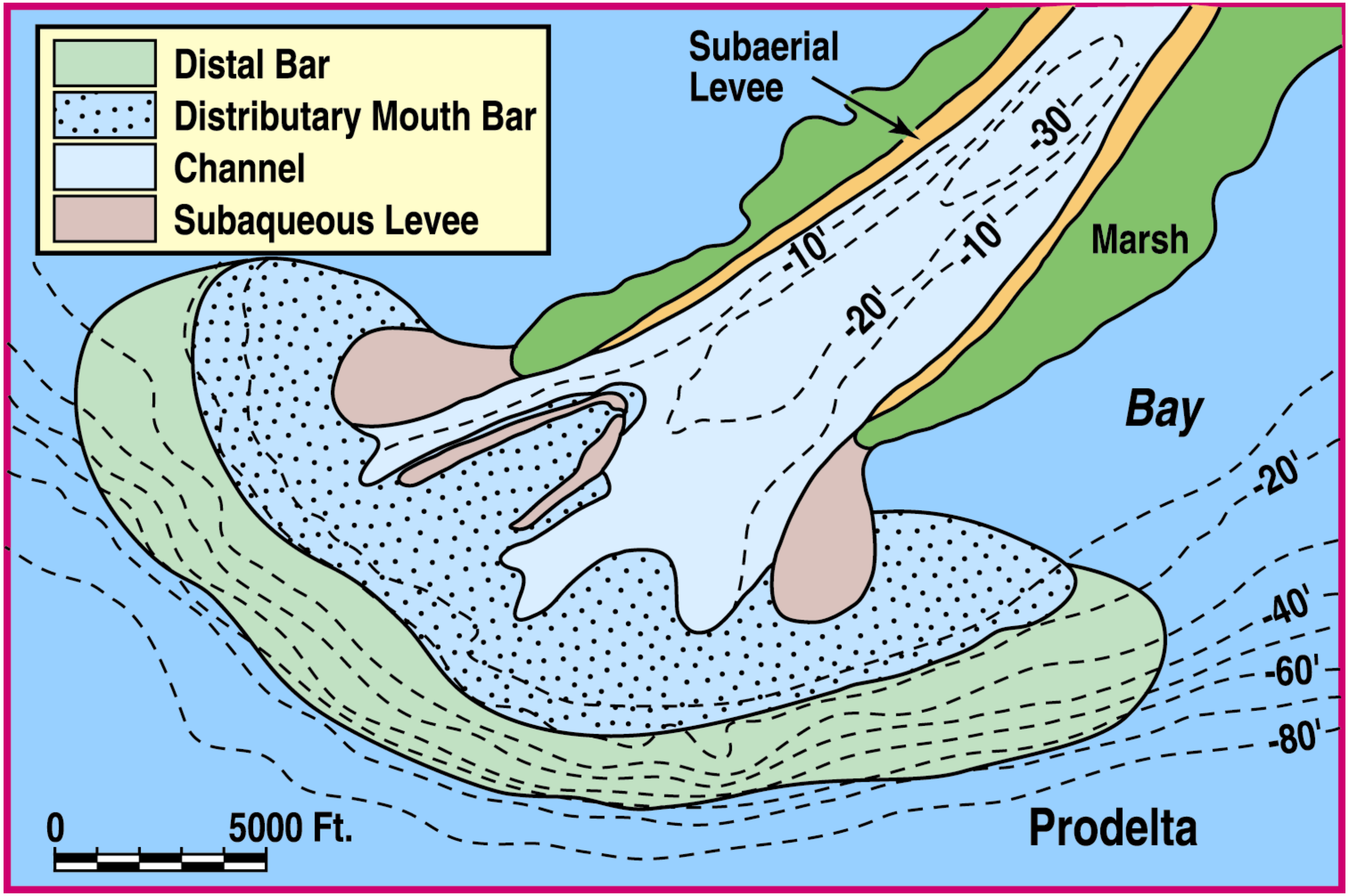
3. Delta environments

Time Lines and Lithofacies in a Prograding Distributary



3. Delta environments

Delta Front Subenvironments



3. Delta environments

Prodelta

Prodelta

- Prodelta has been interpreted as the area where fine mud and silt settle out of suspension. Prodelta may be more or less burrowed, depending on sedimentation rate.
  - Prodelta muds may merge seaward with fine-grained hemipelagic and commonly calcareous sediment of the basin floor.

3. Delta environments

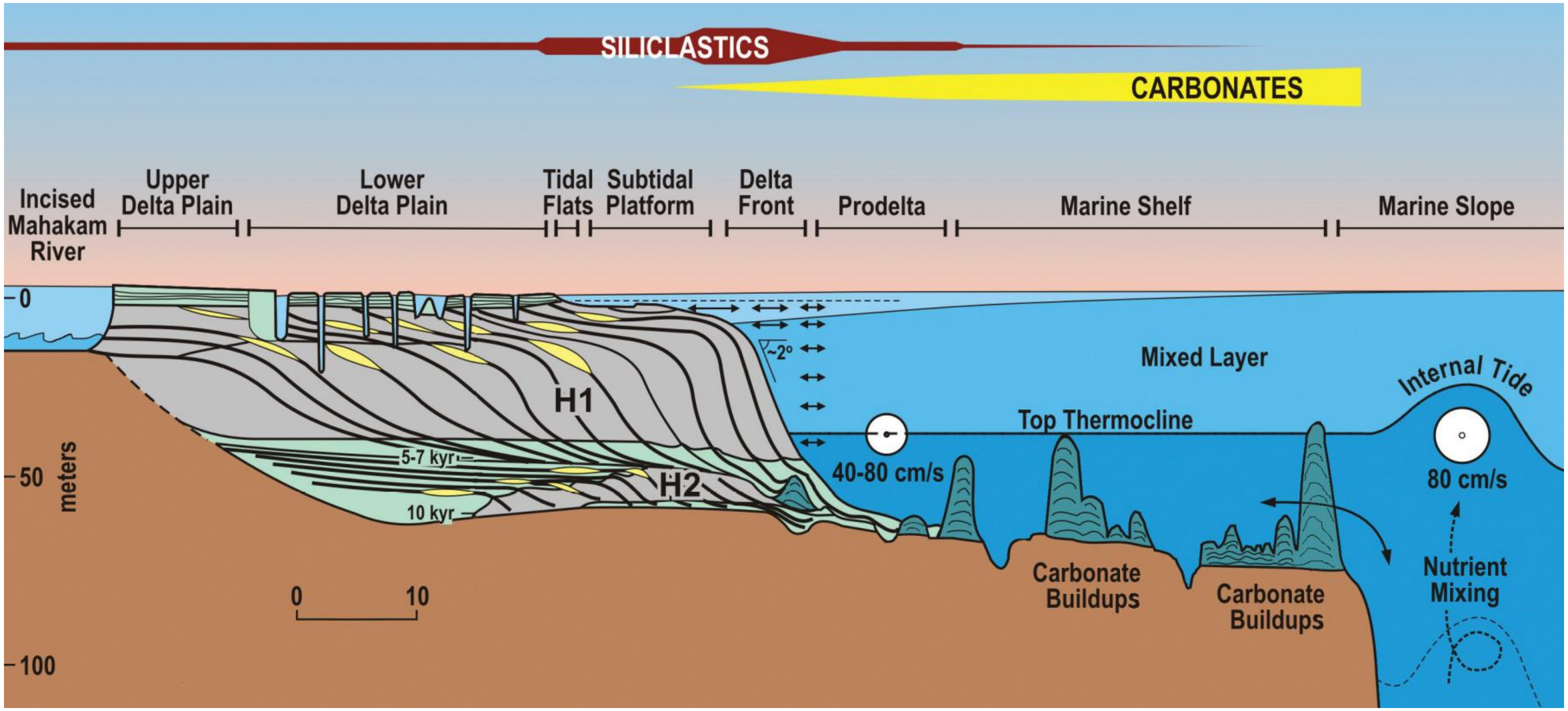


Figure - Morphometric subdivisions of the Mahakam delta, Kalimantan, Indonesia. Note that muddy subaqueous foreset is referred to as the "delta front" (modified after Roberts and Sydow, 2003).

3. Delta environments

Distributary Channels

- Distributary channels may show a wide range of sizes and shapes in different positions on the delta (Olariu and Bhattacharya, 2006).
- Typically, a trunk fluvial system first avulses at the point where the river becomes unconfined, forming a nodal avulsion point (e.g., Nelson, 1970; Mackey and Bridge, 1995).
- Delta-plain channels tend to be few in number and are separated by wide areas of interdistributary bays, swamps, marshes, or lakes on the delta plain, although these interdistributary areas can be replaced by channel deposits, depending on the avulsion frequency and rate of channel migration (Bristow and Best, 1993; Mackey and Bridge, 1995; Holbrook, 1996).
- Distributary channels can show several orders of branching. The smallest-scale channels are referred to as “terminal distributary channels” and are intimately associated with mouth bars that form at the distal delta plain and proximal delta front.

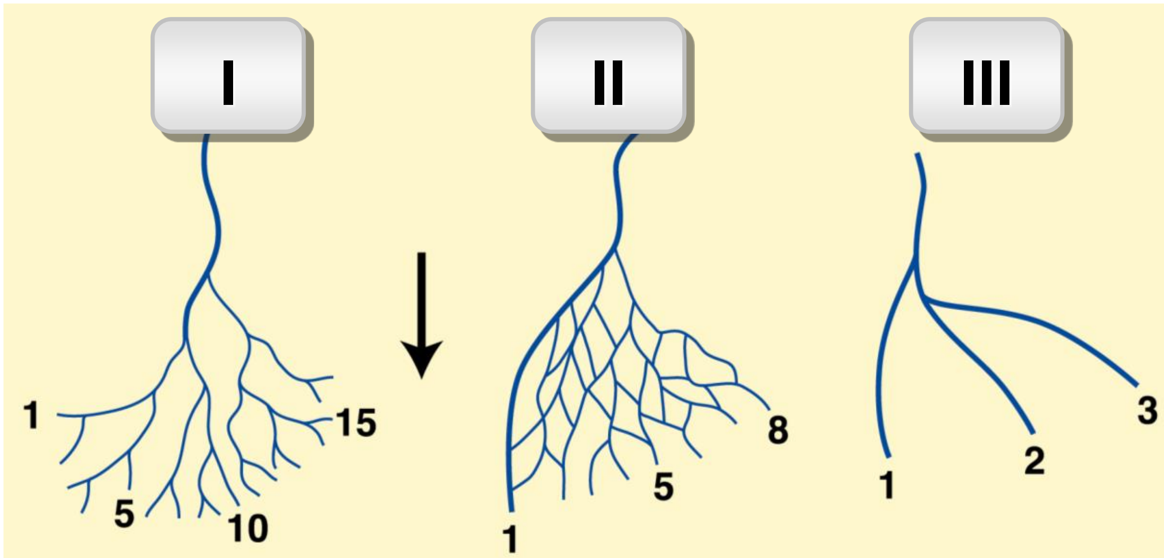
3. Delta environments

Distributary Channels

- Distributary-channel bifurcation occurs at a point where the channel can no longer cut directly through the distributary mouth bar, forcing it to split into two smaller channels flanking the bar crest.
- Channel-bifurcation frequency and branching patterns are strongly dependent on slope, river discharge, water depth, and the interaction of the river plume with marine processes.
- River-dominated deltas, where friction is the dominant process controlling sediment dispersal and deposition, multiple bifurcations favored in low-gradient, high-discharge.
- In wave-modified deltas, much of the sediment is carried away by longshore transport. the progradation rate is slowed. This allows rivers feeding wave- influenced coasts to maintain a higher slope, which inhibits avulsion.
- Many tidally influenced deltas show distributary channels that are stable for hundreds to thousands of years. This results in the development of elongate bars and islands that can be tens of kilometers in length and a few kilometers wide.

3. Delta environments

Distributary Channel Patterns



A. Bifurcating

High subsidence, low waves & offshore slope, small tidal range, fine grained sediments

B. Rejoining

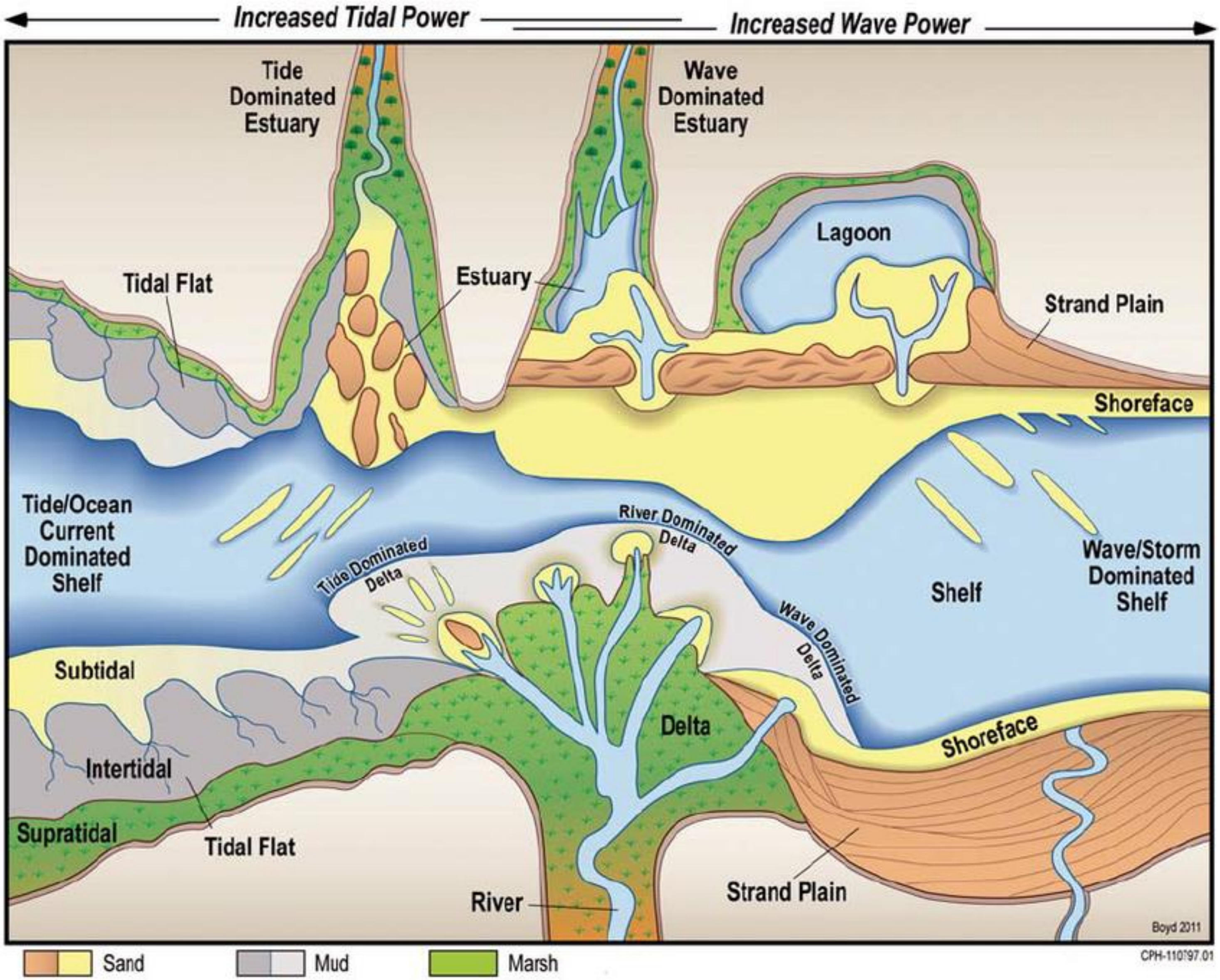
Erratic discharge, intermediate wave energy, high tide range, steep offshore slope

C. Single

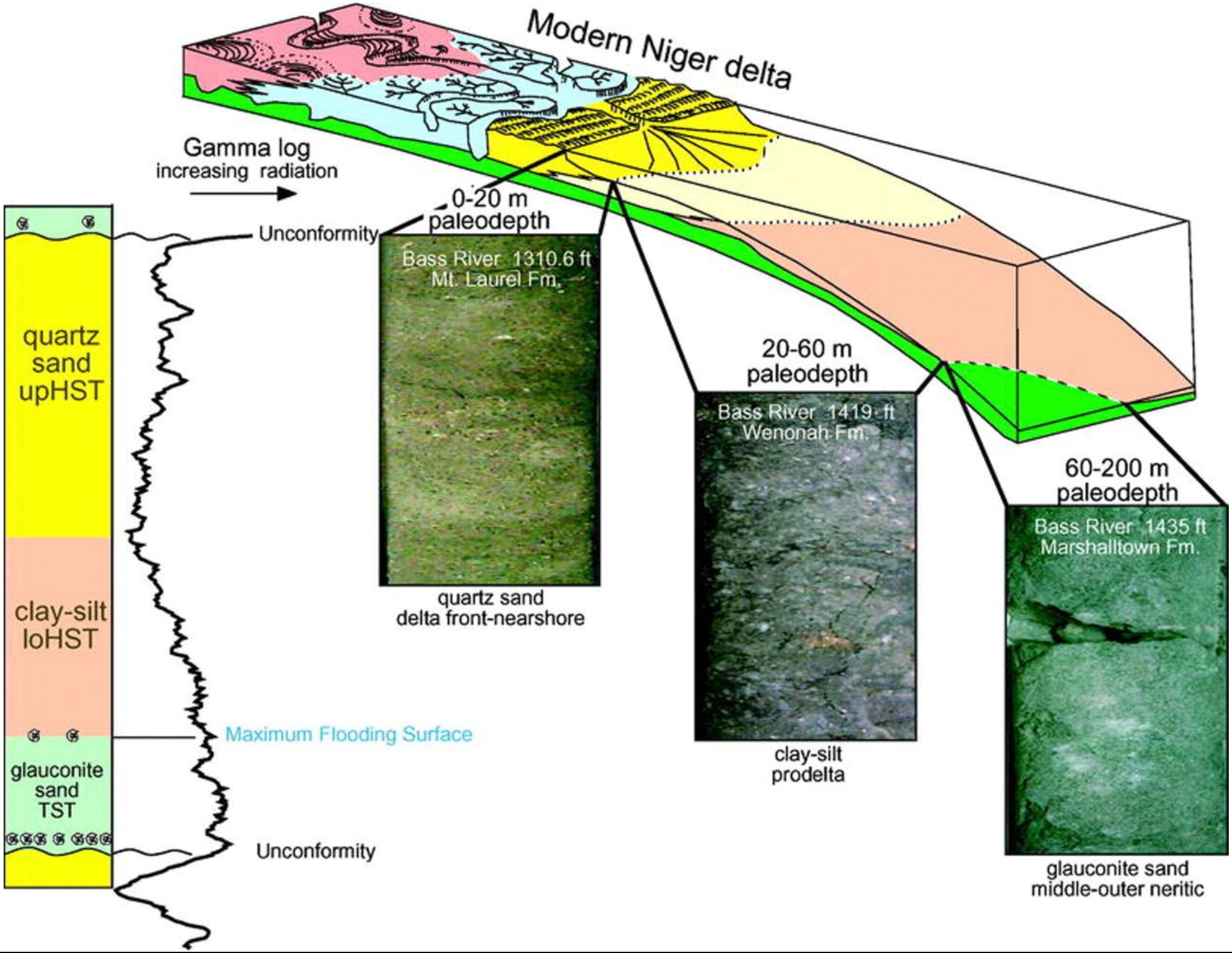
High waves

High tidal range

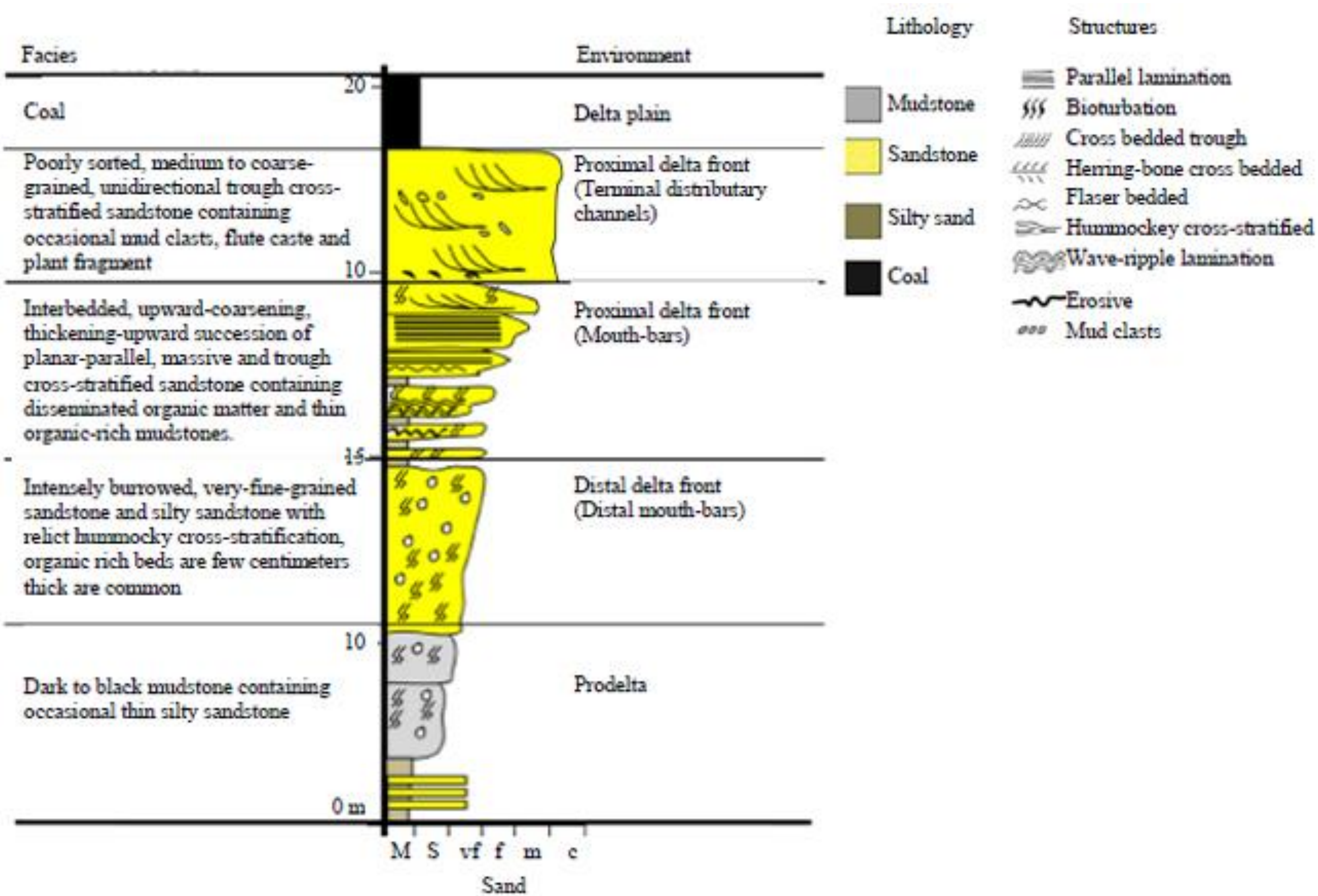
3. Delta environments



3. Delta environments



3. Delta environments



3. Delta environments

Distributary Channels

Figure - River-dominated Lena River delta (Russian Arctic) shows numerous orders of branching with many tens of terminal distributary

3. Delta environments

Distributary Channels

Figure - Bifurcation is inhibited in wave-dominated deltas because the river is unable to prograde into the basin as rapidly. This effectively allows the river to maintain its grade, which in turn inhibits avulsion.

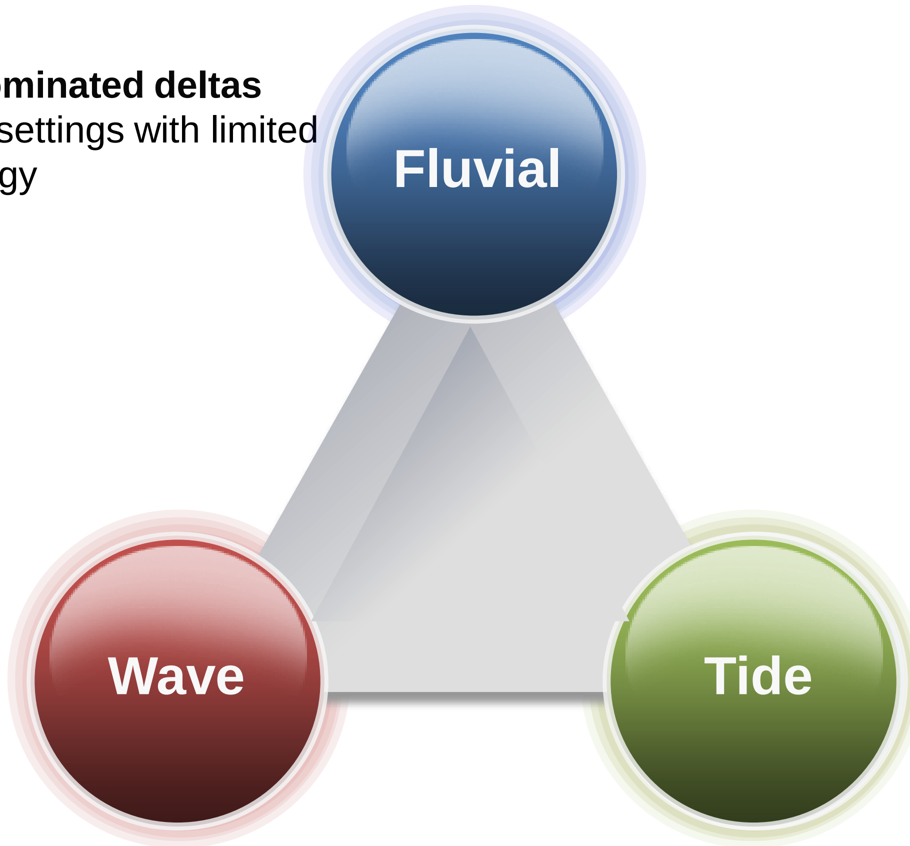
3. Delta environments

Distributary Channels

Figure - Tide-dominated Ganges–Brahmaputra delta shows highly elongate channels

4. Classification of deltas

Fluvial-dominated deltas
microtidal settings with limited wave energy

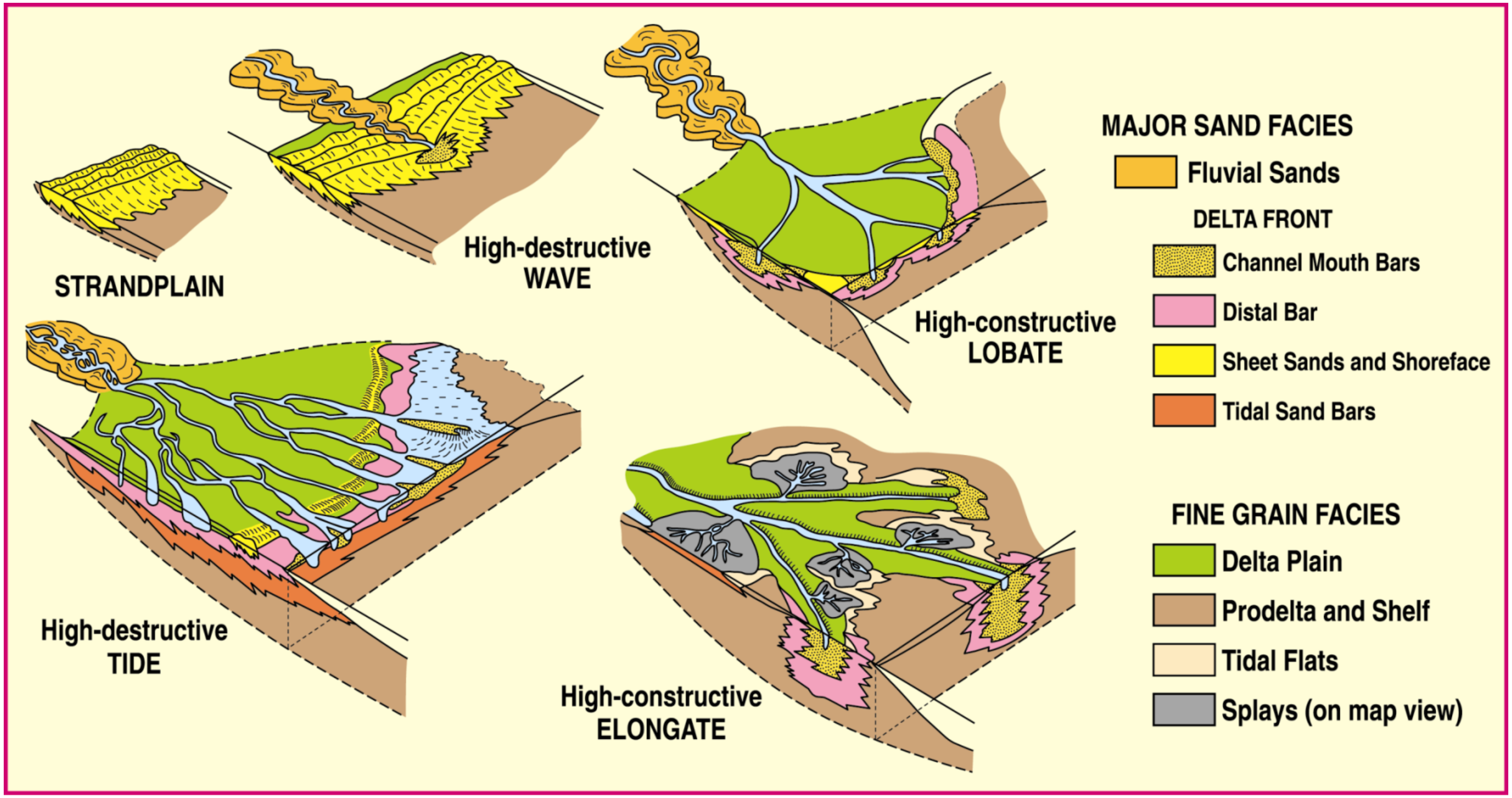


Wave-dominated deltas
high wave energy, open coasts, strong longshore currents.

Tide-dominated deltas
high tidal range.

4. Classification of deltas

Framework Facies in Major Delta Types



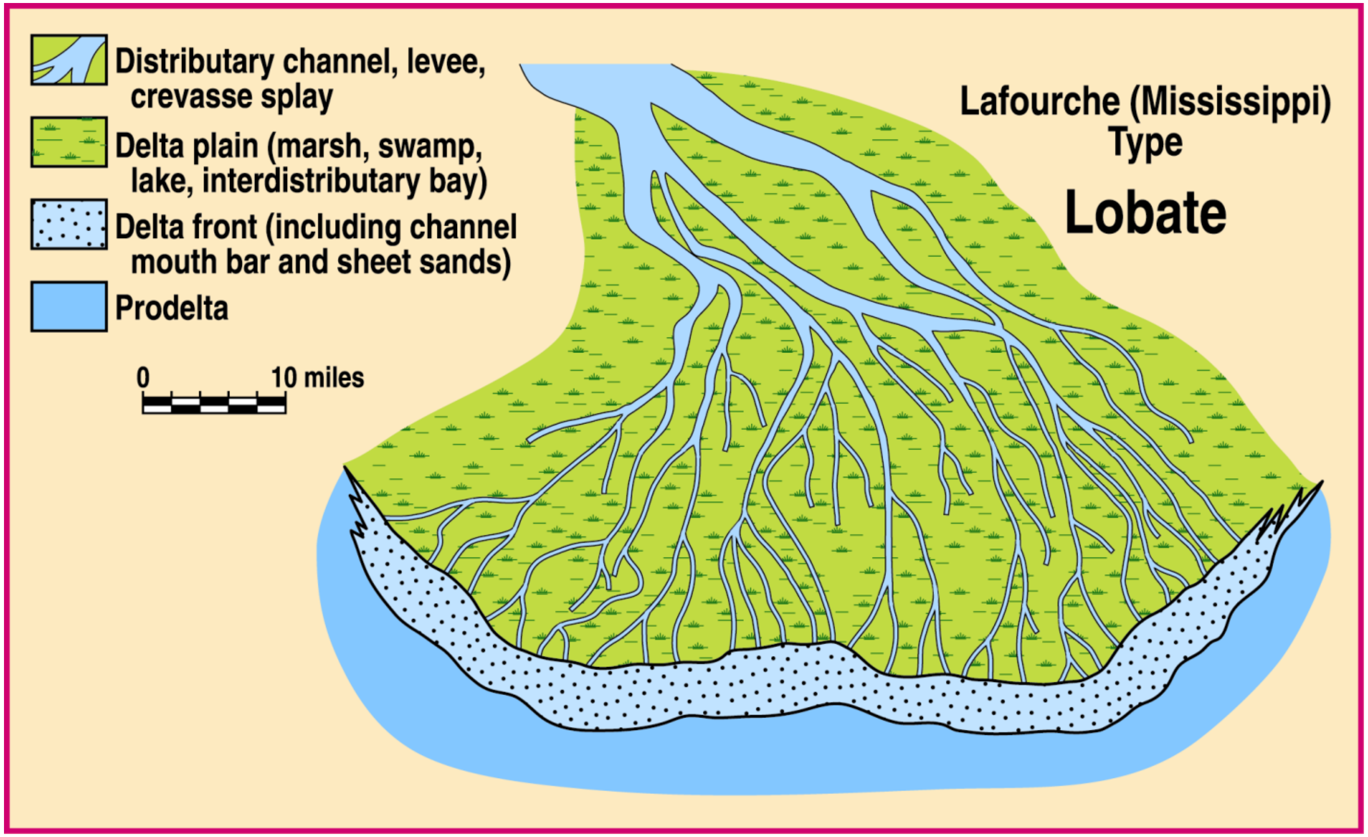
Fluvial dominated delta

❖ Characteristics:

- The unidirectional fluvial current at the mouth of the river continues into the sea or lake as a subaqueous flow. The channel form is maintained, with well-defined subaqueous levees and overbank areas.
- channel instability due to the very low gradient on the delta plain, resulting in frequent avulsion of the major and minor channels.
- The course of the river changes as one route to the sea becomes abandoned and a new channel is formed, leaving the former channel, its levees and overbank deposits abandoned.
- The deposits of river-dominated deltas have well developed delta-top facies, consisting of channel and overbank sediments.
- The channels build out to form the ‘toes’ of the ‘bird’s foot’, between which there are large interdistributary bays. These bays are relatively sheltered and are sites of fine-grained, subaqueous sedimentation.
- The filling of interdistributary bays results in small scale (a few metres thick) coarsening-up successions.
- In front of the channels, mouth bars form and are localised to areas in front of the individual delta lobes.

Fluvial dominated delta

occur in microtidal settings with limited wave energy, where delta-lobe progradation is significant and redistribution of mouth bars is limited



Fluvial dominated delta

High wave energy, open coasts, strong longshore currents

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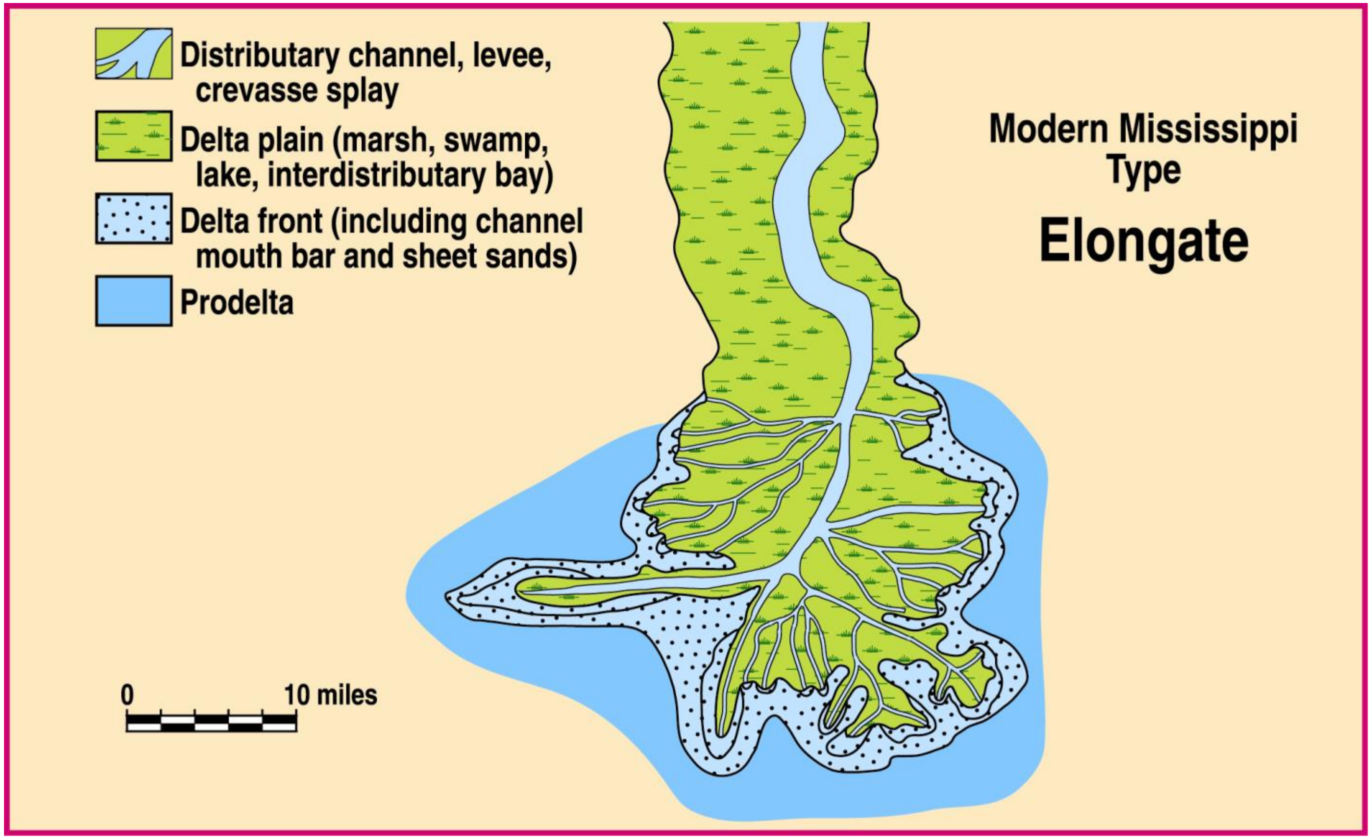
- 1



Wave dominated delta

- Characteristics:
  - wind- driven waves agitate surface
  - rework sediments in shallow water
  - affects mouth bars in basin and mouth of river
  - modifies river –dominated delta

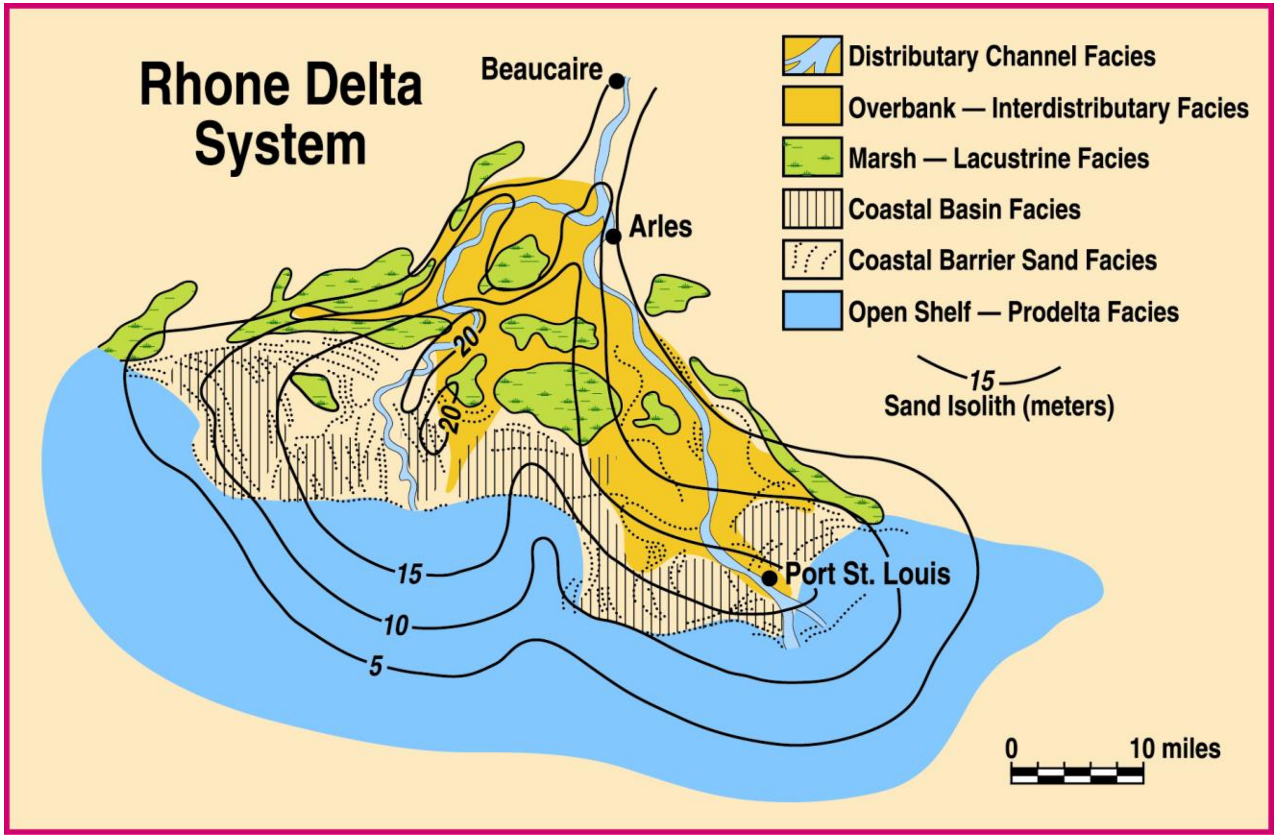
Morphology limits progradation

- can’t form sub-aqueous levees
  - bedload is immediately reworked
  - if waves hit obliquely (and usually do), get lateral migration of sediments and development of spits
- beach and mouth bars form // to coast
  - waves sort grains
  - mouth bar is better sorted sediments

Wave dominated delta

High wave energy, open coasts, strong longshore currents

- Non-marine, swamp to eolian dunes
- Arcuate to strand-parallel sand dominated facies, barrier island sequences



Tide dominated delta

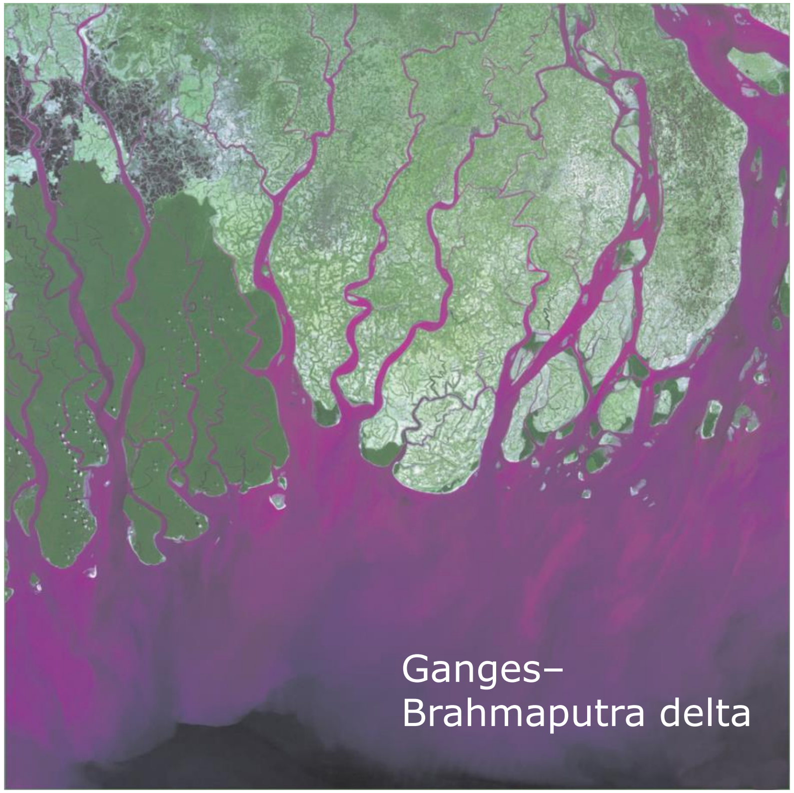
- Characteristics:

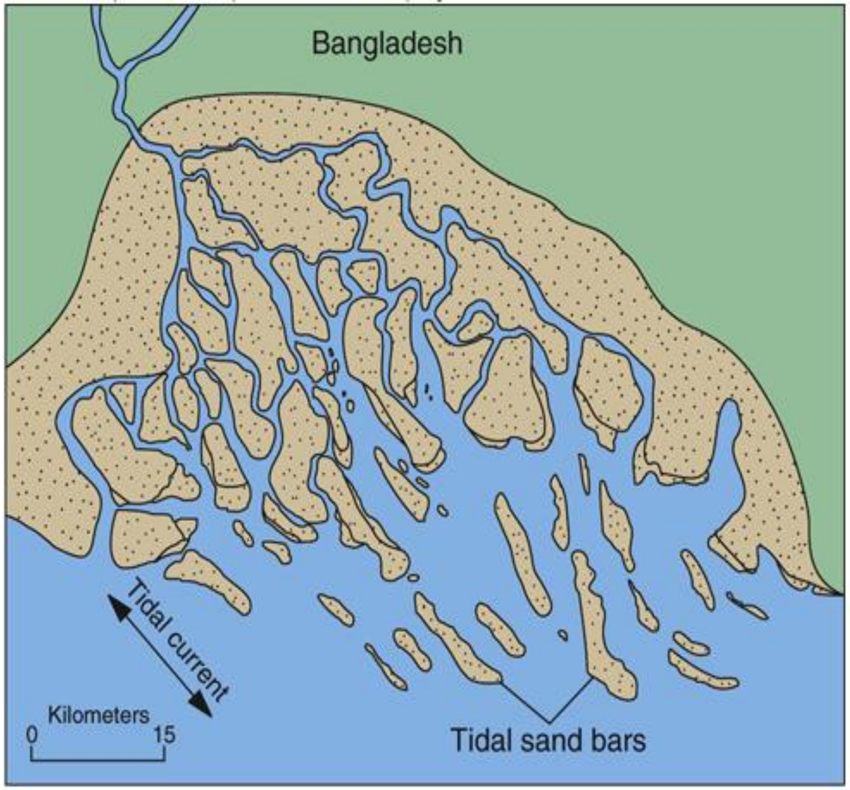
- onshore/offshore currents move bedload/ suspended load back and forth
- very different features delta plain
- tidal currents are bidirectional
  - Herringbone cross-bedding
  - Mud lenses as suspended sediments settles out in slack tide
    - lots of sediment in surface in form of tidal flats
    - lobate shape to mouth bars; perpendicular to shore
    - look for bi-directional flow indicators
    - can confuse with estuarine systems
      - ✓ look at over all sequences
      - ✓ delta is progradational; estuary often retogradational

Tide dominated delta

High Tidal Range

- Extensive lower delta plain/tidal mudflats
- Shore perpendicular, elongate sand dominated facies, tidal channel deposits

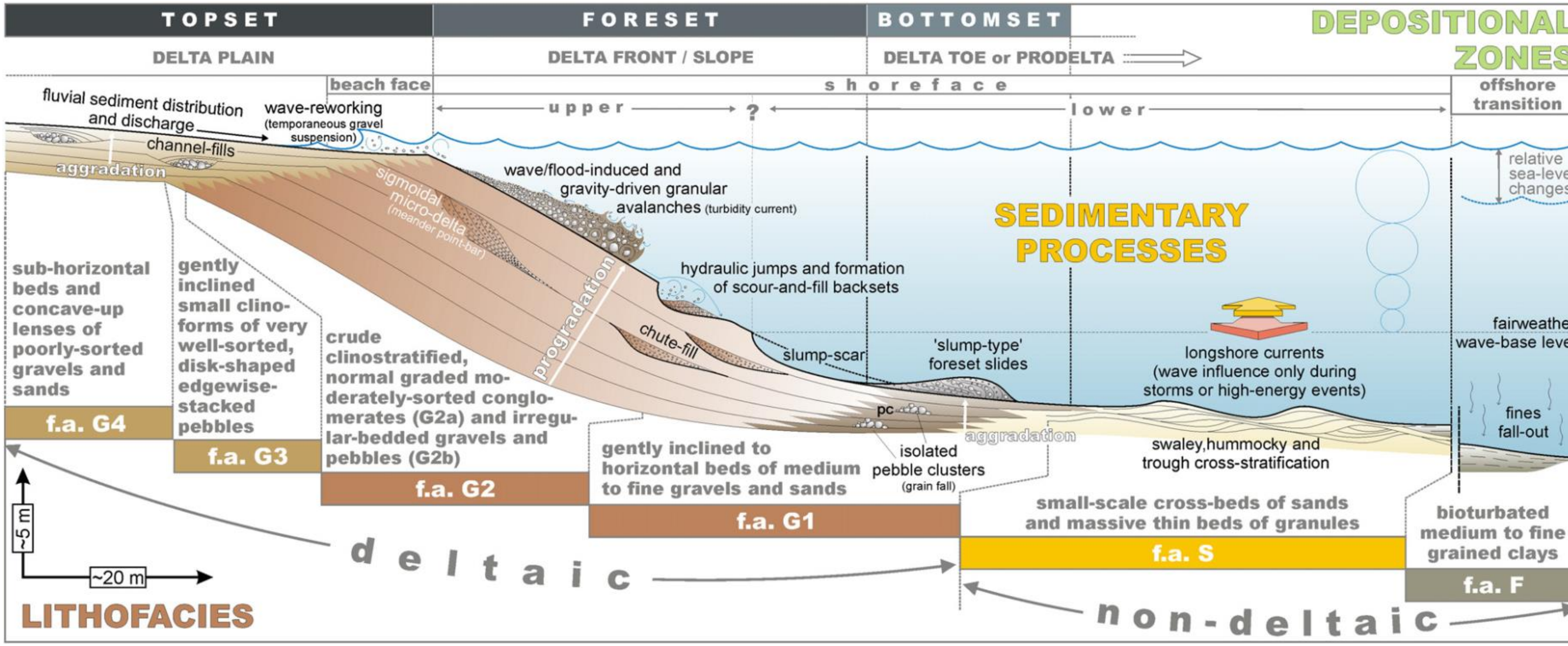




Coarse-grained deltas

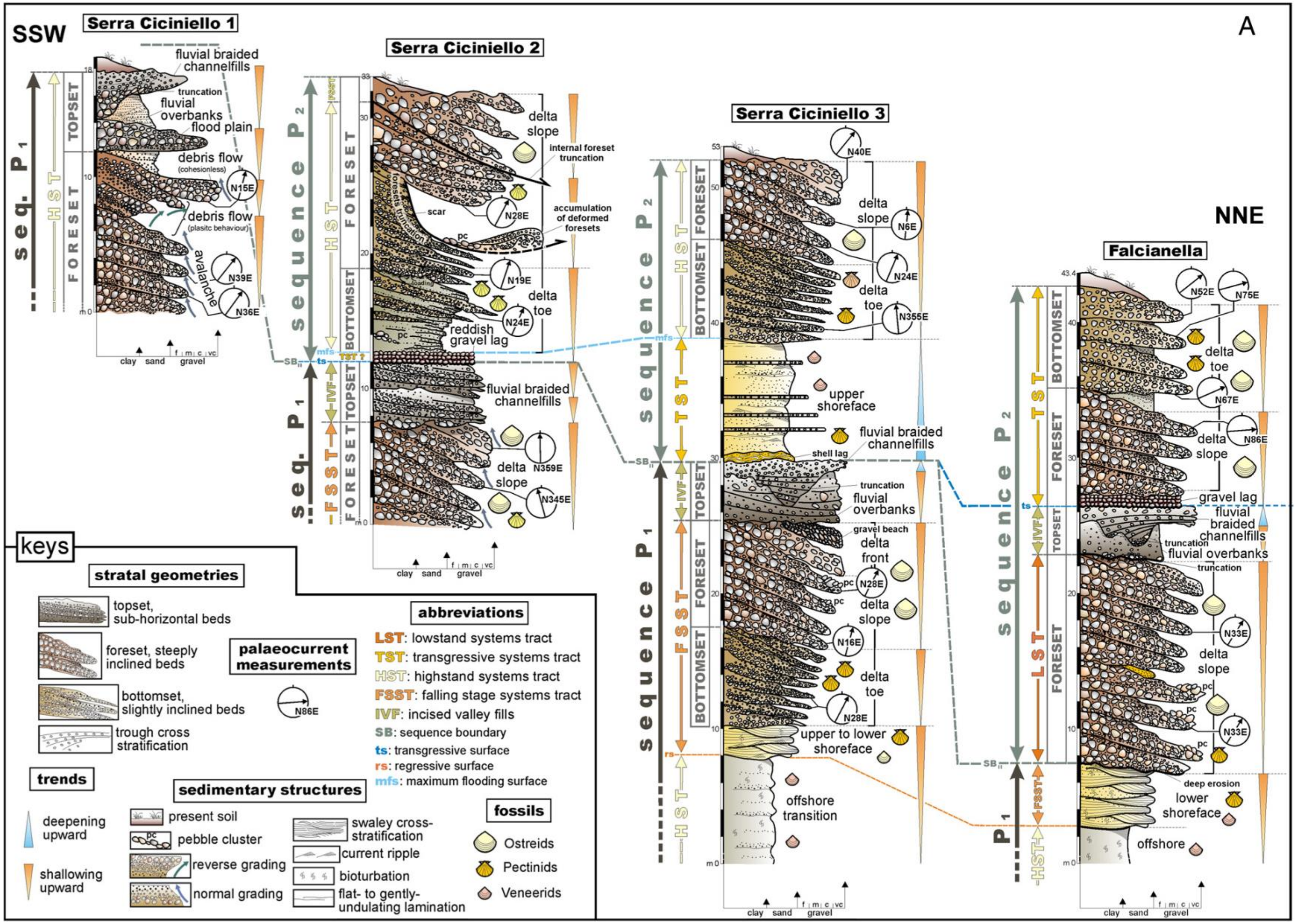
- Coarse-grained deltas, also referred to as fan deltas, are fed by pebbly braided rivers or alluvial fans.
- They form adjacent to areas of steep relief, where streams in the catchment areas of the rivers flow down steep slopes carrying coarse material into rivers or on to alluvial fans that prograde into a lake or the sea. Settings such as the faulted margins of rift basins are typical sites for coarse-grained deltas to form.
- The delta-top environment and hence the facies deposited are those of a coarse braided river or an alluvial fan. Gravelly material is transported by fluvial or alluvial fan processes into the lake or sea.
- Progradation of a coarse-grained delta across a shallow lake or sea floor results in a coarsening-up succession from finer sands deposited furthest offshore through coarser sands, granules, pebbles and even cobbles or boulders at the top of the delta-front succession, which is then overlain by coarse fluvial or alluvial fan facies of the delta top.

Gilbert-type deltas

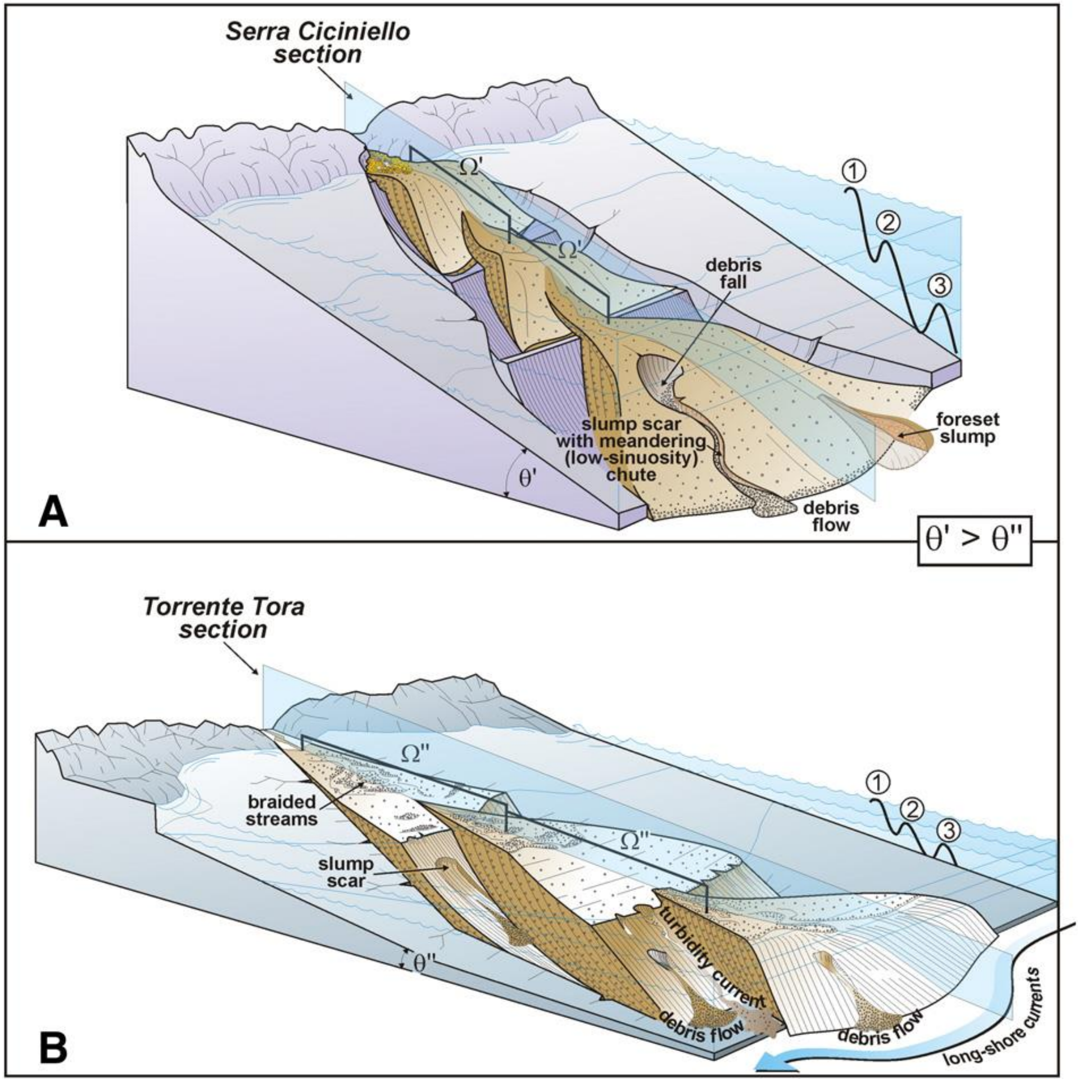


Depositional model of the Gilbert-type deltas observed within the study succession. The model shows the three main geometric components (topset, foreset and bottomset) that comprise the different depositional zones. (From Longhitano, 2008)

Gilbert-type delta



Gilbert-type delta



From Longhitano (2008)

5. Controls on Delta Morphology

Controls

- Tectonics
- Climate
- Sea-level changes

- Hinterland Characteristics
  - Slope
    - Relief
      - Discharge

Delta Regime | Delta Morphology | Delta Facies

- Basin Characteristics
  - Subsidence
    - Depth Control
      - Discharge

5. Controls on delta morphology

A. Climate
B. Water discharge
C. Sediment yield
D. River-mouth processes
E. Wave power
F. Tidal processes
G. Aeolian processes
H. Nearshore currents
I. Shelf slope
J. Tectonics of receiving basin
K. Receiving basin geometry

5. Controls on delta morphology

A. Climate

- **Controls sediment-water yield.**
- **Controls in-situ delta deposits.**

1. Tropical = large thick accumulations of peat.

2. Temperate = thin, high continuous peat layers.

3. Arid = complex interfingering of supratuidal and evaporite deposits.

5. Controls on delta morphology

B. Water discharge

1. **Erratic Discharge** = braided channels with wide lateral continuity.

2. **Nonerratic Discharge** = stable meandering channels (shoe stringing sands).

3. **Erratic Discharge** = numerous interfingering, fining upward sequences showing highly variable porosity-permeability relationships.

v. irregular sedimentation rates.


5. Controls on delta morphology

C. Sediment yield

- **Primarily function of basin area and discharge.**
- **High fine grained sediment loads = expansive sub-aqueous deltas with high H_2O content and unstable clays.**
  - Slumping
  - Deformational features
  - Local diapirism
- **Compaction is high.**

5. Controls on delta morphology

D. River-mouth processes

See 2. River Mouth Processes Slide 6-14

5. Controls on delta morphology

E. Wave processes

- Most important in reshaping deltas.
- Volume sediment delivered/wave energy.
- Depositional units = beaches, barriers, etc.
- Low energy = low profile beaches often overwash dominated.
- High energy = higher profiles with high quartz deposits.
- Subaqueous slope - attenuation capacity.
- Low energy @ 1 x 10^7 ergs/second
- High energy @ 20 x 10^7 ergs/second


5. Controls on delta morphology

F. Tidal processes

- **Reduction in vertical density stratification, therefore buoyancy insignificant.**
- **Bidirectional sediment transport (flood and ebb).**
- **Marine and fluvial mixing zone is expansive (vertical and horizontal).**
  - Linear tidal ridges common.
  - Upstream tidal asymmetry resulting in significant bedload transport into system

5. Controls on delta morphology

G. Winds

- **Can create wind set-up at coast giving rise to current and littoral circulation.**
- **Can create significant increases in nearshore wave energy.**
- **Offshore winds can cause set-down and therefore reduce wave action significantly.**
- **Parallel-to-coast winds can drive longshore currents resulting in significant mud deposits downdrift of delta.**

5. Controls on delta morphology

H. Nearshore currents

- **Driven by:**
  - Deep oceanic currents impinging on shelf.
  - Tidal propagation.
  - Wind and water.
  - Density currents.
- **Offshore sandbodies sub-parallel/parallel to depositional strike.**
- **Sand bodies located significant distances offshore or downdrift form active lobe.**

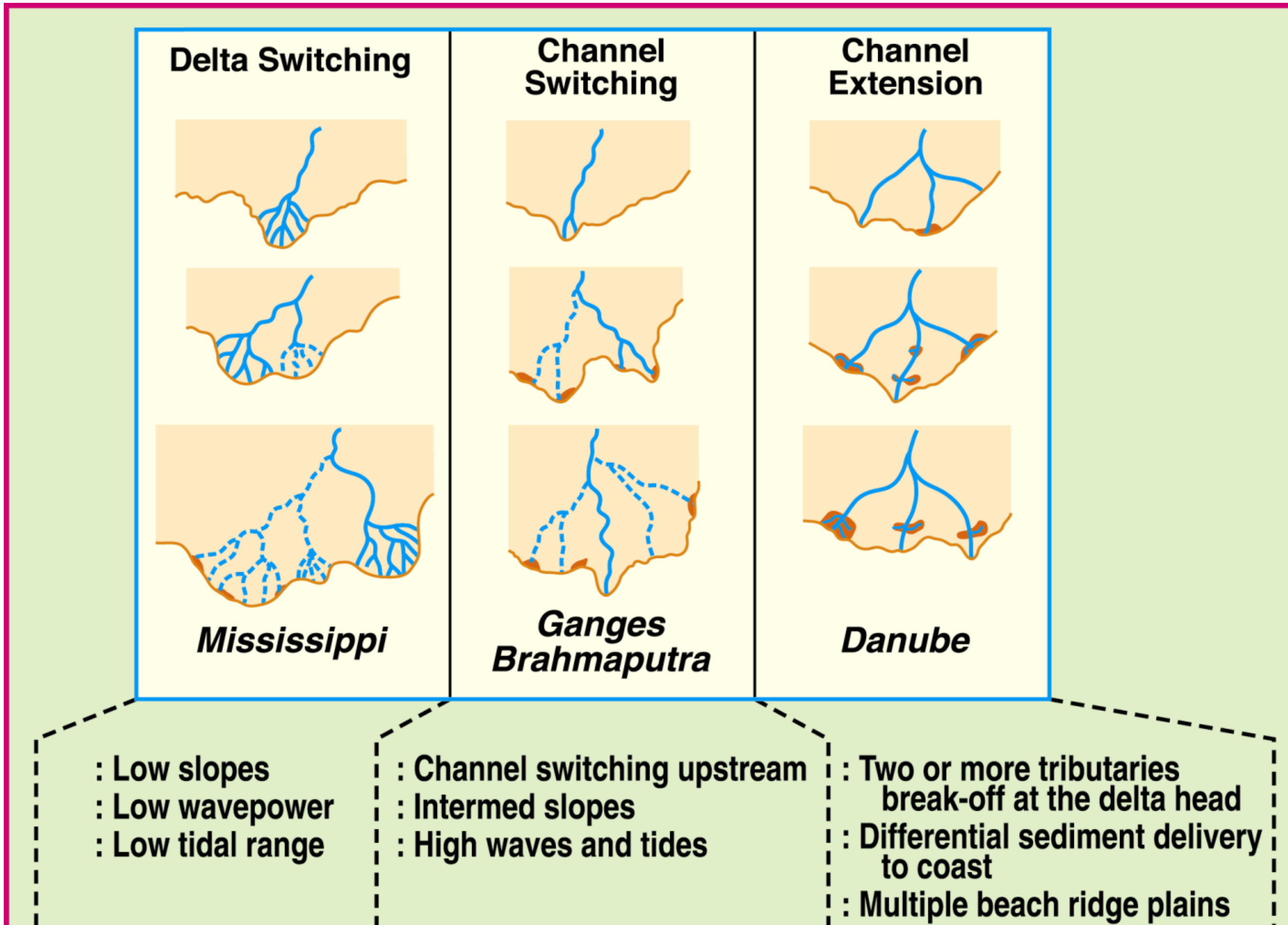
5. Controls on delta morphology

I. Shelf Slope

- **High rates of sediment accumulation and rapid progradation resulting in low angle slopes.**
  - **Frictional attenuation of surface gravity waves.**
- **Slopes may be actively prograding during modern time.**
- **Submarine canyons = net loss of sediment (Congo, Ganges-Brahmaputra).**

5. Controls on delta morphology

Types of Delta Switching Patterns



5. Controls on delta morphology

J. Tectonics of Receiving Basins

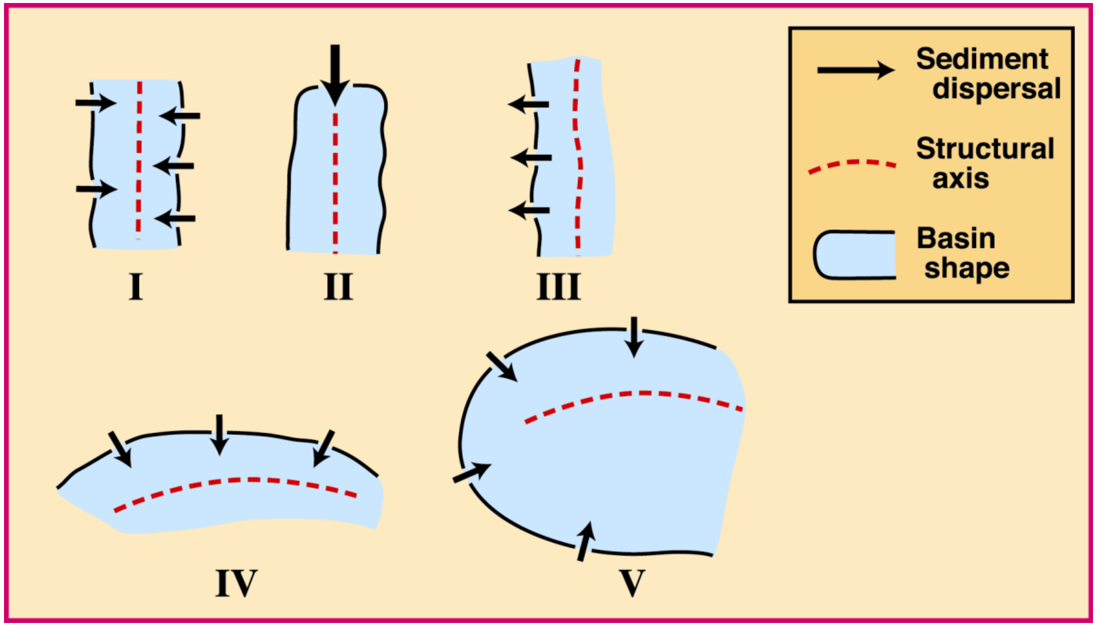
- **Rapidly subsiding basins result in overthickening of deltaic bodies.**

- **Relatively stable result in continuous, widespread, laterally continuous bodies.**

- **Localized differential weighting and dewatering of sediments =**
  - **Subaqueous mass movement.**
  - **Displaced sediments.**
  - **Complex slumping.**

5. Controls on delta morphology

K. Major Configurations of Receiving Basins



I. Skewed deltas due to high current (Sea of Japan).
II.Input of sediment from closed end (Gulf of California).
III. Downwarped area-sediment movement inland (Niger).
IV.Active subsidence seaward of shoreline (Senegal River).
V.Semi-enclosed (Gulf of Mexico).

Thank You !

DSRG

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