Estuaries and Deltas

Estuary = semi-enclosed coastal environment where freshwater and ocean water meet and mix

Delta = sedimentary deposit at mouth of river that causes coastline to protrude into ocean

Reading Material

"The Estuarine Environment", from "The World Ocean"
W.A. Anikouchine and R.W. Sternberg, Prentice-Hall

"River Deltas", from "The Coast of Puget Sound"
J.P. Downing, Puget Sound Books

"River Deltas", from "Coasts"
R.A. Davis, Prentice-Hall

Impact of sea-level rise on fluvial and glacial valleys

20,000 y to 7,000 y ago

valleys flooded, all sediment trapped

7,000 y ago to present

if little sediment supply – estuaries and fjords still filling

trapping mechanisms very important

(Chesapeake Bay)

if moderate sediment supply – estuaries nearly full

some sediment leaks to continental shelf

(Columbia River)

if much sediment supply – estuaries full and sediment overflowing

deltas build seaward

(Mississippi Delta)

Chesapeake and
Delaware Bays

Coastal-Plain
Estuaries

Drowned river valleys

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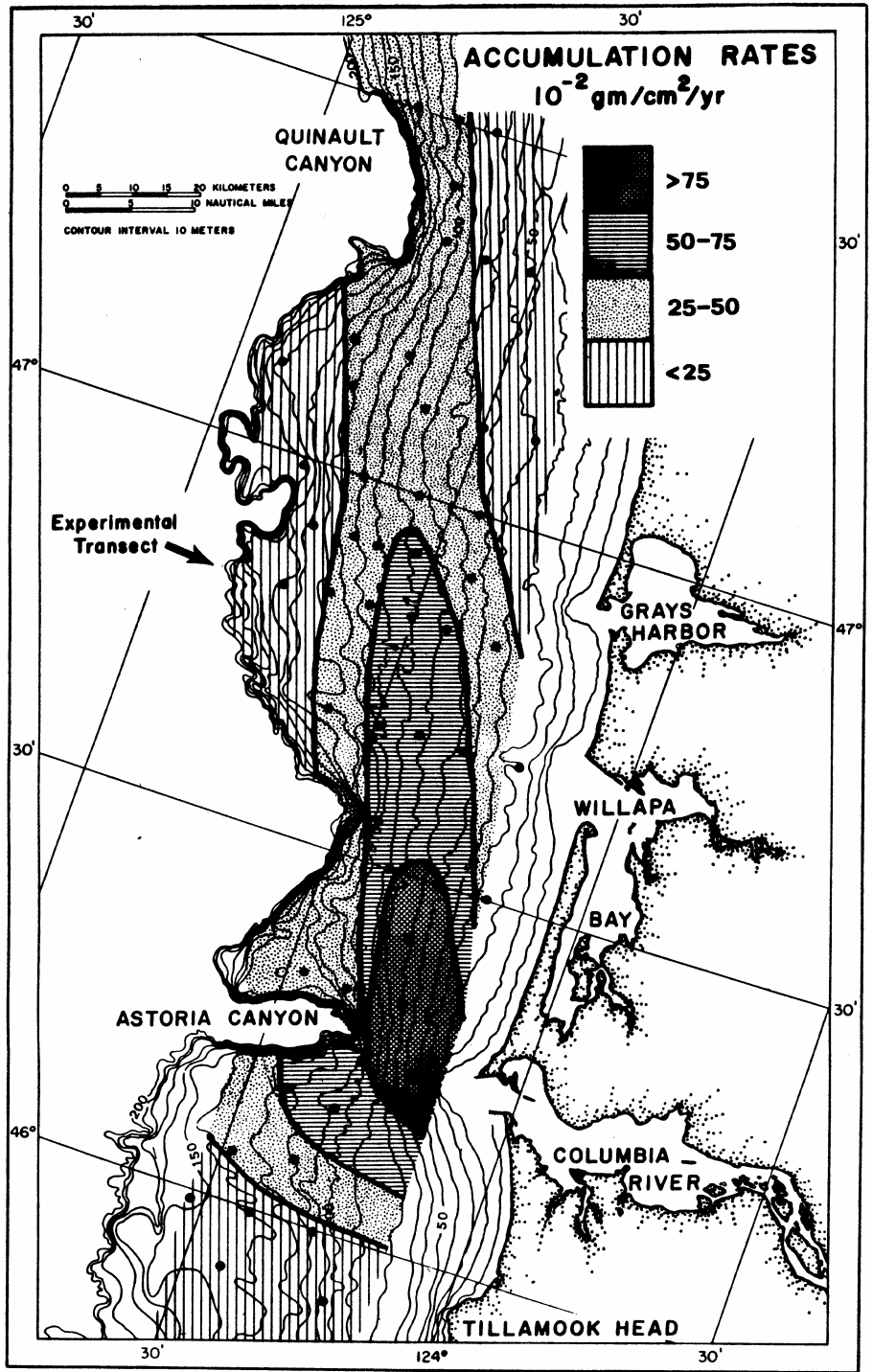
(Mississippi Delta)

Some sediment from Columbia River escapes estuary and accumulates on the adjacent continental shelf.

Prevailing transport mechanisms carry sediment northward, and most accumulates on the middle shelf



Types of Estuaries

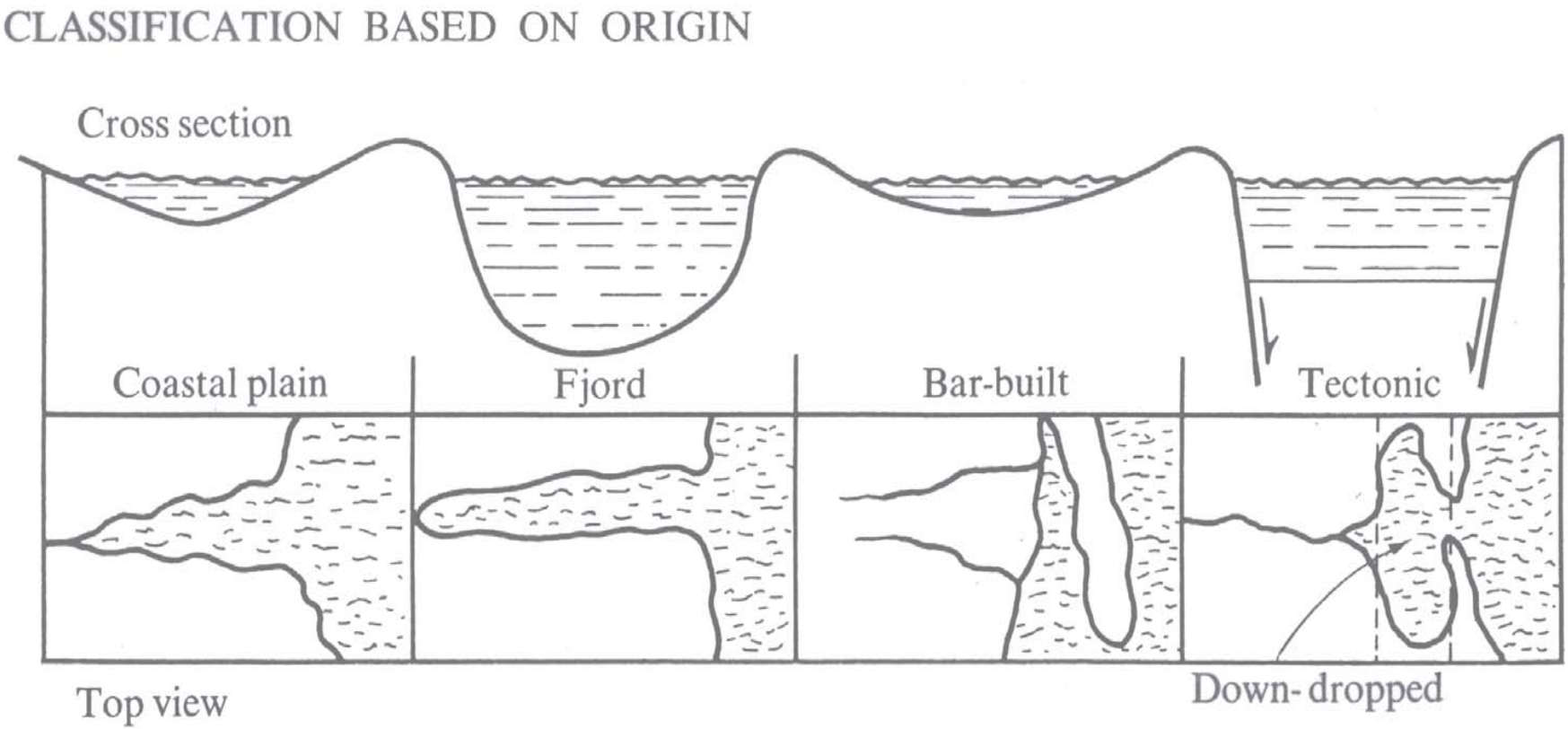
Coastal-Plain estuary (drowned river valley)

- V shape in cross section – result of fluvial erosion
- horn shape (i.e., triangular) in map view – water floods to topographic contour lines
- example: Chesapeake Bay

Fjord (drowned glacial valley)

- U shape in cross section, deep – result of glacial erosion
- shallow sill at mouth
- examples: high latitudes, Alaska, Scotland, Scandinavia, Chile

Types of Estuaries



Types of Estuaries

Bar-built estuary (lagoon)

- sand spit or barrier island encloses embayment
- shallow
- example: Willapa Bay

Tectonic estuary

- down-dropped basin (due to plate tectonics)
- located near ocean, and seawater floods basin
- example: San Francisco Bay (not very common)

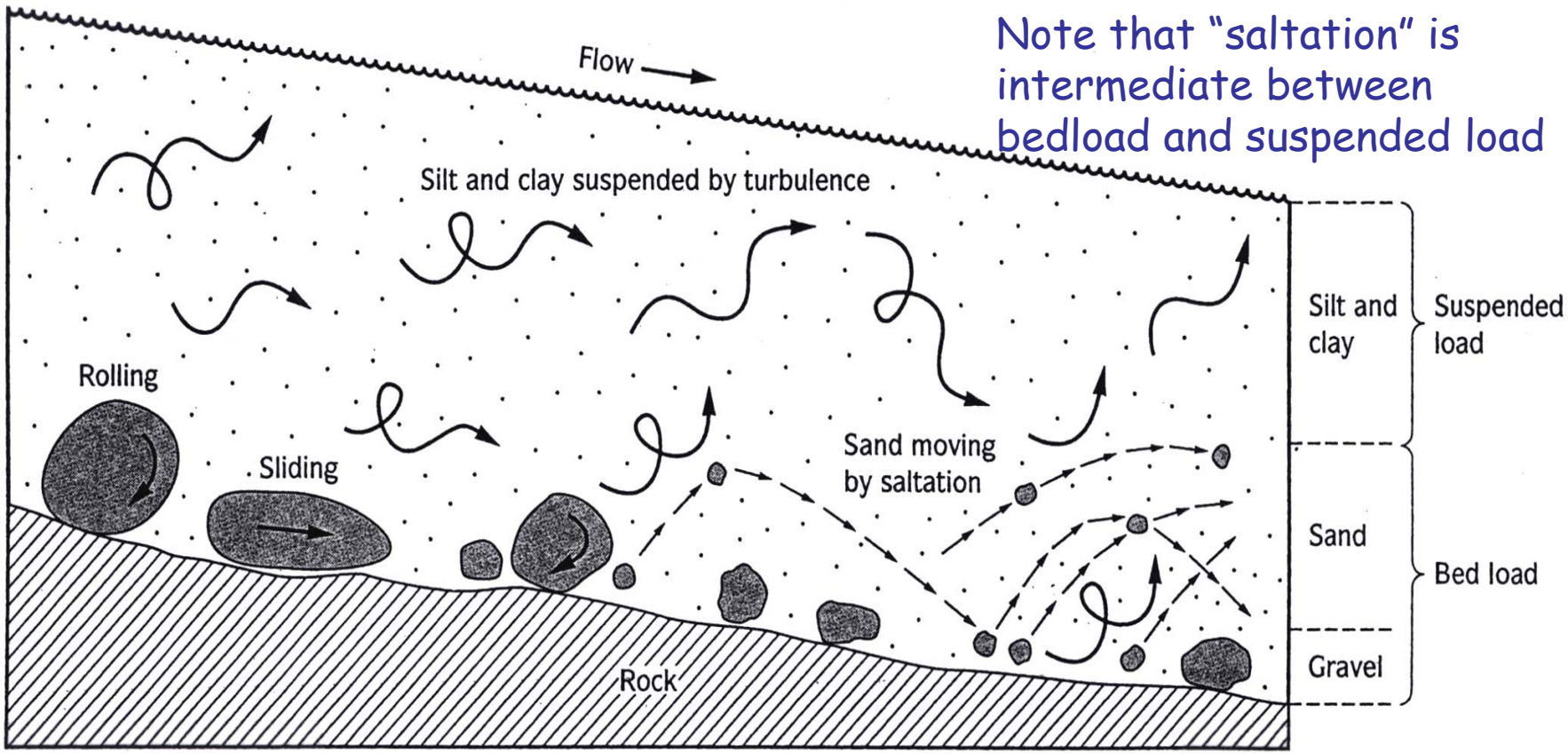
Estuarine Sedimentation

relevant to rivers – end of fluvial processes
relevant to beaches – traps or releases sediment to beach

Sand supplied by rivers (10%)
- transported as bedload (and suspended load)
- trapped near head of estuary
- where gradient of river surface goes to zero (sea level)

Mud supplied by rivers (90%)
- transported as suspended load
- trapped throughout estuary
- critical processes: water circulation
  particle flocculation

Distinction between particle transport as bedload and suspended load



Note that "saltation" is intermediate between bedload and suspended load

Sediment Transport

Bedload

- gravel = >2 mm
- sand = 2 mm to 0.064 mm (or 64 microns)
- particles bounce and roll along bottom
- relatively slow means of transport
- erosion depends on particle size

Suspended load

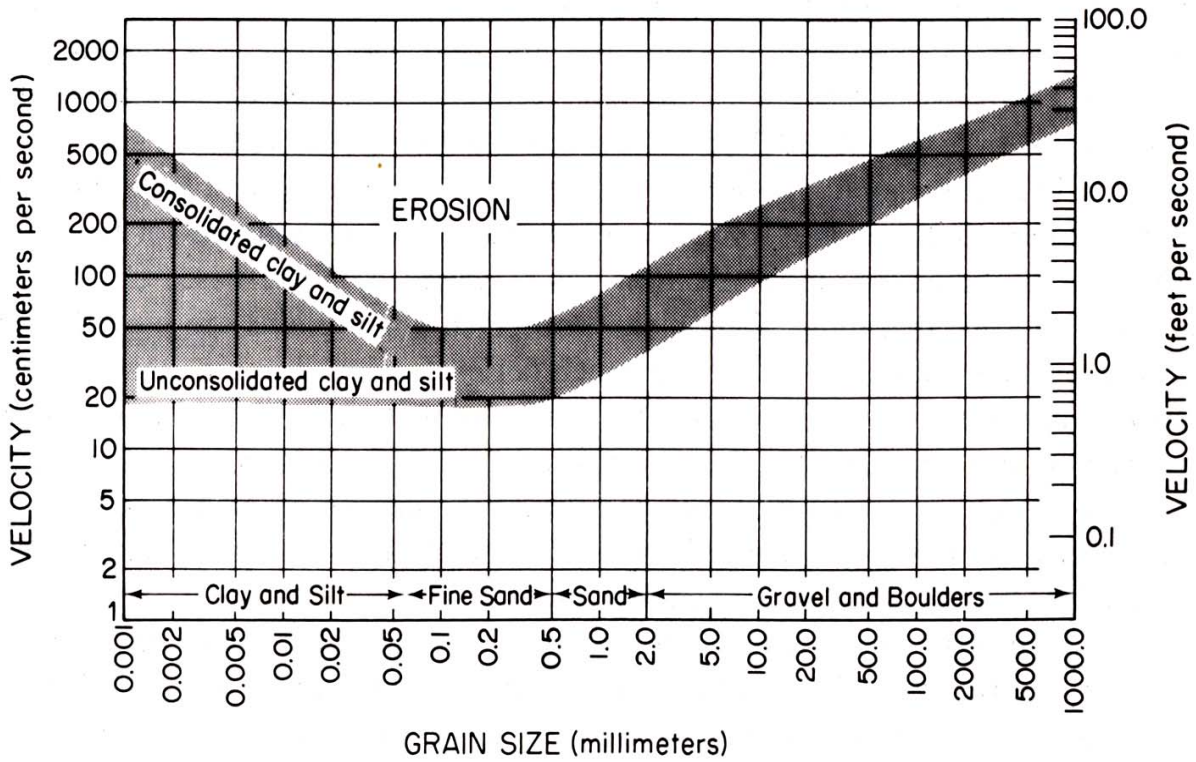
- silt = 0.064 mm to 0.004 mm (64-4 microns)
- clay = <0.004 mm (<4 microns)
- particles float with water
- relatively fast means of transport
- erosion depends on particle size and degree of consolidation

Erosion curve for different grain sizes

Velocity necessary to erode gravel and sand depends on grain size

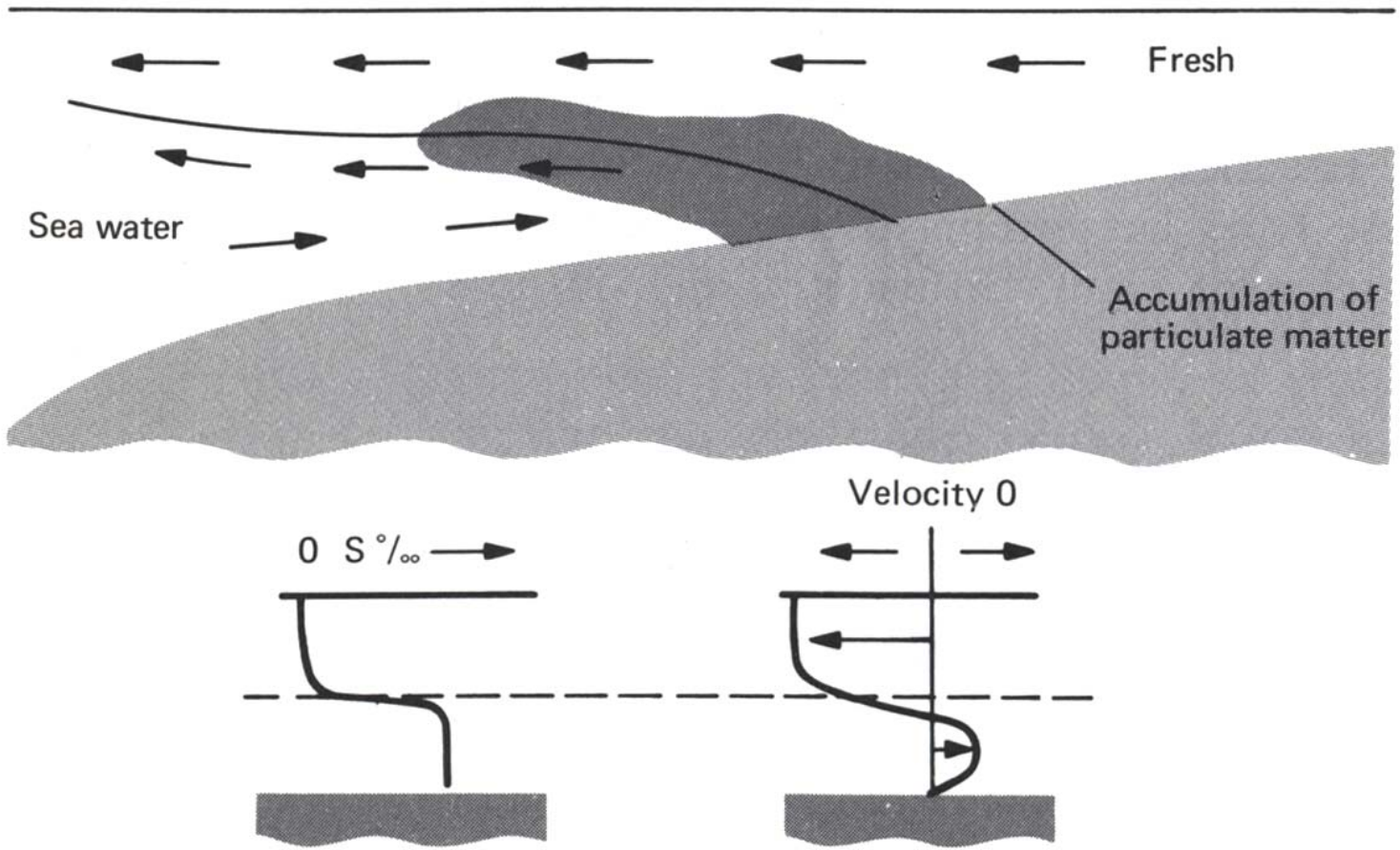
Velocity necessary to erode silt and clay depends on size, but also the degree of consolidation

Consolidation = how much water has been removed from between particles



Estuarine Circulation

Salt wedge



Estuarine Circulation

Salt wedge

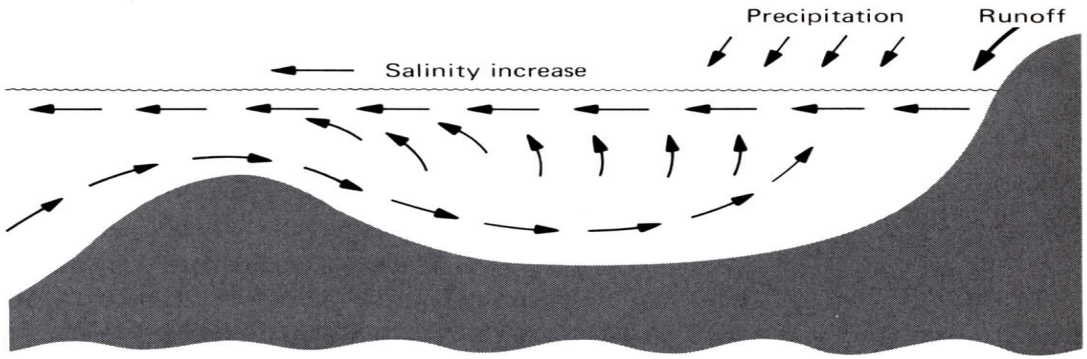
- fresh water at surface moving seaward
- boundary with underlying salt water = halocline
- friction with salt water, causes mixing
- some salt water carried seaward with fresh water
- new salt water moves landward, near bottom
- therefore, landward bottom current = salt wedge

Fjord circulation

- shallow sill inhibits exchange of deep water
- oxygen is consumed by animals in deep water behind sill
- anoxia (absence of oxygen) can develop, and animals die

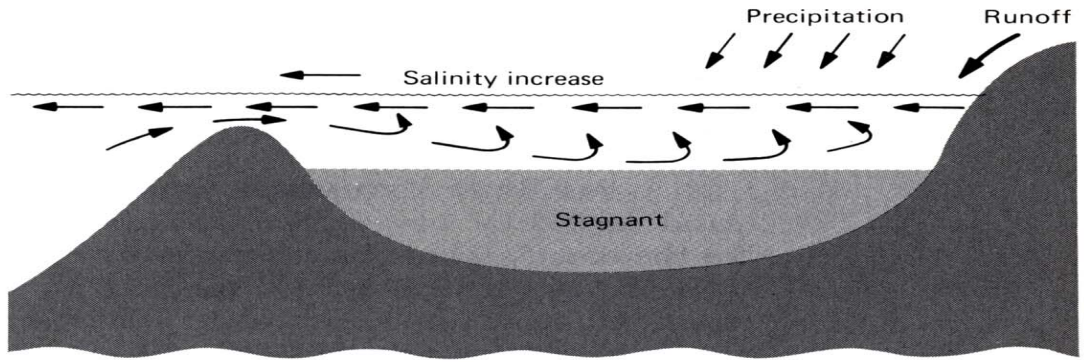
Fjord Circulation

Deep sill



thorough mixing of deep water

Shallow sill



poor mixing of deep water

Particle Flocculation

Flocculation = formation of aggregates from individual silt and clay particles

Electrical charges at surface (due to breaks in mineral structure)
- mostly negative charges
- fresh water - particles repel each other
- brackish/salt water – particles attracted to each other
  - form flocs

Flocs are larger than particles and sink faster

Silt and clay particles have platey shape
- particles join end to face, forming "card-house" structure
- sediment reaches bed of estuary with much water within flocs
- (ultimately leads to consolidation of delta surfaces)

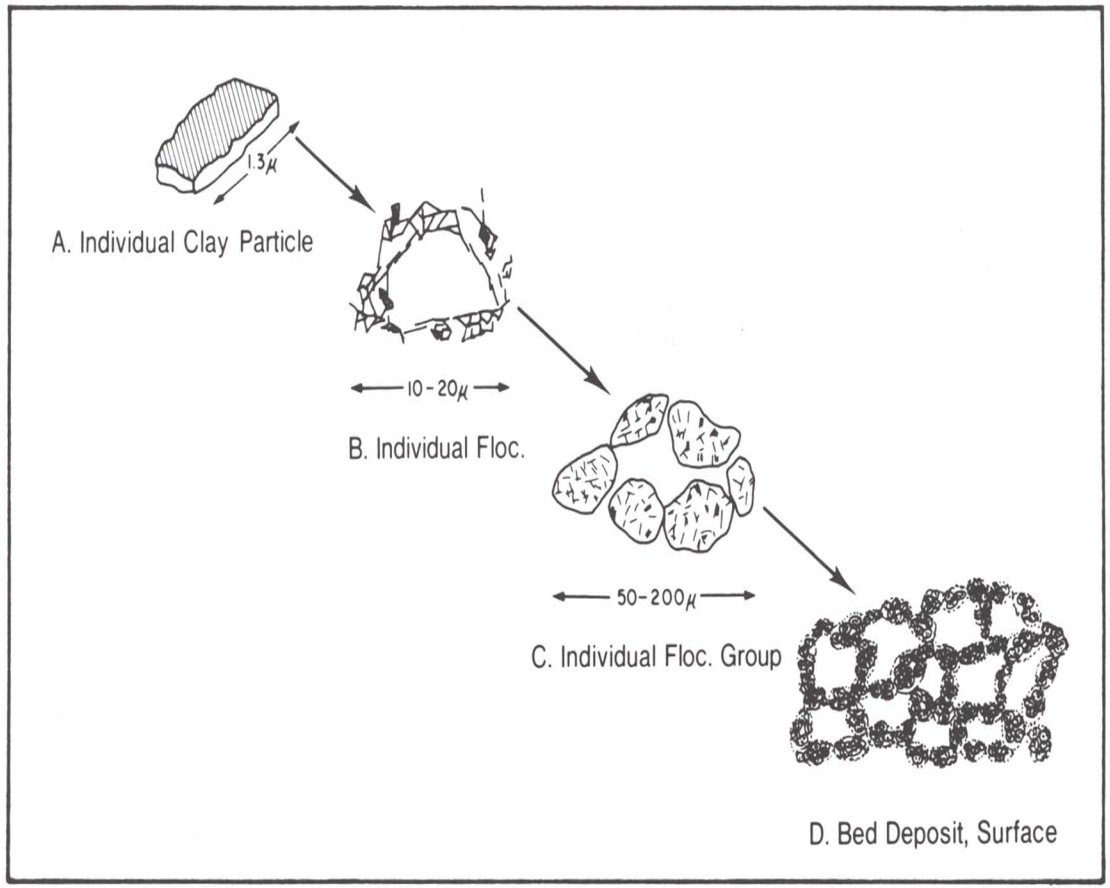
Floc Characteristics

Individual silt and clay particles are platey in shape

Flocs are formed with "cardhouse" structure

Water separates particles

Bed deposit initially has much space filled with water



Turbidity Maximum

Turbidity = sediment in suspension

Fluvial suspended particles carried seaward in surface water
they flocculate and sink
Estuarine suspended particles carried landward in bottom water

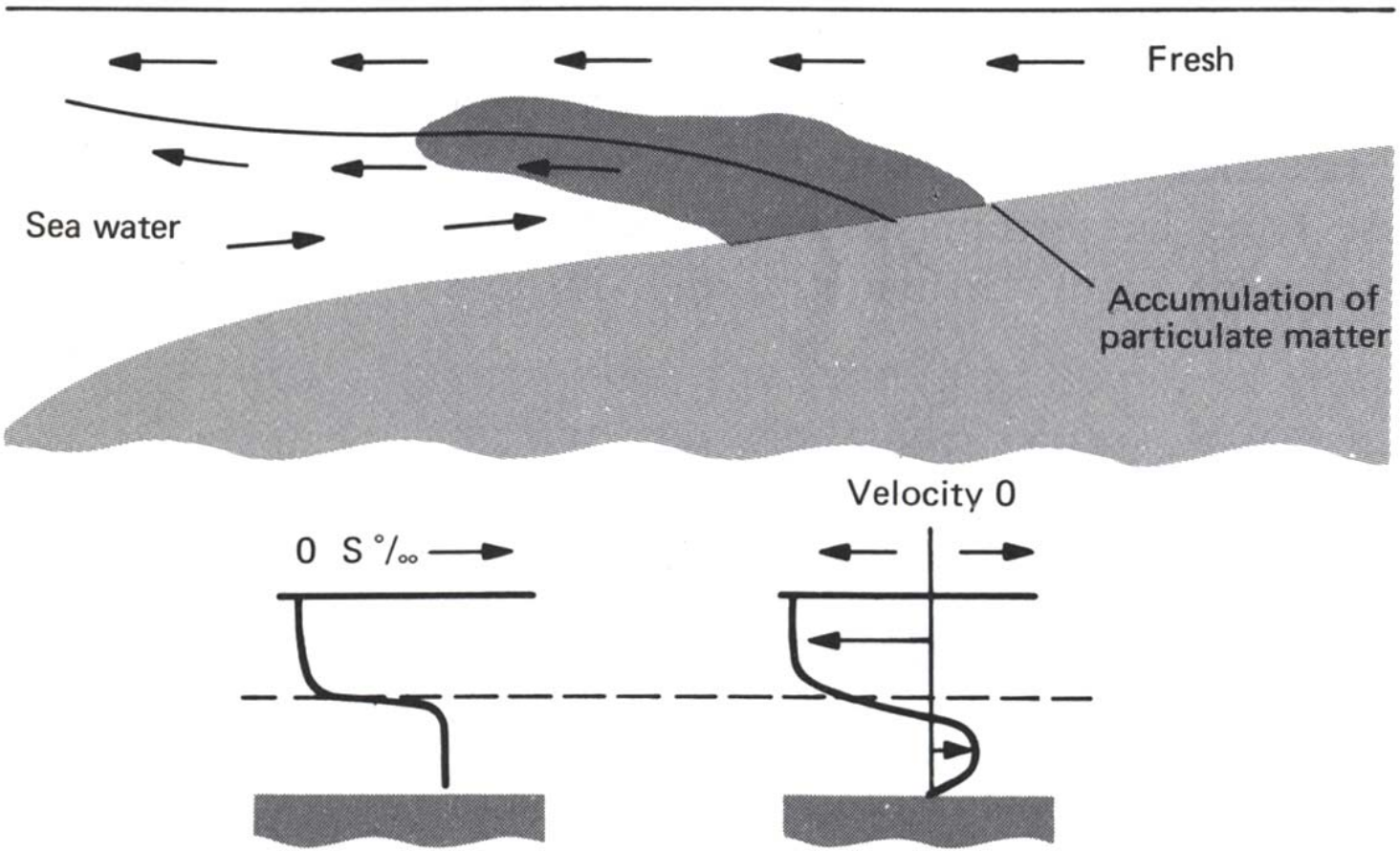
They meet at the halocline and cause highest turbidity in estuary
this is the turbidity maximum

Base of turbidity maximum is where most particles deposit on bed

Location of turbidity maximum moves upstream and downstream:
over hours, due to tides
over months, due to seasonal changes in river discharge

Ultimately, muddy sediment deposits over most of estuary
ESTUARIES ARE EXCELLENT SEDIMENT TRAPS

Estuarine Circulation



River Deltas

Evolve from coastal-plain estuaries

Rivers with much sediment filled their estuaries during the past ~7000 y
- sea-level rise was slow
- estuaries are excellent sediment traps

Infilled estuaries have triangular shape = Greek letter Δ
- from shape of Nile Delta

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

Nile Delta

Flowing northward in Mediterranean Sea

Two primary distributaries today

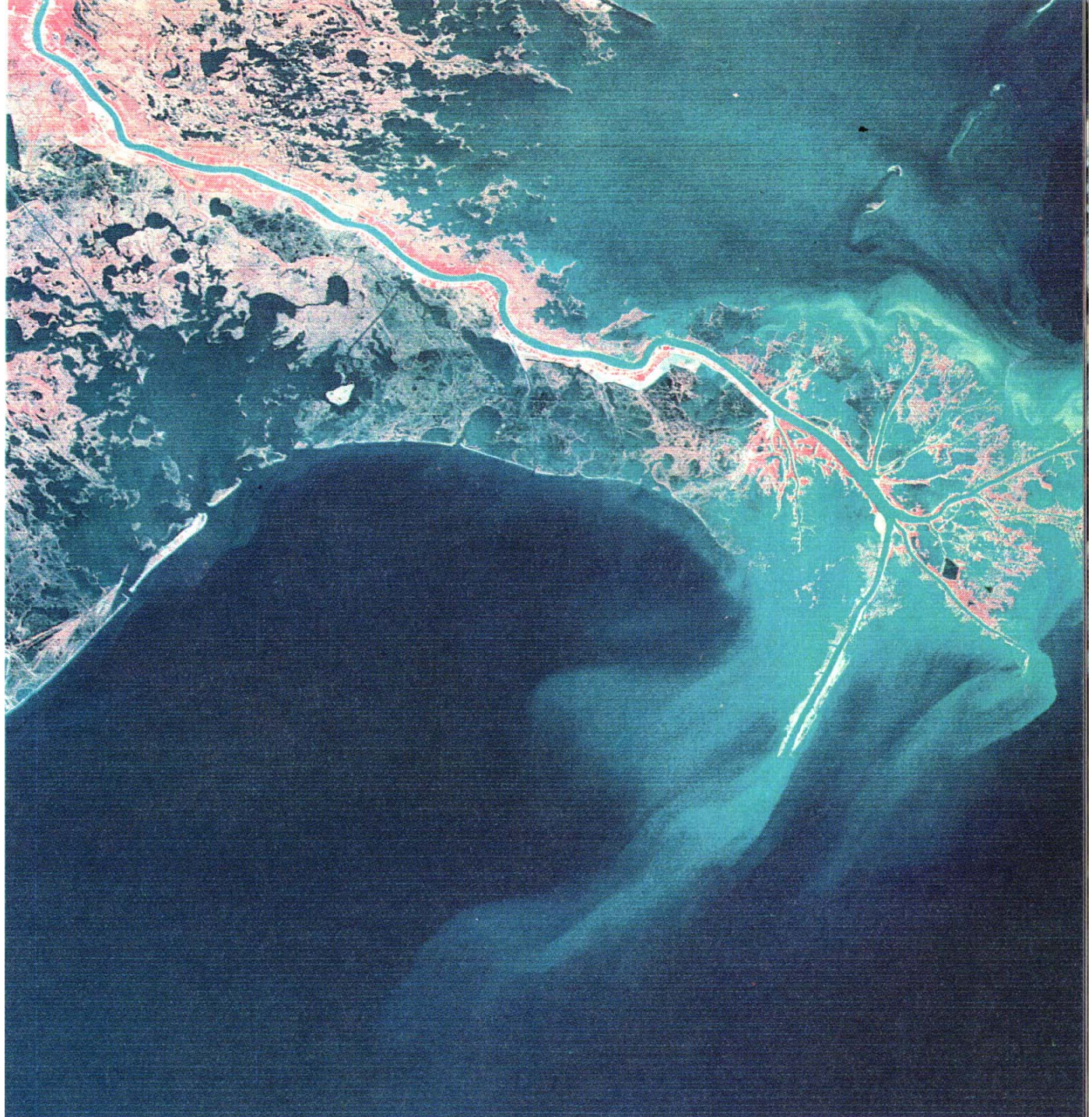
Waves rework shore into cuspate shape

Active portion of Mississippi Delta

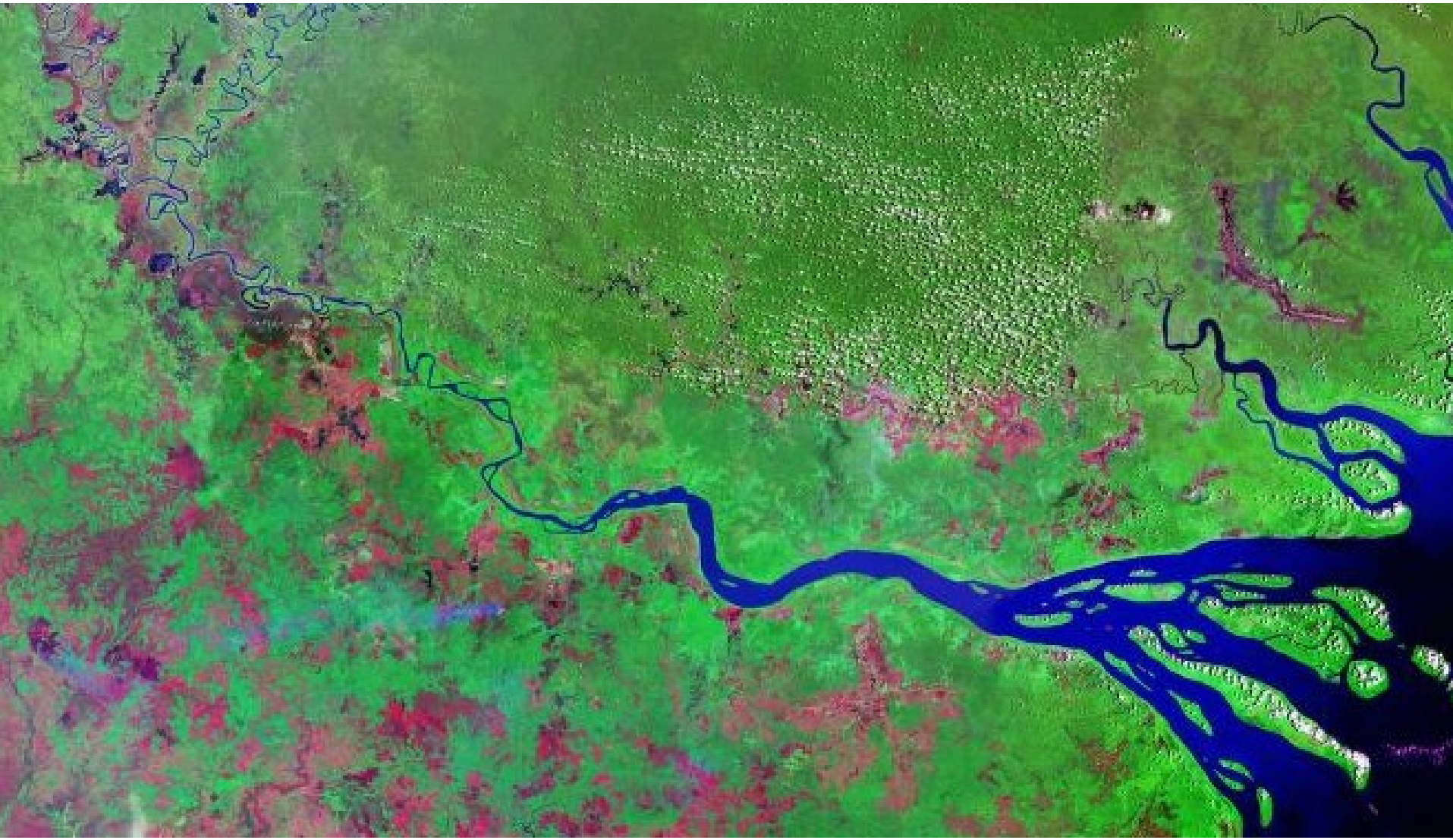
The shape is a bird-foot delta

Sedimentation is associated with individual distributary channels

These form because tidal currents are very weak and waves are generally very small

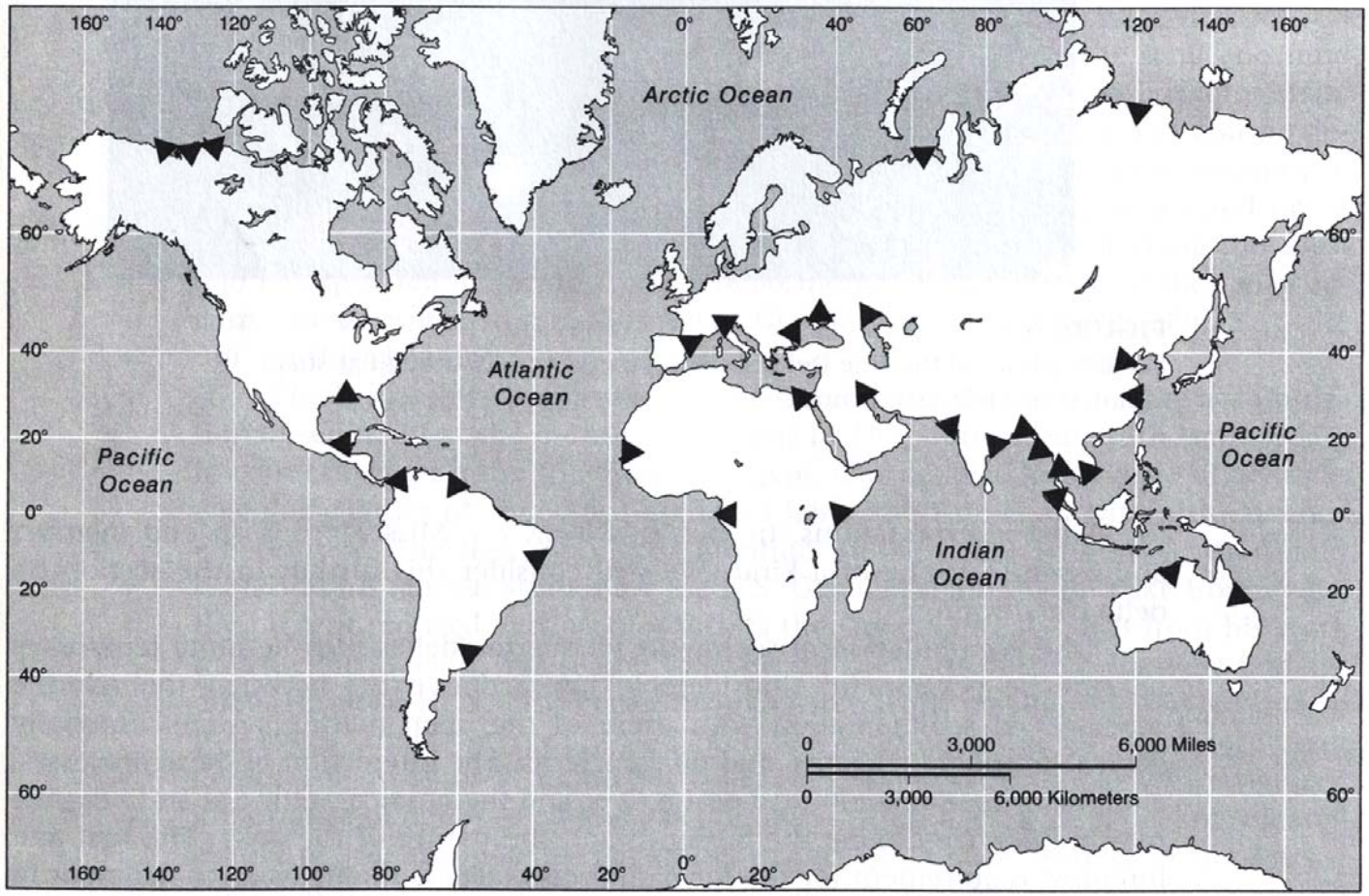


Fly River Delta



Classic example of tide-dominated delta –
tidal currents enlarge distributary channels

Global Distribution of Deltas



Location and Shape of Deltas

Deltas found many places in world

most common where river with much sediment enters protected setting

e.g.: small body of water (Mediterranean Sea, Gulf of Mexico, Puget Sound)

behind island or reef (Trinidad, Great Barrier Reef)

behind seasonal sea ice (Bering Sea, Arctic Ocean)

Where river reaches sea level, it divides into smaller distributary channels

Shape of protrusion from shoreline depends on oceanographic processes

weak waves and tidal currents: each distributary channel builds seaward

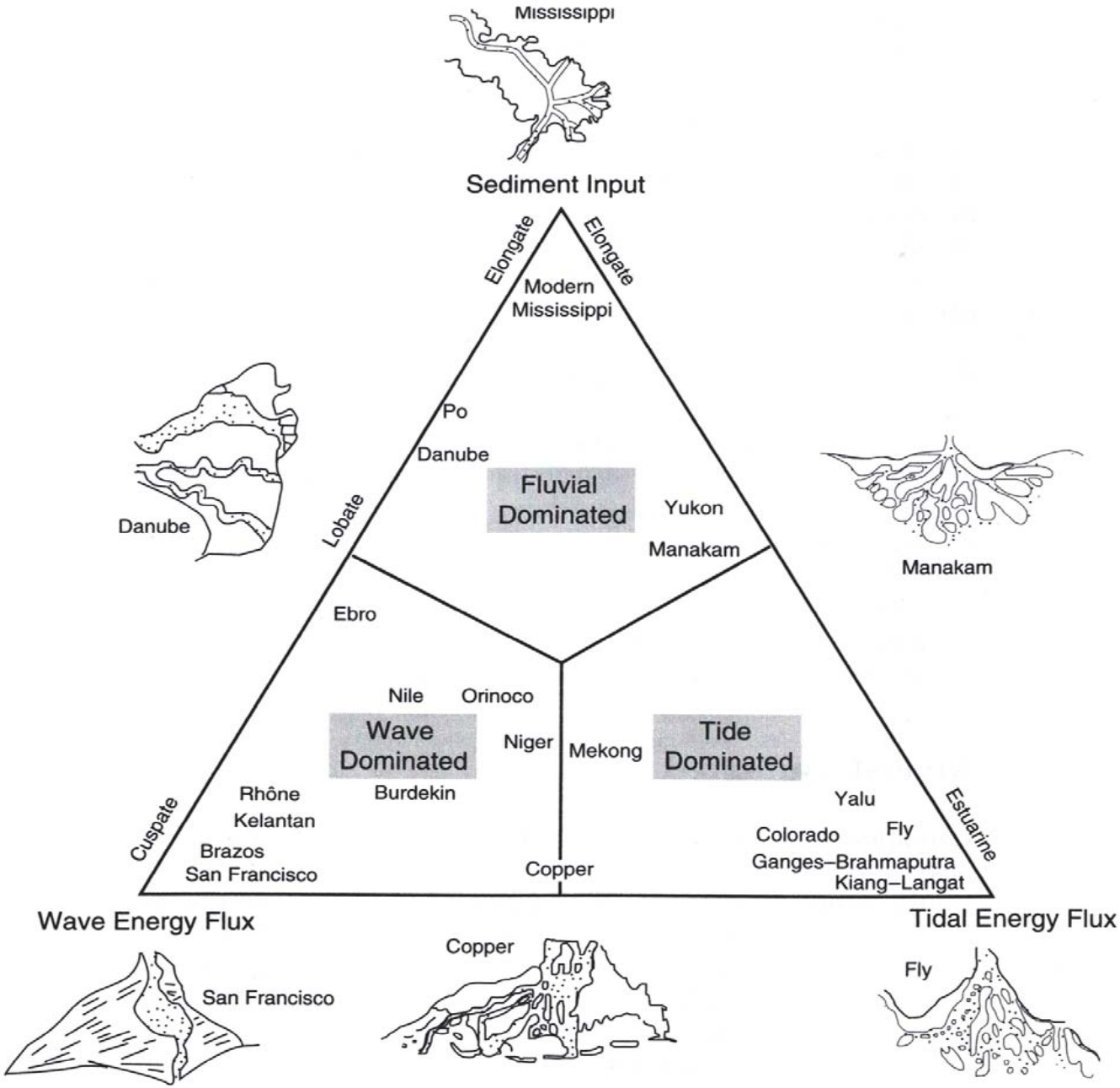
"bird-foot" delta builds with delicate digitation

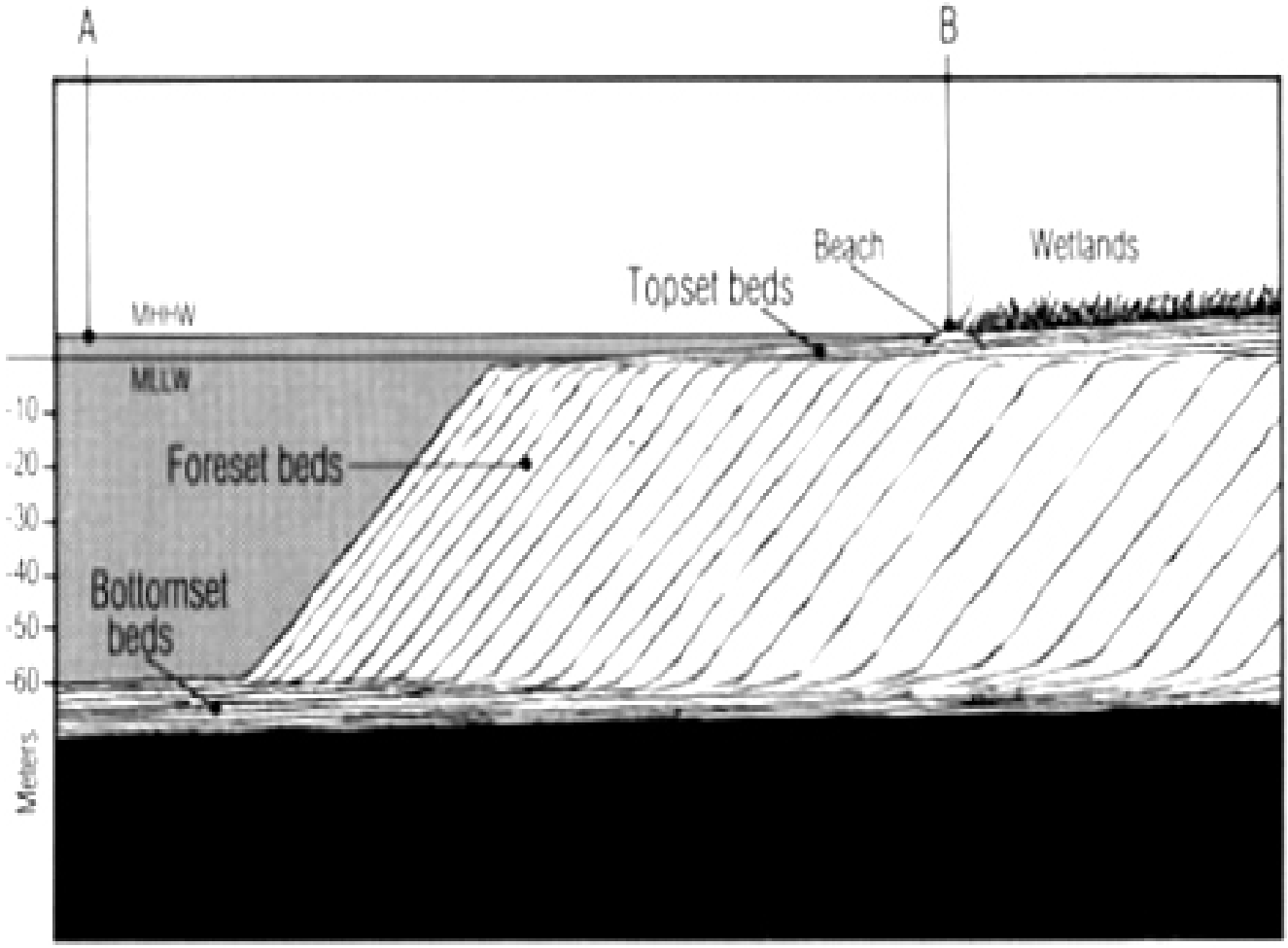
strong waves: longshore drift smears sediment along coast

cuspate shape forms

strong tidal currents: distributary channels eroded and expanded

islands formed between broad channels


Mississippi
Sediment Input
Elongate
Elongate
Modern
Mississippi
Po
Danube
Fluvial
Dominated
Yukon
Manakam
Lobate
Danube
Manakam
Ebro
Nile
Orinoco
Wave
Dominated
Niger
Mekong
Tide
Dominated
Rhône
Kelantan
Burdekin
Yalu
Colorado
Fly
Brazos
San Francisco
Copper
Ganges–Brahmaputra
Kiang–Langat
Cuspate
Estuarine
Wave Energy Flux
Tidal Energy Flux
San Francisco
Copper
Fly


A
B
Beach
Wetlands
Topset beds
MHHW
MLLW
-10
-20
-30
-40
-50
-60
Meters
Foreset beds
Bottomset beds

Deltaic Sedimentation

Estuarine processes (e.g., flocculation, turbidity max) displaced into ocean

Topset (uppermost region)

- freshwater swamps, brackish water marshes, sandy channel floors
- sediment accumulation controlled by sea-level rise
- land surface sinks due to consolidation of underlying mud

Foreset (middle region)

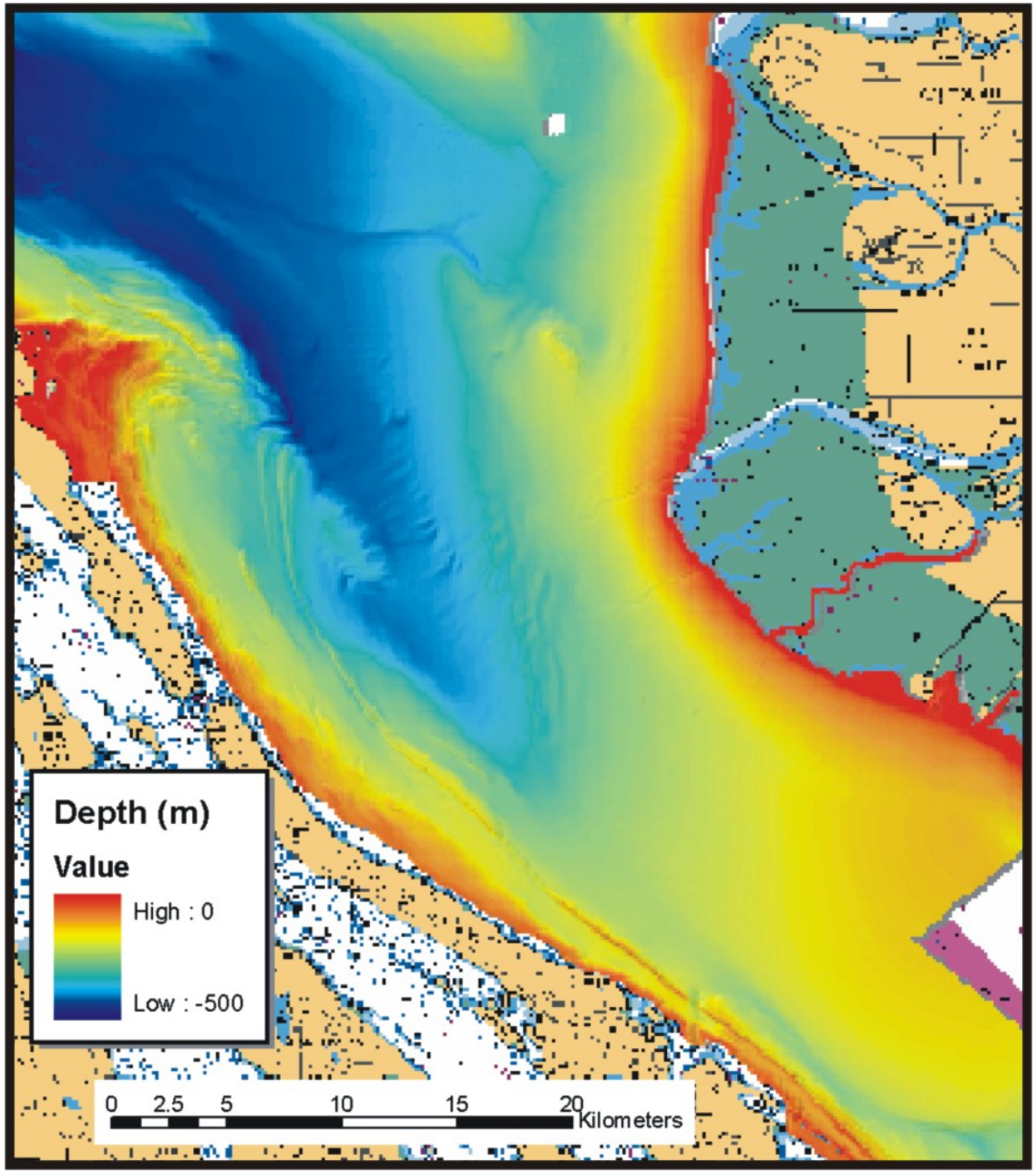
- very high rates of sediment accumulation = thick, muddy deposits
- sloped surface (few degrees)
- gullies form from turbidity currents, landslides occur from slope failure

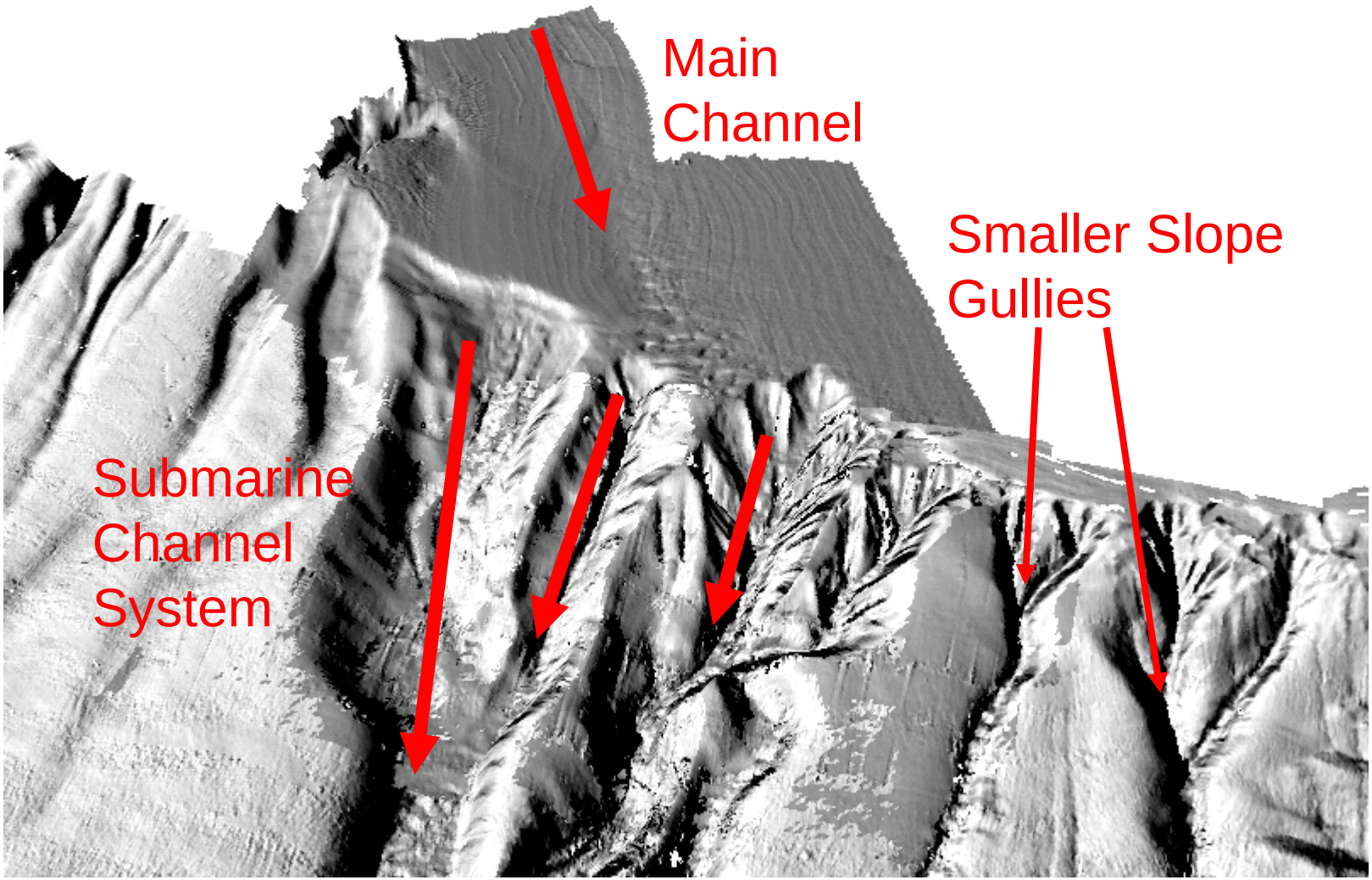
Bottomset (deepest region)

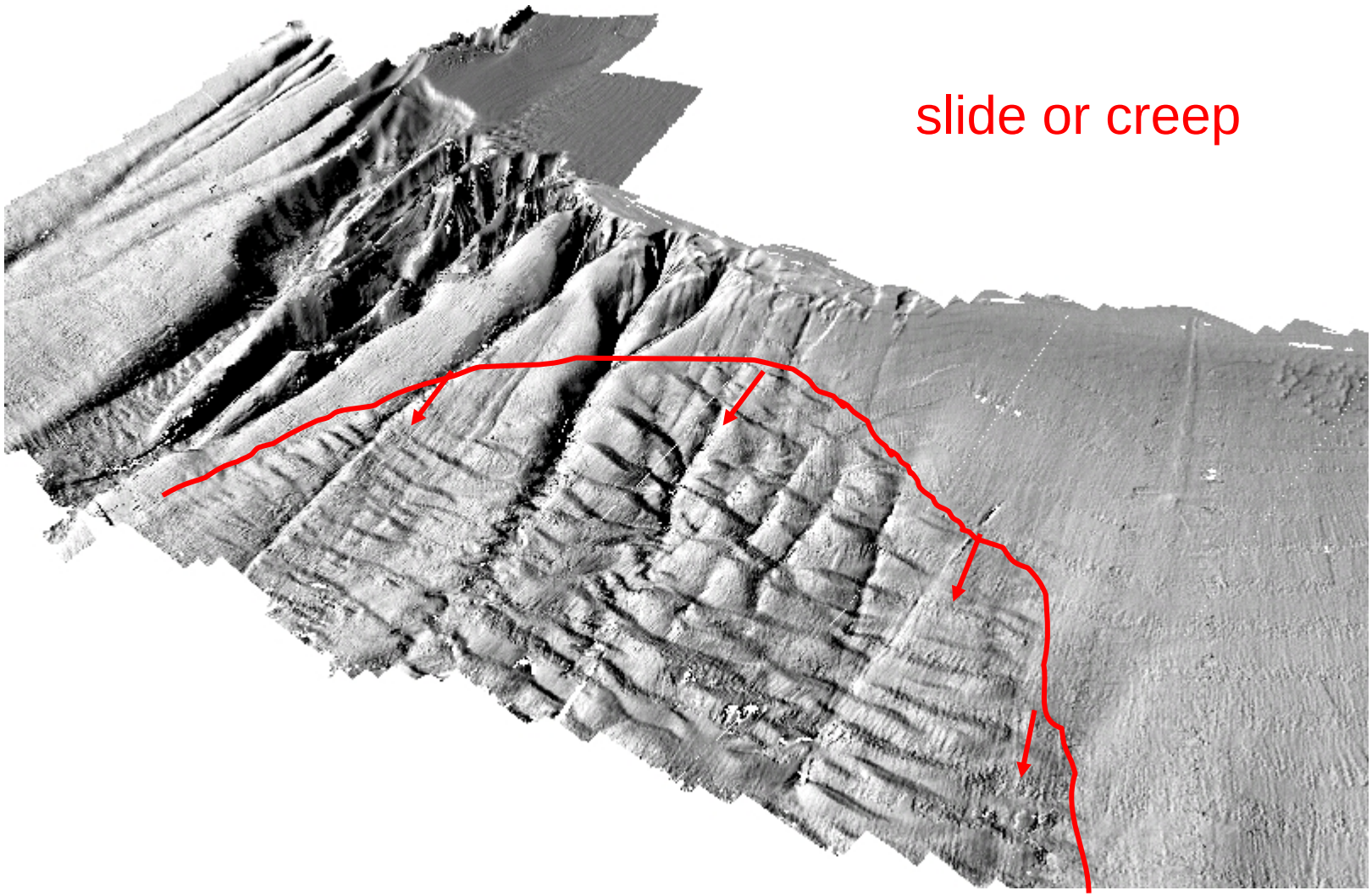
- forerunner of advancing delta
- thin deposits of mud over inner-shelf sand

Lobe of maximum sedimentation changes over centuries

- depression filled, and lobe switches to another location


Depth (m)
Value
High : 0
Low : -500
0 2.5 5 10 15 20
Kilometers


Main
Channel
Smaller Slope
Gullies
Submarine
Channel
System


slide or creep

History of lobe switching for the Mississippi Delta

The Mississippi Delta has has switched its lobe of active sedimentation many times during the past several thousand years

The active lobe of the Mississippi is the Balize