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
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)
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

CLASSIFICATION BASED ON ORIGIN

Cross section

Coastal plain  Fjord  Bar-built  Tectonic

Top view  Down-dropped
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

Sea water

Fresh

Accumulation of particulate matter

Velocity 0

$0 \text{ } S^\circ_{\infty}$
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

through 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

Sea water

Accumulation of particulate matter

Fresh

0 S°/o

Velocity 0
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 $\Delta$
  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 into Mediterranean Sea

Two primary distributaries today

Waves rework shore into cuspatate 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
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
Main Channel

Smaller Slope Gullies

Submarine Channel System
slide or creep
The Mississippi Delta has switched its lobe of active sedimentation many times during the past several thousand years.

The active lobe of the Mississippi is the Balize.