Deltaic environments

- Deltaic environments are gradational to both fluvial and coastal environments.
- The density relationship between sediment-laden inflowing water and the receiving, standing water body varies:
  - **Hyperpycnal**: inflowing water has a higher density than basin water, leading to inertia-dominated density currents.
  - **Hypopycnal**: inflowing water has a lower density than basin water (buoyancy), leading to separation of bed load and suspended load.
- Deltas consist of a subaerial **delta plain**, and a subaqueous **delta front** and **prodelta**.
- The delta slope is commonly 1-2° and consists of finer (usually silty) facies; the most distal prodelta is dominated by even finer sediment.
Deltaic environments

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, saltwater 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
Deltaic environments

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)

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- Minor (secondary) deltas commonly form when distributaries enter lakes or lagoons
Deltaic environments

Delta plain

- Distributaries are to a large extent comparable to fluvial channels, but are commonly at the low-energy end of the spectrum (meandering to straight/anastomosing).
- Delta plain distributaries are usually characterized by narrow natural levees and numerous crevasse splays.
- Avulsion (i.e., delta-lobe switching) is frequent due to high subsidence rates, as well as rapid gradient reduction associated with channel progradation.
Deltaic environments

**Delta plain**

- In humid climates, delta plains may have an important organic component (peat that ultimately forms coal)
- Hydrosere: vertical succession of organic deposits due to the transition from a limnic, through a telmatic, to a terrestrial environment
- **Terrestrialization** (= hydrosere): gyttja --> fen peat --> wood peat --> moss peat (commonly a transition from a minerotrophic to an ombrotrophic environment)
- **Paludification** (= reversed hydrosere) is caused by a rise of the (ground)water table
- Peats are essentially the downdip cousins of paleosols, representing prolonged periods of limited clastic sediment influx
Deltaic environments

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**Delta front processes**

- Bed load transported by fluvial related currents
- Transportation during flood stage
- Intensive winnowing by wave action (Bar crest)
- Winnowing by storm waves (Distal bar)
- Transportation by longshore currents

**Diagram notes**

- Marsh
- Channel
- Subaqueous levee
- Subaerial levee

**Scale**

0 km to 1 km

**Wind direction**
Deltaic environments

Delta front and prodelta

- **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.
- The prodelta is the distal end outside wave or tide influence where muds accumulate, commonly with limited bioturbation.
Deltaic environments

- Delta morphology reflects the relative importance of fluvial, tidal, and wave processes, as well as gradient and sediment supply
  - **River-dominated deltas** occur in microtidal settings with limited wave energy, where delta-lobes progradation is significant and redistribution of mouth bars is limited
  - **Wave-dominated deltas** are characterized by mouth bars reworked into shore-parallel sand bodies and beaches
  - **Tide-dominated deltas** exhibit tidal mudflats and mouth bars that are reworked into elongate sand bodies perpendicular to the shoreline
Series of 3–10 m coarsening upwards sequences representing the repeated infilling of interdistributary areas

Ripple-laminated silts and sands with scour surfaces

60–150 m coarsening upwards sequence produced by mouth bar progradation

Interbedded muds, silts and sands

Slump sheet

Homogeneous muds, laminated or bioturbated
Deltaic environments

- The typical **progradational** delta succession exhibits a transition from prodelta offshore muds through silty to sandy (mouth bar) deposits (coarsening-upward succession), the latter commonly with small-scale (climbing) cross stratification and overlain by:
  - Distributary channel deposits (sometimes tidal channel deposits) with larger scale sedimentary structures
  - Subaqueous levees grading upward into interdistributary sediments
- **Transgression** occurs upon delta-lobe switching, leading to:
  - Intense wave reworking and transformation of mouth bar/beach ridge sands into barrier islands
  - Drowning of barrier islands leading to offshore sand shoals
  - Increasing salinity and eventual drowning of (part of) the delta plain
Transgressive Mississippi Delta barrier model

**Active delta**
- Fresh Marsh
- Beach ridge
- Interdistributary bay
- Distributary mouth bar
- Abandonment
- Reoccupation

**Stage 1: Erosional headland with flanking barriers**
- Salt Marsh
- Restricted inter-distributary bay
- Recurved spit
- Tidal inlet

**Stage 2: Transgressive Barrier Island arc**
- Curved spit
- Flood-tidal delta
- Interdeltaic lagoon
- Washover terrace
- Tidal inlets
- Subaqueous barrier sands

**Stage 3: Inner-shelf shoal**
- Shell reefs
- Shoal front
- Shoal base
- Shoal crest
- Subaqueous barrier sands
- Sand sheet

Submergence
Deltaic environments

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  - Increasing salinity and eventual drowning of (part of) the delta plain
Deltaic environments

- Shallow-water deltas are thinner but larger in area than their deep-water counterparts.
- Deformation processes are very common in deltas due to the high sediment rates and associated high pore-fluid pressures:
  - *Growth faults* result from downdip increasing sedimentation rates; they develop contemporaneously with sedimentation.
  - *Mud diapirs* may form when thick prodelta deposits are covered by mouth-bar sands.
  - *Slumping* can lead to the anomalous occurrence of shallow-water facies in prodelta deposits.
Fig. 12. Sedimentación teórica en la desembocadura de un río dominada por las olas: A, olas paralelas a la costa; B, olas oblicuas a la costa (según Wright, 1977).

Fig. 13. Sedimentación teórica en la desembocadura de un río dominada por las marcas (según Wright, 1977).
Fig. 7. Difusión y deceleración de un efluente dominado por la fracción (flujo hipersónico) (según Wright, 1977).

Figura 5.1. Ilustración de la geomorfología y facies sedimentarias de un delta actual. Adviértase la complejidad de secciones verticales que pueden resultar.
Control of grain size on mixing behaviour at the river mouth. Suspended- and mixed load examples based on the Mississippi (Wright, 1977) and Bella Coola rivers (Kostaschuk, 1985), respectively. Gravelly river mouth is hypothetical. Note different horizontal scales.
PLAYAS, ISLAS BARRERAS – LAGOON, ESTUARIOS
Coastal environments

- The classification of deltas can be extended to include those depositional coastal environments that are in large part fed by marine sediments
  - Wave-dominated shorelines
  - Tide-dominated shorelines

- Depending on the balance between sediment supply and accommodation, coastal environments can be regressive (progradation) or transgressive (retrogradation)
Increasing marine sediment supply

- Maine sediment source
- Minimal sediment supply
- Mixed sediment supply

Increasing fluvial sediment supply

- Fluvial sediment source
- Fluvial-dominated deltas
- Regressive

Increasing relative tidal power

- Wave-dominated estuaries and tidal flats
- Tide-dominated estuaries and tidal flats

Increasing relative wave power

- Strandplains (sand-rich)
- Cheniers
- Tidal flats (mud-rich)

FLUVIAL

WAVE

TIDE
Symmetrical ripples passing landward into asymmetrical ripples, and possibly dunes, often wiped out during storms and replaced by storm-deposited facies such as 'laminated and bioturbated facies'—extent of bioturbation variable, but tends to decrease landwards.

Storm-dominated deposition, unless shelf regime impinges—storm-generated sand beds of laminated (HCS) and bioturbated facies prevail, possibly with mud-silt interbeds deposited during fairweather periods.
Coastal environments

- Waves can be subdivided into **swell waves** that travel long distances, and **sea waves** that are generated more locally.

- Waves that approach a shoreline consisting of unconsolidated sediment will produce a series of environments (oscillatory wave zone, shoaling wave zone, breaker/surf/swash zone) with characteristic bedforms (symmetric ripples – asymmetric ripples or dunes – plane beds).

- **Long-shore currents** and **rip currents** can lead to sediment transport along the shoreline and away from the shoreline respectively, with associated unidirectional bedforms (commonly dunes).
Coastal environments

- **Reflective shorelines** have steep, coarse-grained foreshores and lack breaking waves and associated bars away from the shoreline.

- **Dissipative shorelines** are low-gradient, fine-grained, barred systems where waves may be entirely attenuated.

- Many coasts can alternate from more reflective to more dissipative conditions during fairweather and storm conditions, respectively.

- The high-energy shoreline tends to trap coarse-grained (sandy to gravelly) sediment in what is known as the **littoral energy fence**; escape of sediment to the shelf occurs by means of:
  - River mouth bypassing (floods)
  - Estuary mouth bypassing (ebb currents)
  - Shoreface bypassing (storms)
Swell (summer) profile

Storm (winter) profile

Mean water level

Swell profile shoreline

Storm profile shoreline

Berm

Sea cliff
Coastal environments

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Centre of mass, Earth-Moon system

Tidal bulge

FORCES-
Tide-generating

Centripetal

Gravitational

MOON
Coastal environments

- Tides are formed by the gravitational attraction of the Moon and Sun on the Earth, combined with the centrifugal force caused by movement of the Earth around the center of mass of the Earth-Moon system
  - **Semi-diurnal** or **diurnal tidal cycles** are essentially caused by the Earth’s rotation relative to the Moon
  - **Neap-spring tidal cycles** are mainly caused by the alignment of the Moon and the Sun relative to the Earth
  - **Semi-annual tidal cycles** are driven by the interplay of various cyclicities (including the elliptic orbit of the Moon)

- Tidal currents are modulated by the configuration of oceans and seas, and typically lead to a pattern of circulation; even in small tidal basins flood currents tend to dominate in different areas than ebb currents
OOSTERSCHELDE

HW in cm with respect to MSL

NEAP

SPRING

LW in cm with respect to MSL

DIURNAL INEQUALITY
Coastal environments

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Tidal cycle with equivalent sand/mud depositional sequence

Dominant current

\[ [U(t) - U_{ces}]^3 \]

Subordinate current

Sand transport threshold

Mud transport threshold

Current speed, \( U \)

D

A

B

C

U_{ces}

U_{cdm}

Sand transport
Coastal environments

- Tide-influenced sedimentary structures can take different shapes:
  - **Herringbone cross stratification** indicates bipolar flow directions, but it is rare
  - Mud-draped cross strata are much more common, and are the result of alternating bedform migration during high flow velocities and mud deposition during high or low tide (slackwater)
  - Tidal bundles are characterized by a sand-mud couplet with varying thickness; **tidal bundle sequences** consists of a series of bundles that can be related to neap-spring cycles
  - **Tidal rhytmites** can form in fine-grained facies that aggrade vertically, to a large part from suspension, and consist of commonly very thin (mm-scale), but distinct laminae
(a) Dominant current stage

Megaripple/sand wave migration

(b) First slack water stage

1st mud drape

(c) Subordinate current stage

Reactivation surface

Rippled sand

(d) Second slack water stage

2nd mud drape

Mud depositional episode ('double mud layer') sand depositional episode
Coastal environments

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Coastal environments

- **Beach-ridge strandplains** and **chenier plains** result from coastal progradation in sand- and mud-dominated settings respectively; both are dominantly fed by sediments transported by long-shore currents.

- **Tidal flats** occur in a wide variety of settings (e.g., directly facing the open sea/ocean, in lagoons behind barrier islands, near tidal inlets) and contain a supratidal zone, an intertidal zone, and tidal channels.
  - Tidal channels can be extremely deep and dynamic and are commonly filled with large-scale cross-stratified tidal-bundle sequences and/or laterally accreted heterolithic (sandy and muddy) strata.
  - Intertidal environments include sandy to muddy tidal flats where tidal rhytmites may form, commonly bordered by salt marshes or mangroves where muddy facies or peats accumulate.
Beach ridge complexes defined by discontinuities

V.E. = 200 × Distance (km)
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Directional Features</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Beach placers</td>
<td>Roots at top; Low angle cross-stratification inclined 0-5° NE (seaward); Heavy mineral placers</td>
<td>Beach foreshore deposition by swash</td>
</tr>
<tr>
<td>5</td>
<td>High angle cross-stratification</td>
<td>High angle (15-25°) cross-stratification in trough-shaped sets, formed by currents flowing SE and NW (parallel to shore)</td>
<td>Upper shoreface or surf-zone with scour and deposition by longshore currents</td>
</tr>
<tr>
<td>10</td>
<td>Wave ripples</td>
<td>Wave ripples with crests oriented NW-SE (parallel to shore)</td>
<td>Some burrows in lower part</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Scour surfaces</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Wave ripple crests</td>
<td>Tabular beds with low angle hummocky cross-stratification with indistinct orientation</td>
<td>Lower shoreface Rapid deposition by storm surge and slow deposition with bioturbation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wave ripples with crests oriented parallel to shore</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Abundant burrows</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rare marine fossils</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Siltstone-shale</td>
<td>Siltstone-shale with abundant burrows</td>
<td>Offshore-transition Slow deposition from suspension with bioturbation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marine fossils</td>
<td></td>
</tr>
</tbody>
</table>
1. Mudflat progradation

2. Chenier Reworking

3. Progradation

Vert. exag. = 240
Coastal environments

- **Beach-ridge strandplains** and **chenier plains** result from coastal progradation in sand- and mud-dominated settings respectively; both are dominantly fed by sediments transported by long-shore currents.

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Coastal environments

- **Barrier islands** form in transgressive settings where beach ridges get separated from the mainland by a *lagoon*
  - Lagoons commonly accumulate relatively fine-grained (muddy) facies, especially when tidal range is low
  - Washovers bring sheets of relatively coarse-grained (sandy) facies into the lagoon during storms
  - Tidal inlets vary in number, width, and depth dependent on the tidal range; they are associated with flood-tidal deltas and ebb-tidal deltas

- Barrier island shorelines can exhibit shoreface retreat or in-place drowning; prolonged shoreface regression ultimately leads to filling of the back-barrier lagoon
Stage I – Pleistocene beach-ridge plains (falling relative sea level)

Stage II – Maximum Holocene transgression 5.1 ka
Barrier island/lagoon

Fluvial

Wetlands

Holocene beach ridges
(a) Shoreface retreat

Washover of barrier sands
Advancing shoreface/shelf sand
Storm current erosion
Lagoonal facies
Rising sea level
Pleistocene
Ravinement surface

(b) In-place drowning

New barrier
Shoreface sediments
Drowned barrier
Pleistocene
Rising sea level

SL_3
SL_2
SL_1
Coastal environments

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Facies boundary between estuarine sand body and normal marine sediments

32% salinity

Limit of tidal influence

0.1% salinity

Wave processes

Tidal processes

River processes

Fluvial sediment

(a)

Marine sediment

Marine

Estuary (Pritchard 1967)

River

(b)

ESTUARY

Relative energy (%)

100

50

0

Marine

Outer

Marine processes
(waves & tides)

Central

Mixed-energy

Inner

River currents

River-dominated

50

0

Marine-dominated

Eddy processes

Estuary (Dalrymple) et al. 1992

River

100
- **Estuaries** are transgressed, drowned river valleys where fluvial, tide, and wave processes interact; they are characterized by a net landward movement of sediment in their seaward part.

  - Tide-dominated estuaries contain tidal sand bars at the seaward end, separated from the fluvial zone by relatively fine-grained tidal flats (e.g., salt marshes); fluvial channel deposits exhibit heterolithic characteristics and sometimes tidal-bundle sequences.
  
  - Wave-dominated estuaries have a coastal barrier with a tidal inlet and flood-tidal delta, separated from a bayhead delta by a central basin where fine-grained sediments (muds) accumulate.
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Figura 5.5.—Arriba, secuencias positivas (+) generadas por tormentas en el shoreface. La primera consiste en arena con laminación paralela de régimen de flujo alto, estratificación cruzada debida a megapiles de oscila- ción, laminación cruzada de ripples de oscilación y plisas de lutita que registran sucesivamente el período de máxima energía de la tormenta y su progresiva disminución y, finalmente, el asentamiento de finos tras la tormenta. La segunda muestra una alternancia arena/lutita con secuencias positivas en la arena indicativas de una menor energía del oleaje que la anterior. La tercera consiste en lutita bioturbada y arenas gravales con laminación cruzada, que incluyen microsecuencias positivas, indicadoras de una débil acción del oleaje sobre el fondo durante las tormentas. Abajo, estratificación cruzada «hummocky».

Figura 5.6.—Laminación paralela típica del foreshore (zona de batida). Obsérvese los sets de láminas separados por superficies de discordancia. Arenas de Neurión, Mioceno (Alemania).

Figura 5.7.—Secuencia ideal producida por la migración de un sistema de cresta y surco (ridge and runnel) en el foreshore. La estratificación cruzada de gran escala formada por la migración de la cresta, ajusta hacia tierra, pero las direcciones de corriente en el surco su- lleno apuntan paralelamente a la costa. Igual que las crestas de los ripples de oscilación, las láminas de la parte alta de la secuencia se inclinan hacia el mar. Obsérvese las secuencias positivas (+) de tamaño de grano decreciente a tocho y la espesor de las lá- minas concurren entre las superficies erosivas en la facies de cresta.

Figura 5.8.—Imperfección de la estructura interna de los sedimentos de backshore, integrada por laminación paralela difusa y alguna cruzada, niveles de conchas y de acumulación de minerales pesados y bioturbación producida por animales y raíces de plantas.
Fig. 64 – Perfil teórico de progradación en depósitos marinos poco profundos y litorales.

A. Eolianitas costeras.
C. Berma y cresta de playa; techo con estrat.amiento bipolar perpendicular a la costa de bajo ángulo. Tramo medio a superior entrecruzadas planares al continente. Base: estrat. plana. Textura general gruesa.
D. Estratificación por aposición unimodal al mar. Ondulitas variadas, m de escurrimiento, de resaca, sombras, concentrados de pesados. Bioturbación.
E. Canal costero. Ondulitas con crestas transversales a la línea de costa.
F. Cresta subacuática. Entrecruzados tabulares unimodales hacia la costa (ondas de arena).
G. Barras longitudinales. Entrecruzados en arista unimodales paralelos a la costa. Canales de corriente con aristas orientadas hacia el mar.
H. Barra de rompiente. Estratificación plana; hacia arriba onduladas paralelas al tren de olas; interna gradada.
I. Megaojedras arqueadas. Aristas con interna gradada; unidireccionales a la costa u oblicuas, también bimodales transversales u oblicuas.
L. Limositas con fuerte bioturbación.
M. Barras arenosas de offshore. Intraslastos pelíicos; entrecruzado tabular de gran escala, unidireccional paralelo a la costa (ondas de arena); bioturbación.
N. Limositas y arcillas; laminación gradada; fuerte bioturbación.
O. Arcillas con bioturbación.
Fig. 20. Principales litofacies depositadas en ambientes someros-silicilásticos (modificado de Johnson, 1978, y Boersma, 1975).