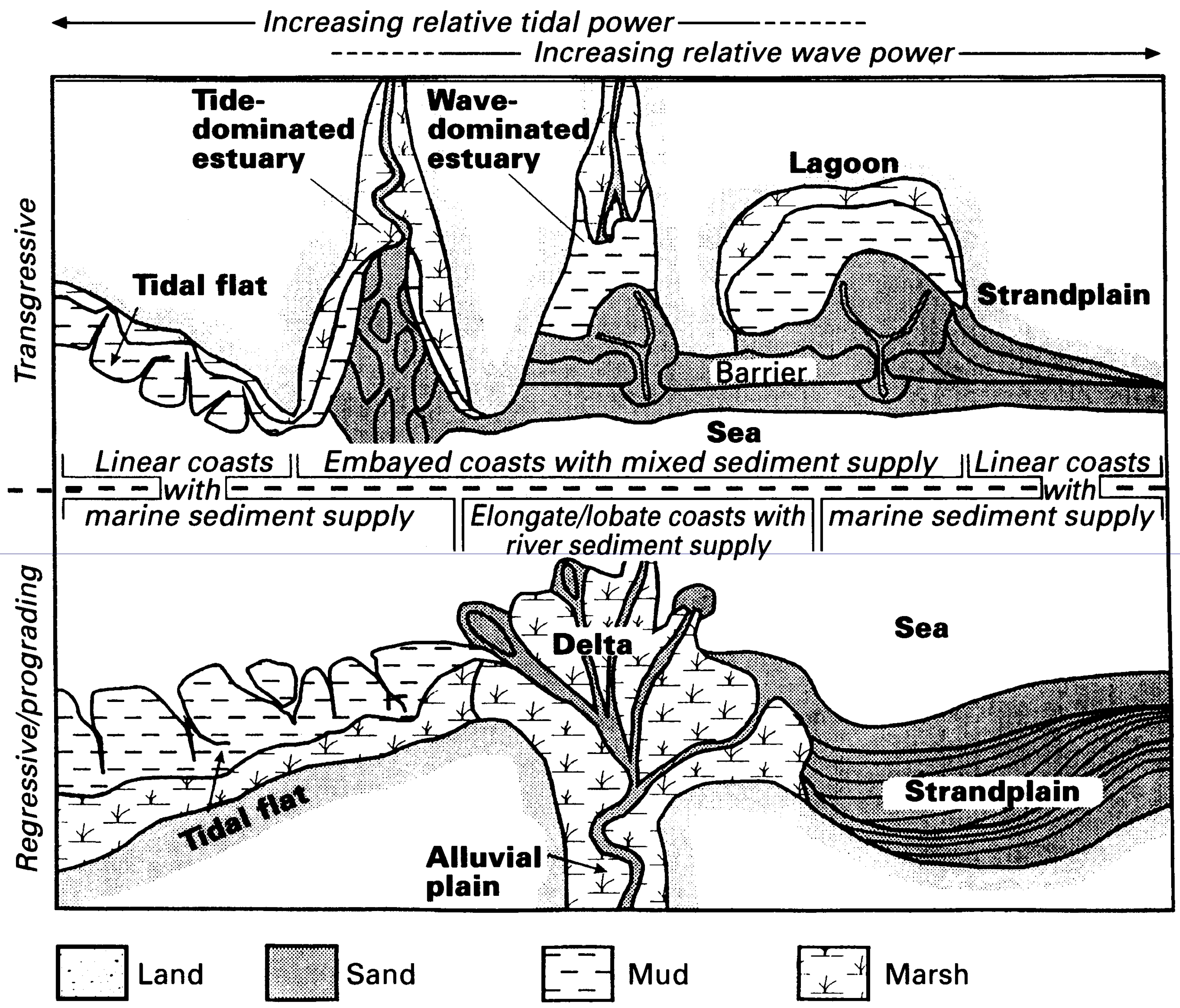
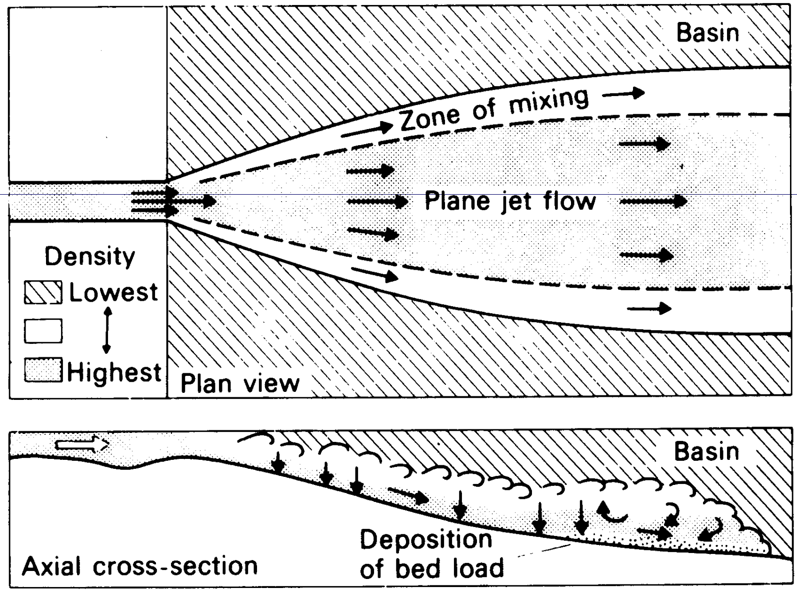
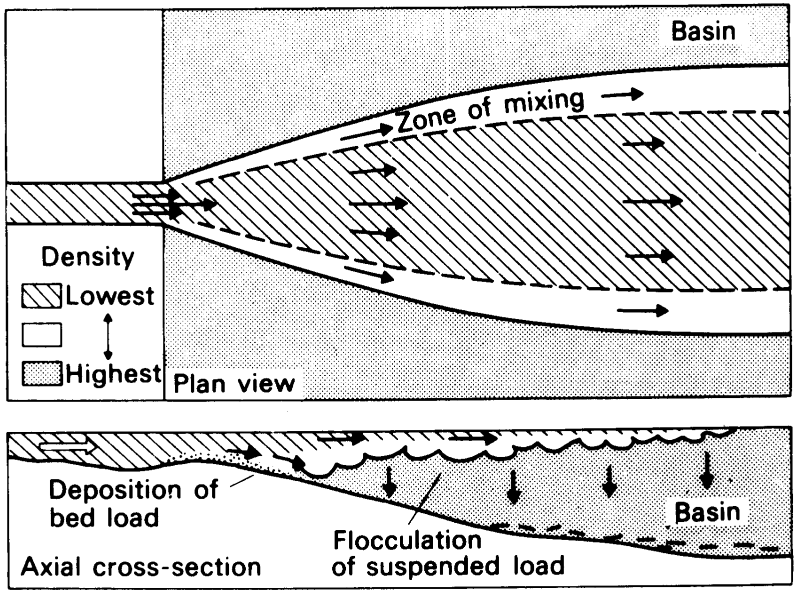
Deltaic environments

- 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


Increasing relative tidal power
Increasing relative wave power
Transgressive
Tide-dominated estuary
Wave-dominated estuary
Lagoon
Tidal flat
Strandplain
Barrier
Sea
Linear coasts with marine sediment supply
Embayed coasts with mixed sediment supply
Linear coasts with marine sediment supply
Elongate/lobate coasts with river sediment supply
Regressive/prograding
Delta
Sea
Tidal flat
Strandplain
Alluvial plain
Land
Sand
Mud
Marsh





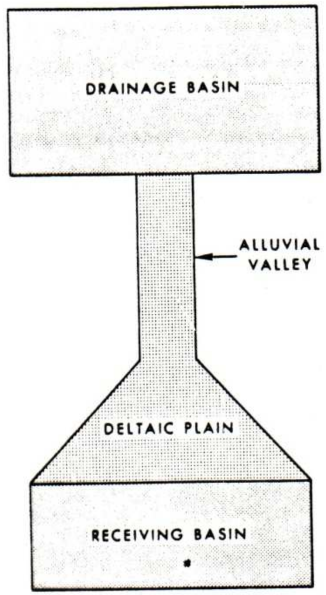


Figure 1 Major components of a river system (from Coleman and Wright, 1971).
in Wright (1978)

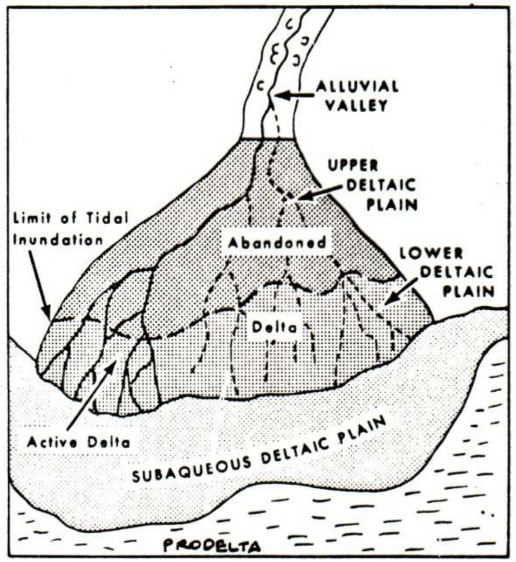
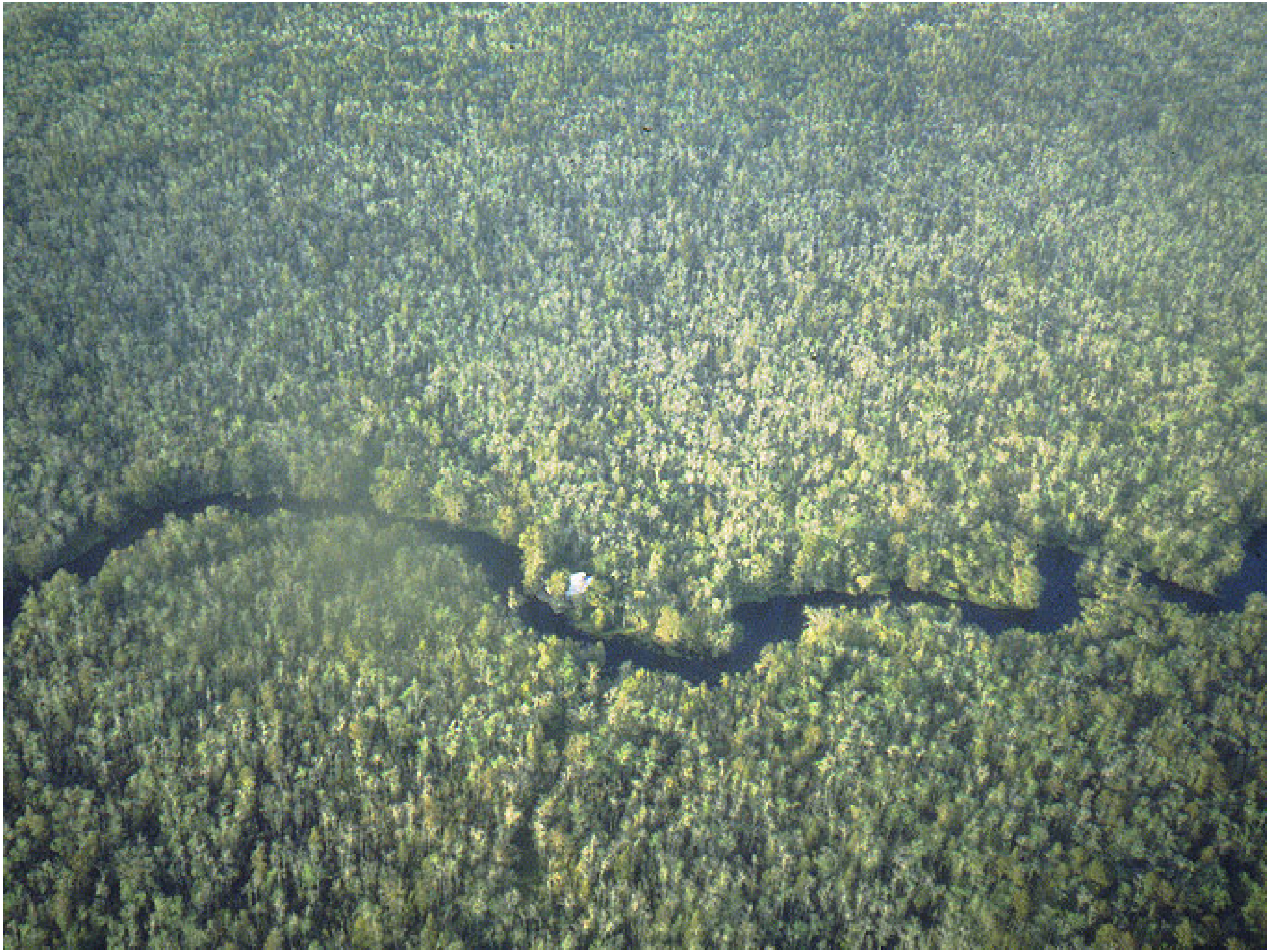


Figure 2 Components of a delta (from Coleman and Wright, 1971).
in Wright (1978)

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)
- 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

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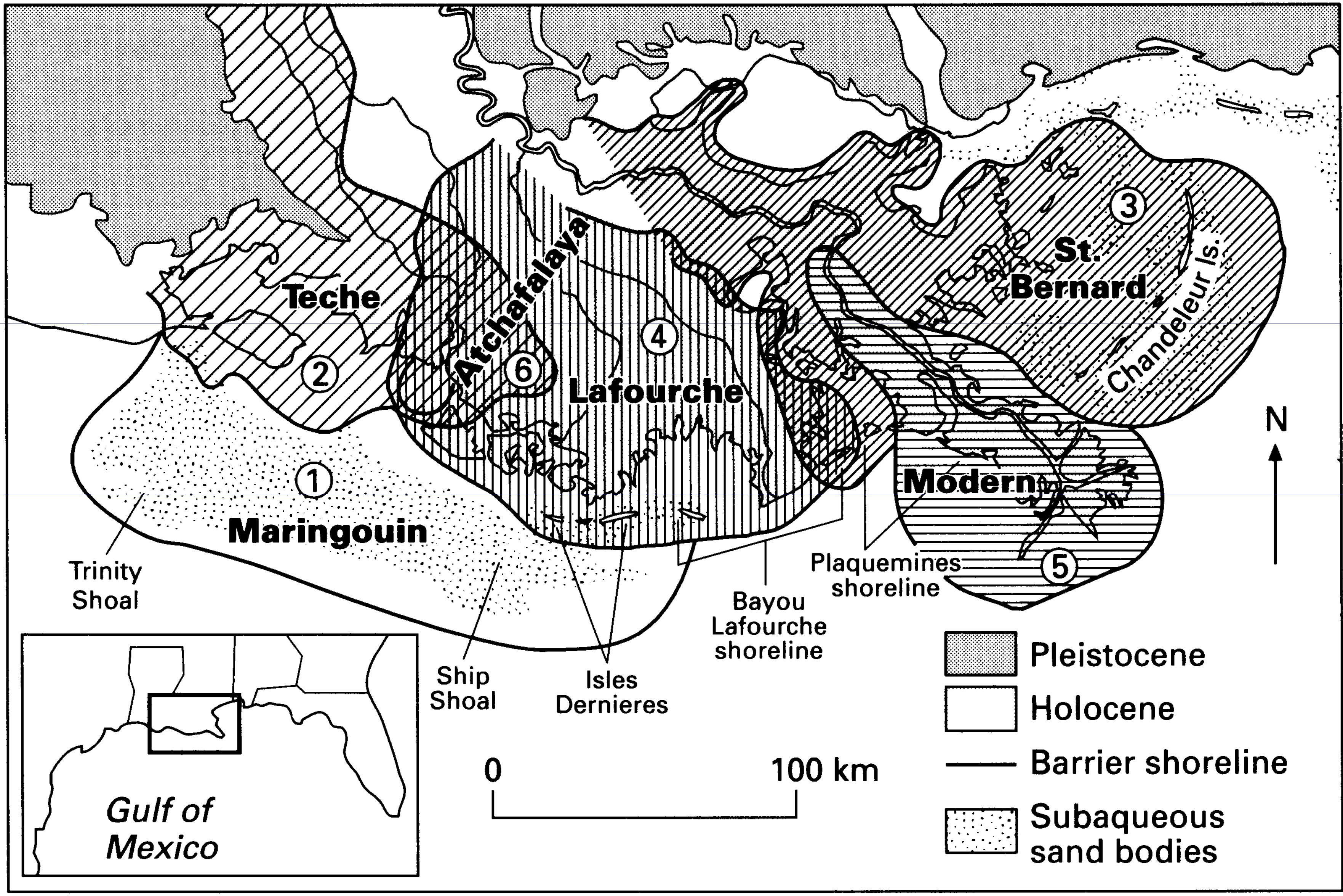
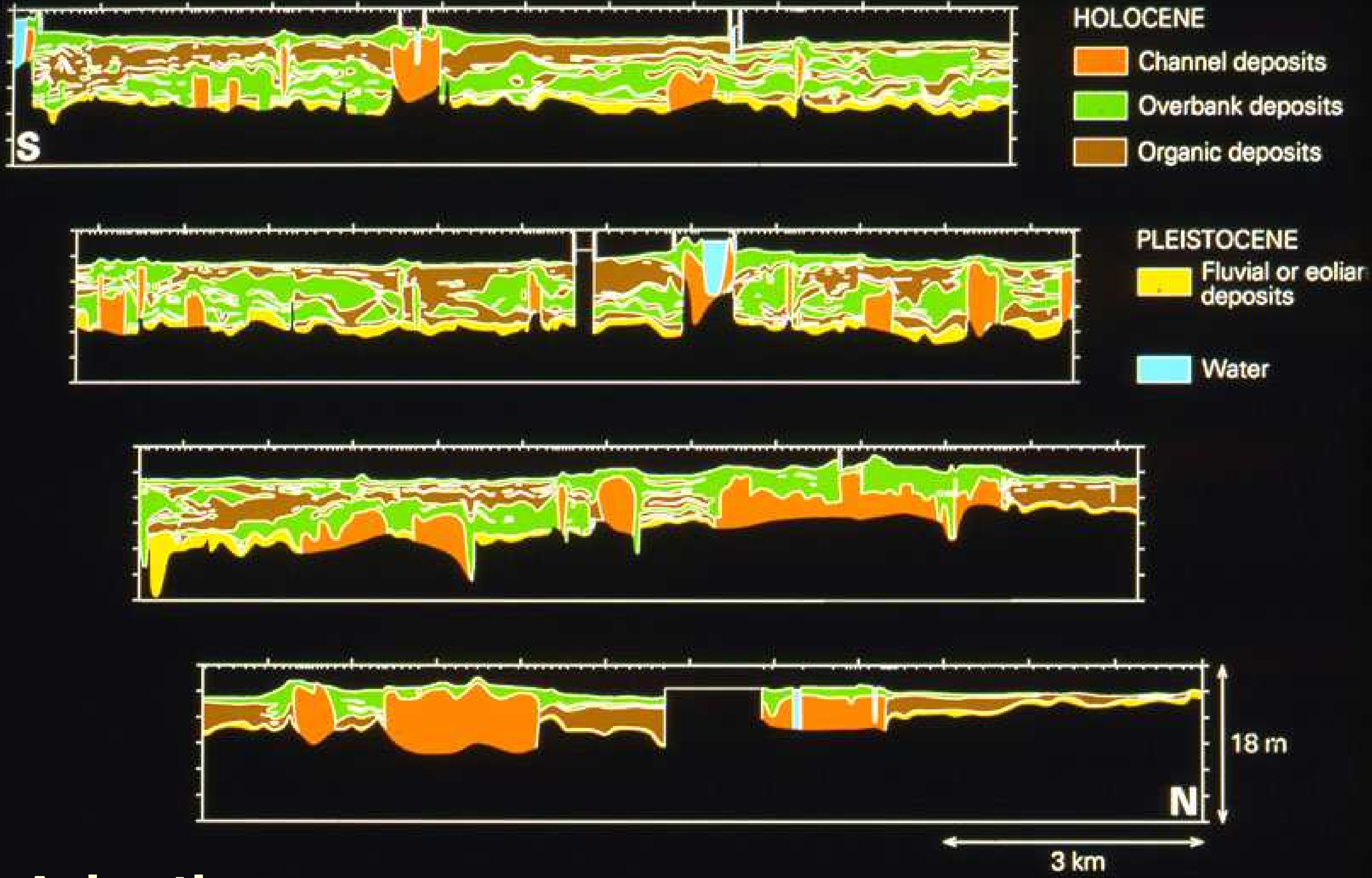
Deltaic environments

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



Teche
2
Atchafalaya
6
4
Lafourche
3
St. Bernard
Chandeleur Is.
1
Maringouin
Modern
5
N
Trinity Shoal
Ship Shoal
Isles Dernieres
Bayou Lafourche shoreline
Plaquemines shoreline
Gulf of Mexico
0
100 km
Pleistocene
Holocene
Barrier shoreline
Subaqueous sand bodies

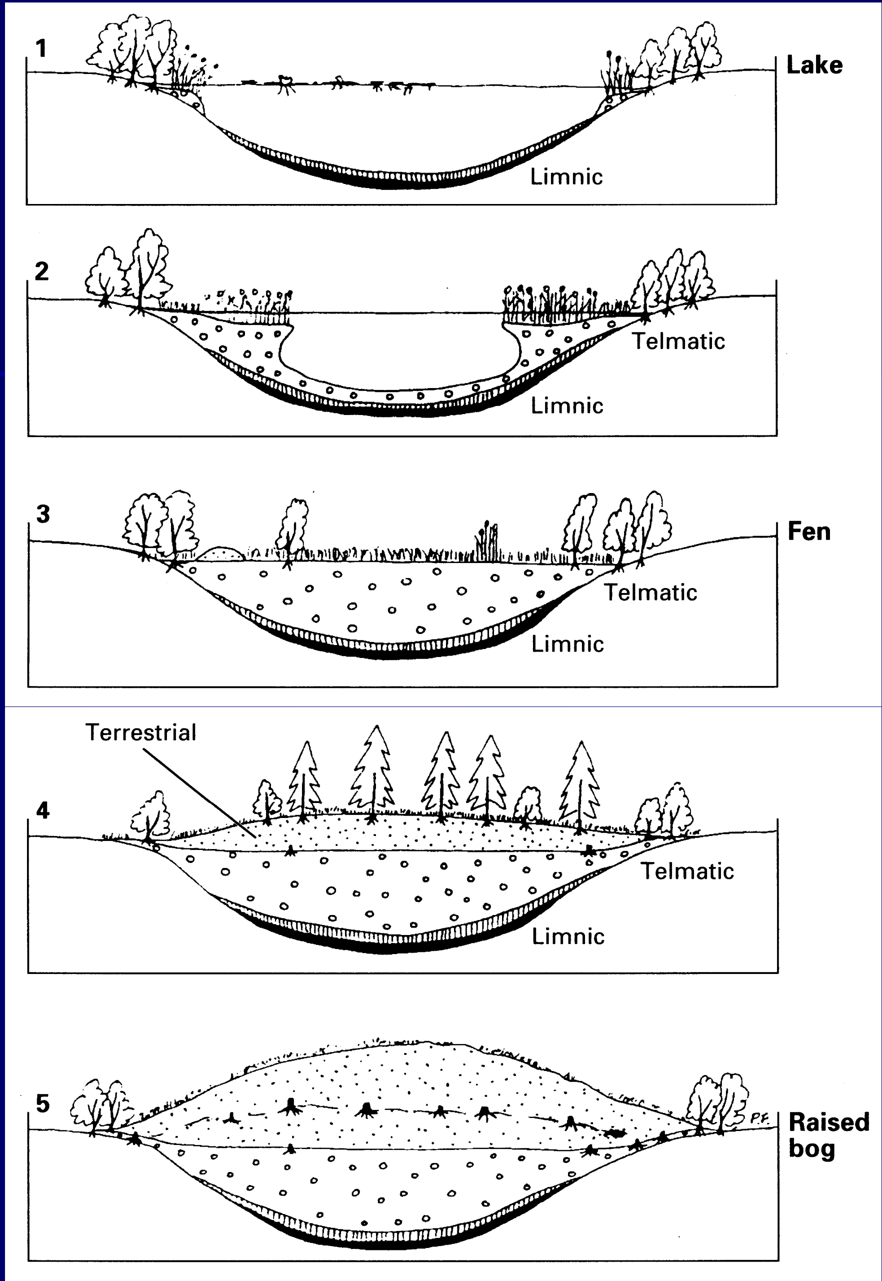

HOLOCENE
Channel deposits
Overbank deposits
Organic deposits
PLEISTOCENE
Fluvial or eoliar deposits
Water
S
N
18 m
3 km

Animation

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


1
Lake
Limnic
2
Telmatic
Limnic
3
Fen
Telmatic
Limnic
Terrestrial
4
Telmatic
Limnic
5
Raised bog

Deltaic environments

Delta plain

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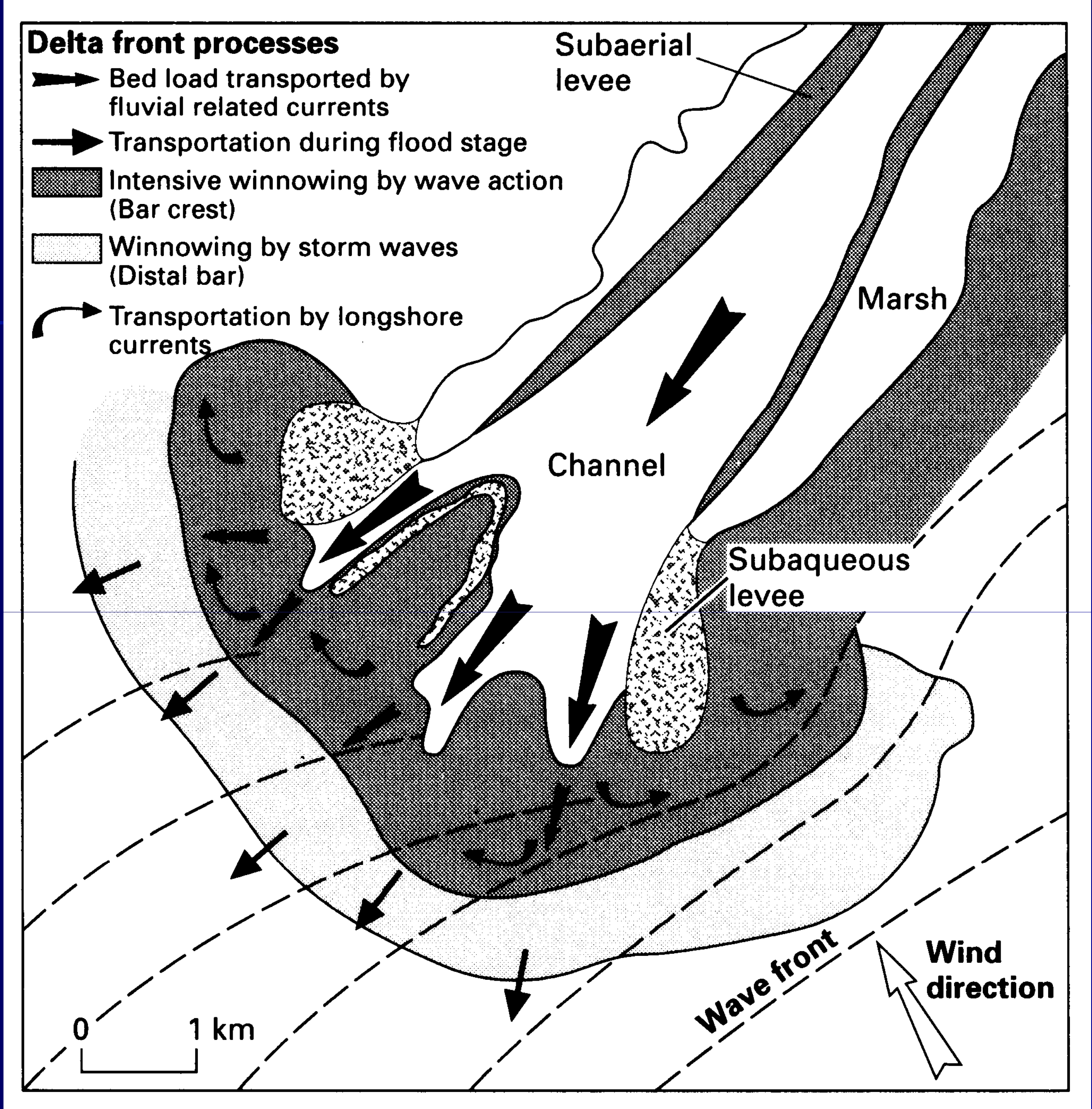
ESTWING

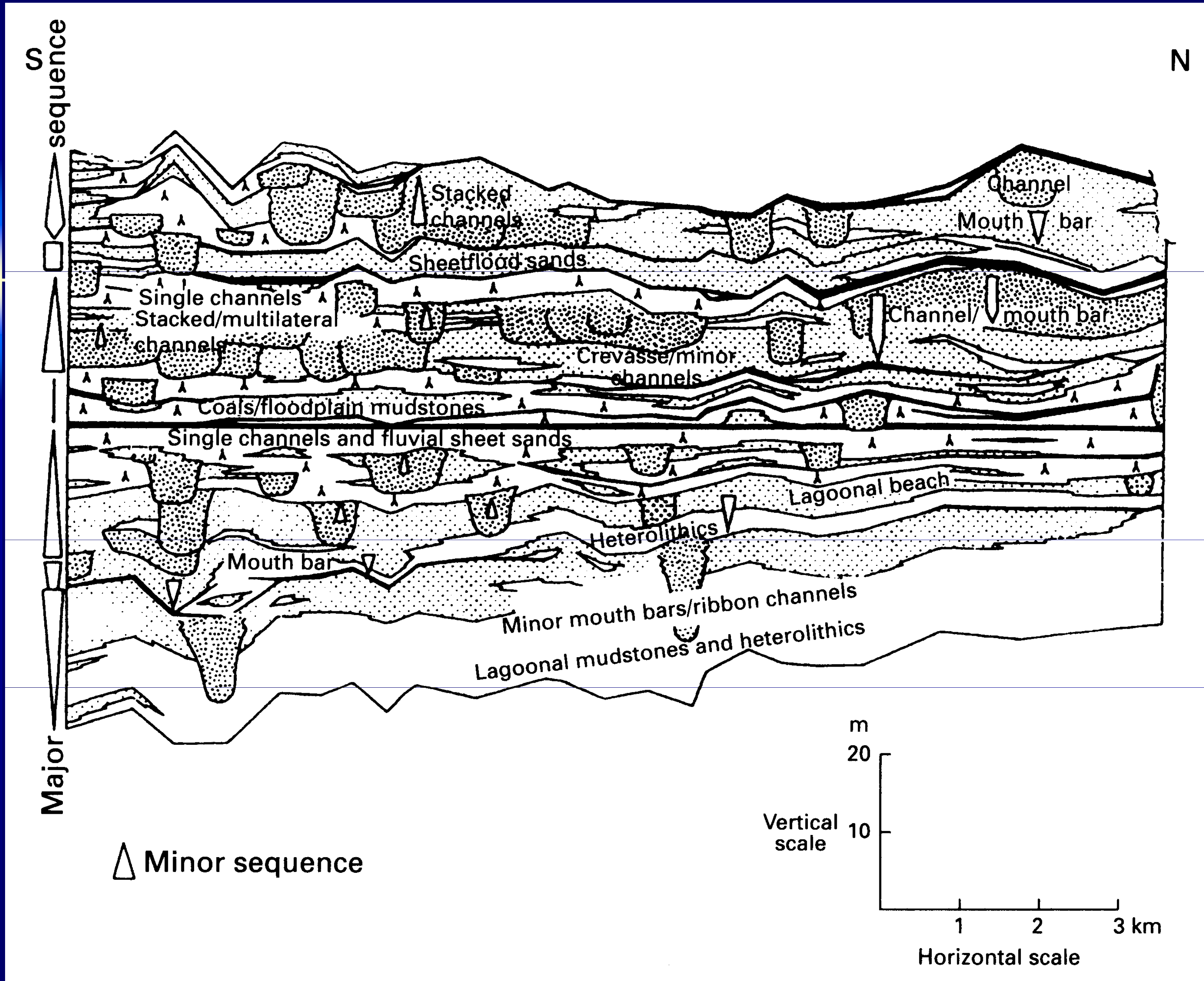


Delta front processes
Bed load transported by fluvial related currents
Transportation during flood stage
Intensive winnowing by wave action (Bar crest)
Winnowing by storm waves (Distal bar)
Transportation by longshore currents
Subaerial levee
Marsh
Channel
Subaqueous levee
Wave front
Wind direction
0
1 km

Deltaic environments

Delta front and prodelta

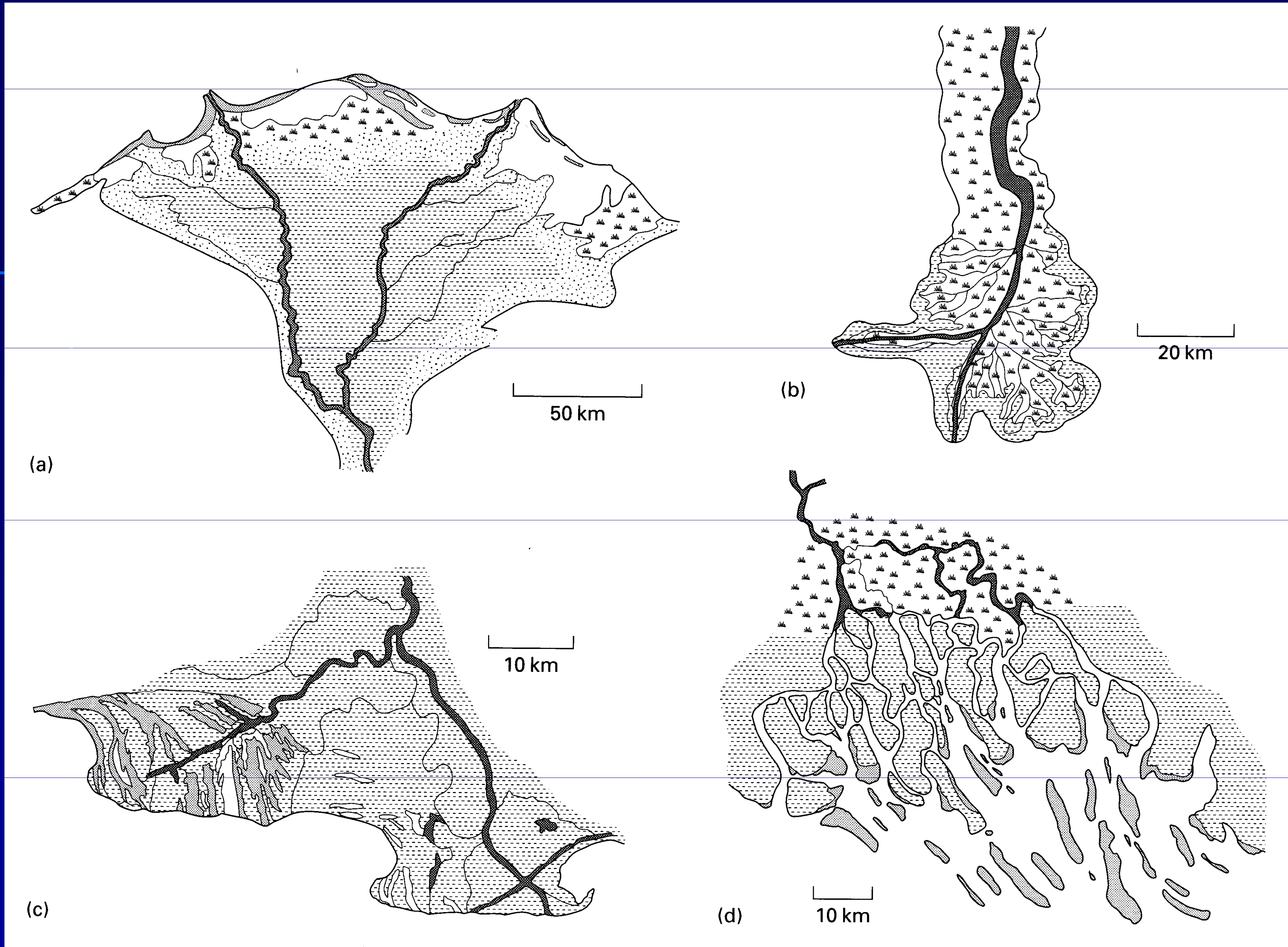
- **Mouth bars** form at the upper edge of the delta front, at the mouth of distributaries (particularly in hypopycnal flows); they are mostly sandy and tend to coarsen upwards
- Wave action can play an important role in winnowing and reworking of mouth-bar deposits; this may lead to merging with prograding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

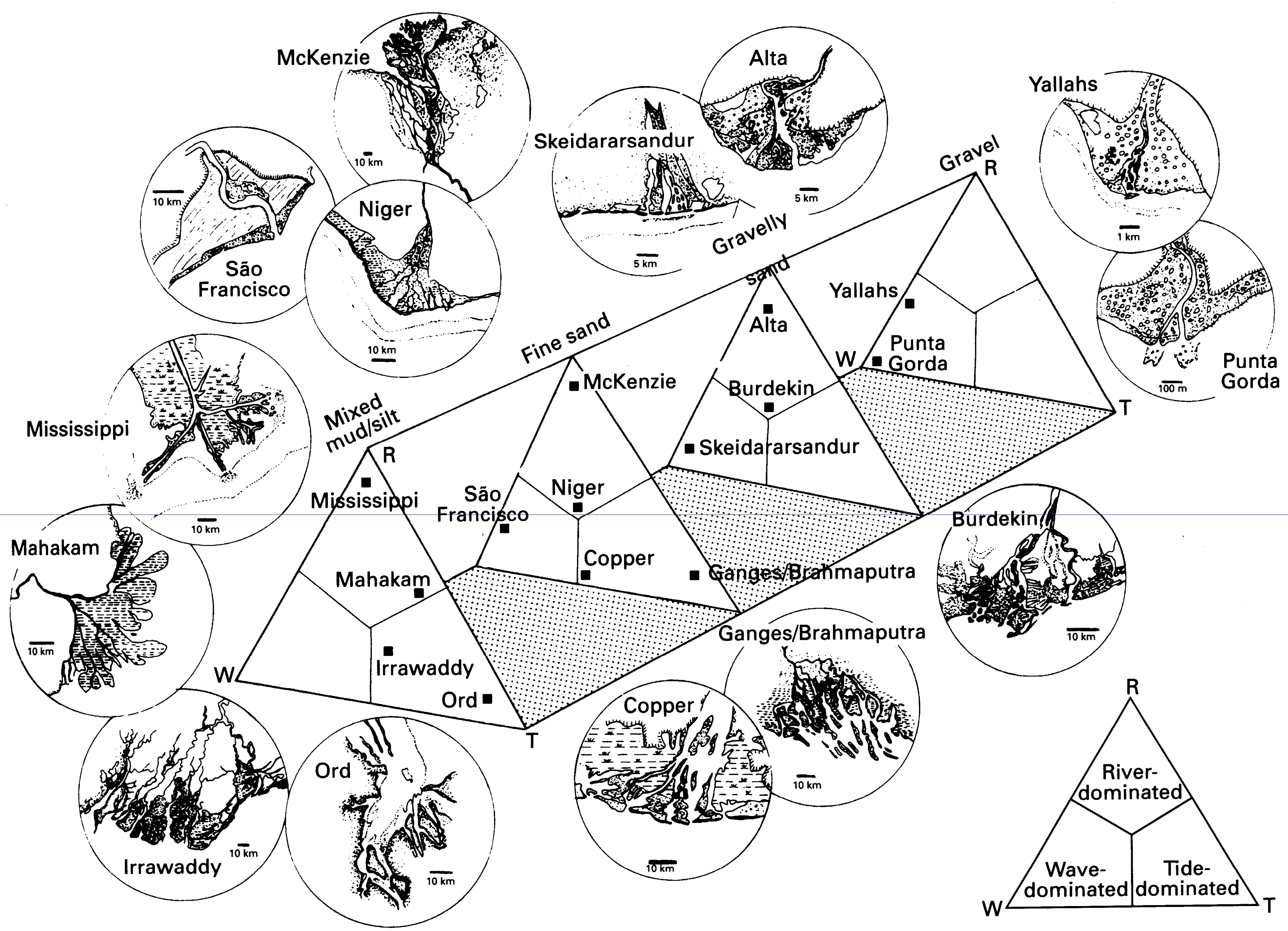


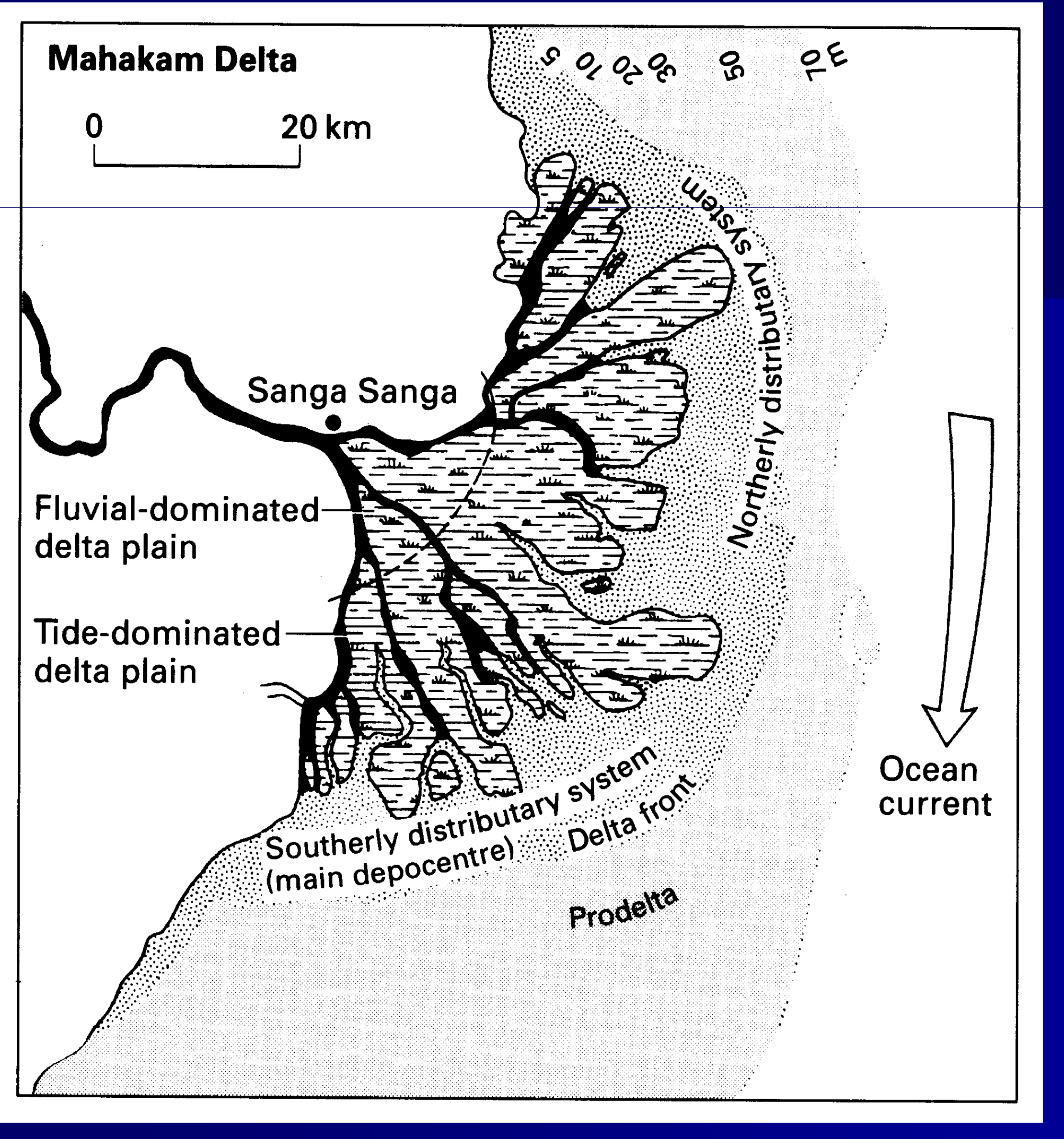
S
N
Major sequence
Stacked channels
Channel
Mouth bar
Sheetflood sands
Single channels
Stacked/multilateral channels
Channel/ mouth bar
Crevasse/minor channels
Coals/floodplain mudstones
Single channels and fluvial sheet sands
Lagoonal beach
Heterolithics
Mouth bar
Minor mouth bars/ribbon channels
Lagoonal mudstones and heterolithics
Minor sequence
m
20
10
Vertical scale
1
2
3 km
Horizontal scale

Deltaic environments

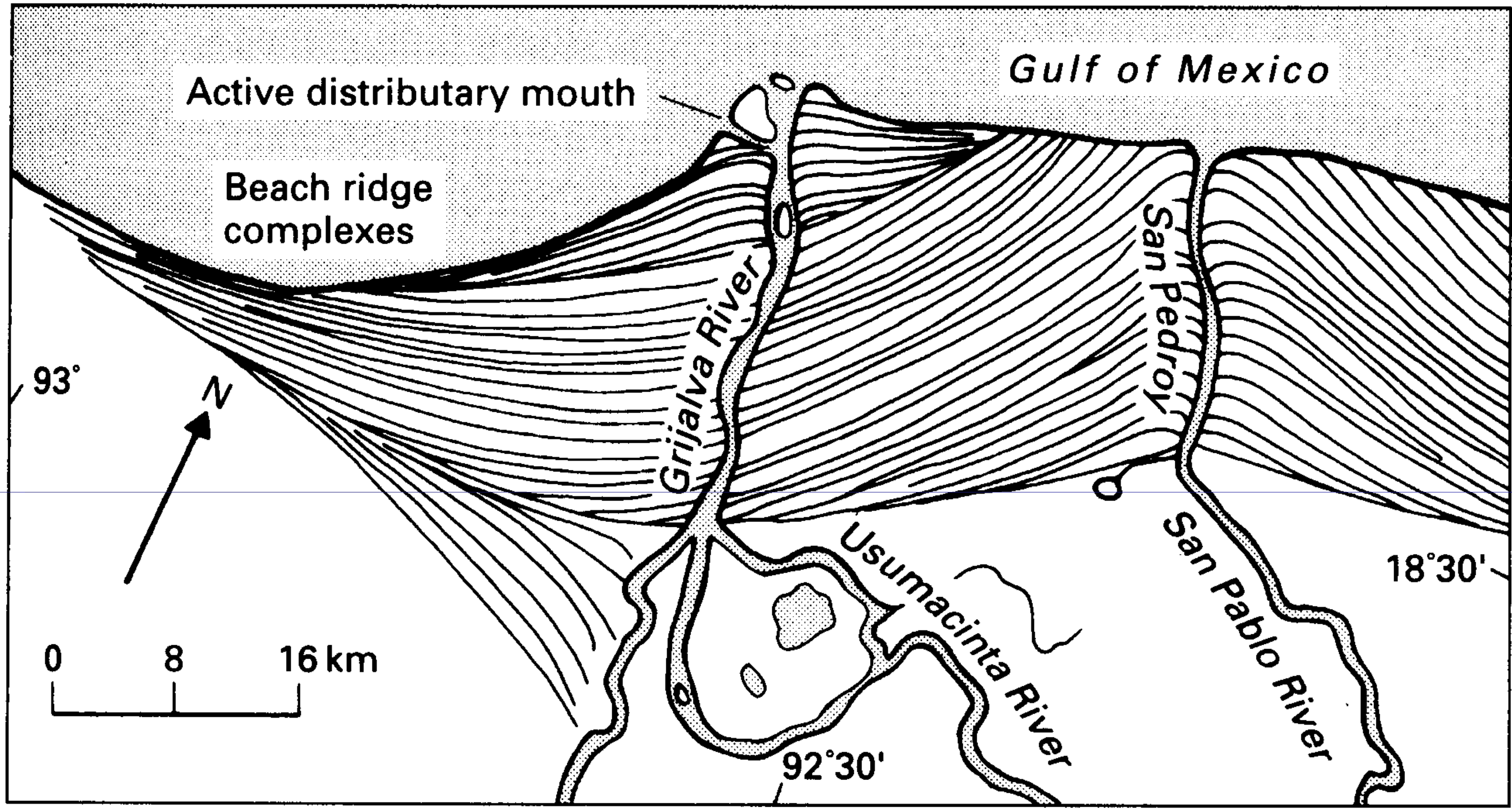
- Delta morphology reflects the relative importance of fluvial, tidal, and wave processes, as well as gradient and sediment supply
  - **River-dominated deltas** occur in microtidal settings with limited wave energy, where delta-lobe progradation is significant and redistribution of mouth bars is limited
  - **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


50 km
(a)
20 km
(b)
10 km
(c)
(d)
10 km

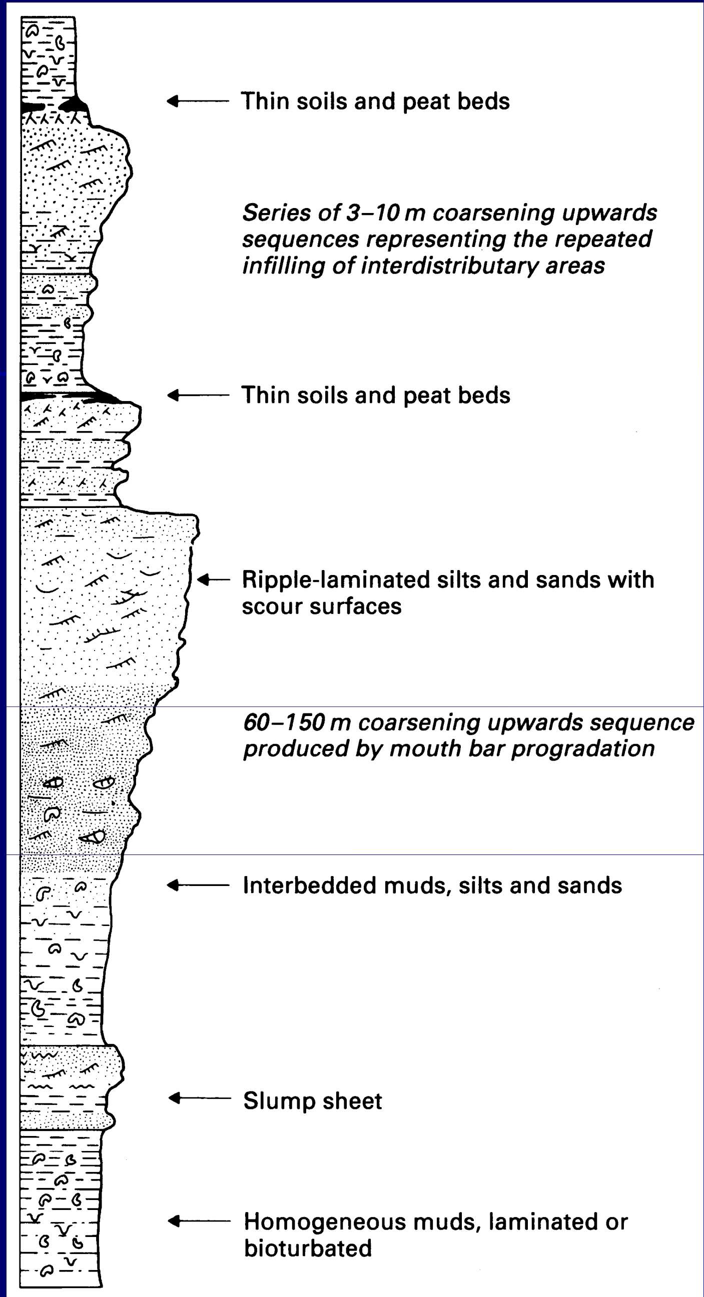

McKenzie
Alta
Yallahs
Skeidararsandur
Gravel
R
10 km
5 km
10 km
Niger
1 km
Gravelly
São
Francisco
5 km
sand
Yallahs
Alta
10 km
Fine sand
Punta
Gorda
W
Punta
Gorda
100 m
McKenzie
Burdekin
Mixed
mud/silt
Mississippi
T
Skeidararsandur
R
Mississippi
São
Francisco
Niger
Burdekin
10 km
Mahakam
Copper
Ganges/Brahmaputra
Mahakam
Ganges/Brahmaputra
10 km
10 km
Irrawaddy
W
Ord
R
Copper
T
Ord
10 km
River-
dominated
10 km
10 km
Irrawaddy
Wave-
dominated
Tide-
dominated
W
T



Mahakam Delta
0
20 km
5
10
20
30
50
70 m
Sanga Sanga
Northerly distributary system
Fluvial-dominated delta plain
Tide-dominated delta plain
Ocean current
Southerly distributary system (main depocentre)
Delta front
Prodelta



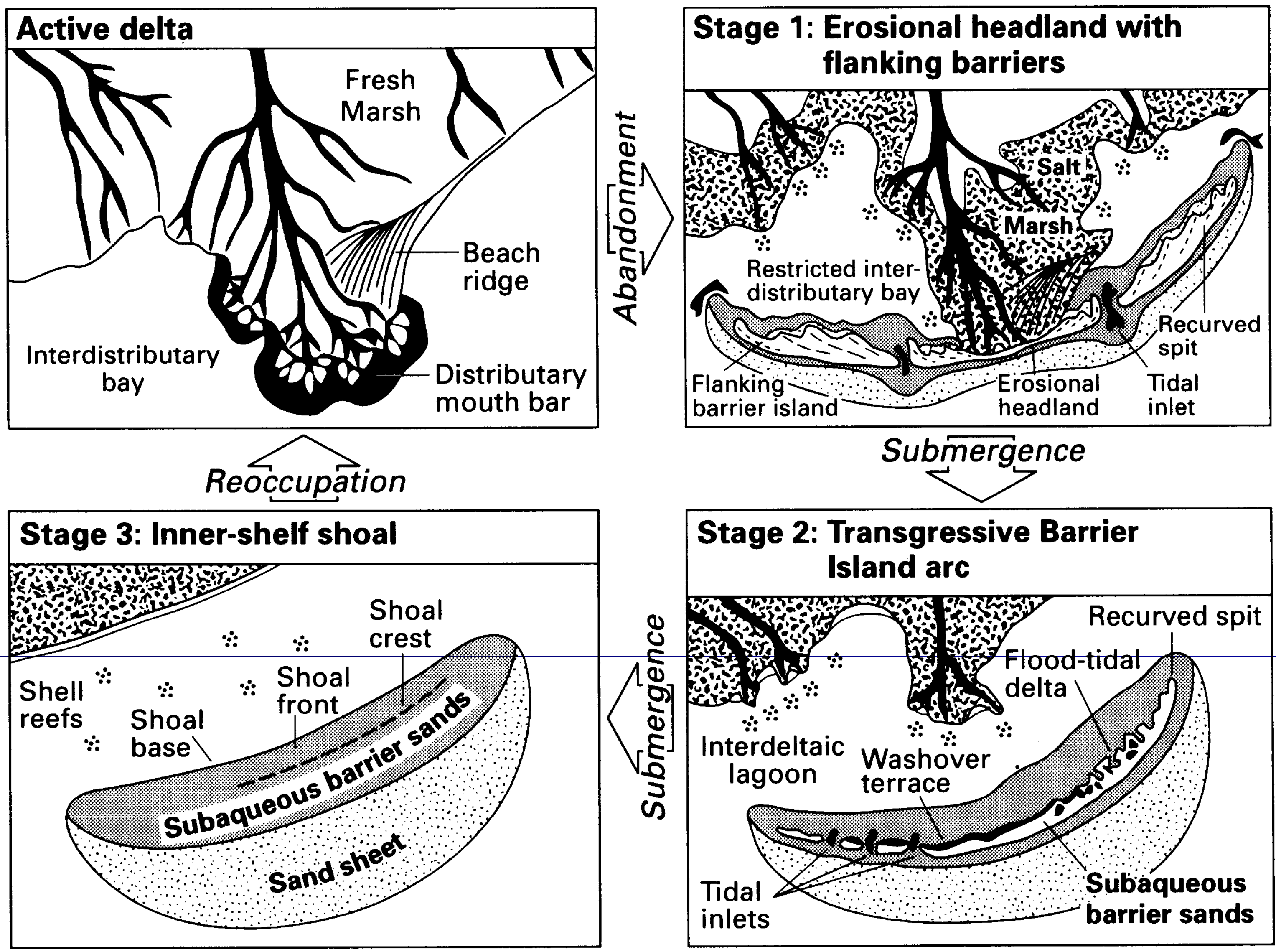
Gulf of Mexico
Active distributary mouth
Beach ridge complexes
Grijalva River
San Pedro y
San Pablo River
Usumacinta River
93°
N
0
8
16 km
92°30'
18°30'


Thin soils and peat beds
Series of 3–10 m coarsening upwards sequences representing the repeated infilling of interdistributary areas
Thin soils and peat beds
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



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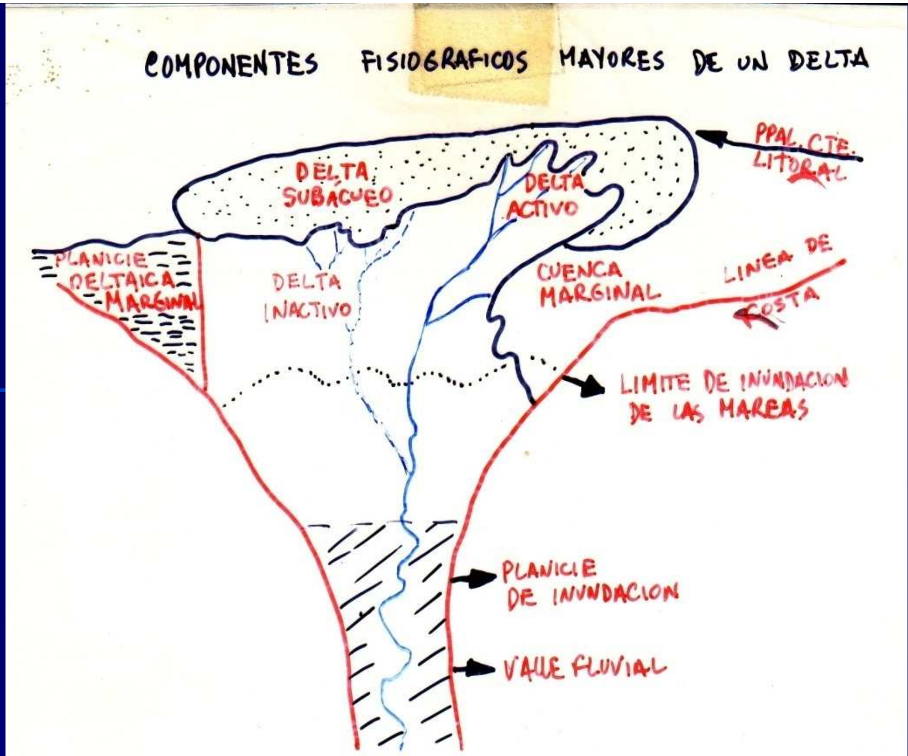
Deltaic environments

- 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



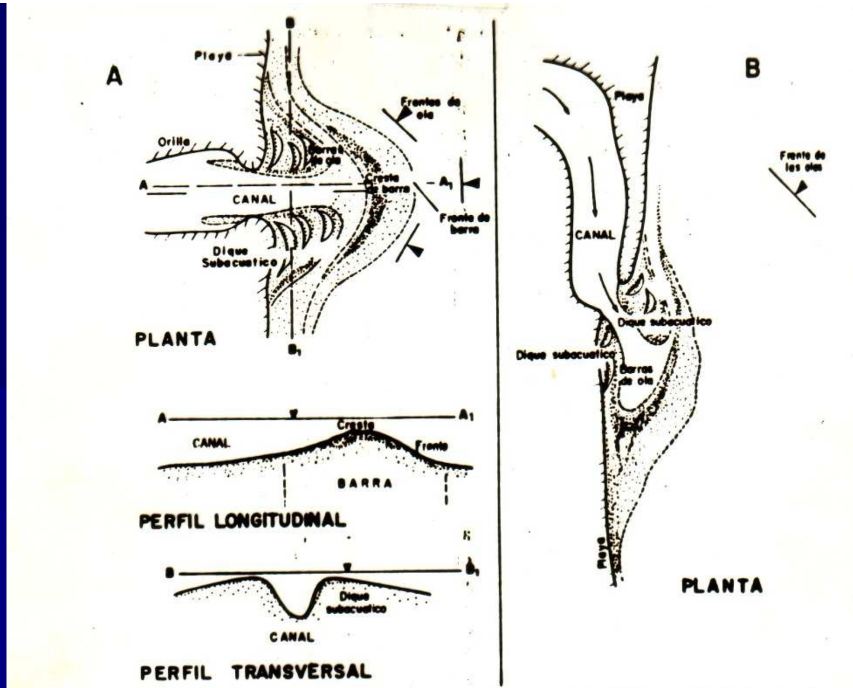


Fig. 12. Sedimentación teórica en la desembocadura de un río dominada por las olas: A, olas paralelas a la costa; B, olas oblicuas a la costa (según Wright, 1977).

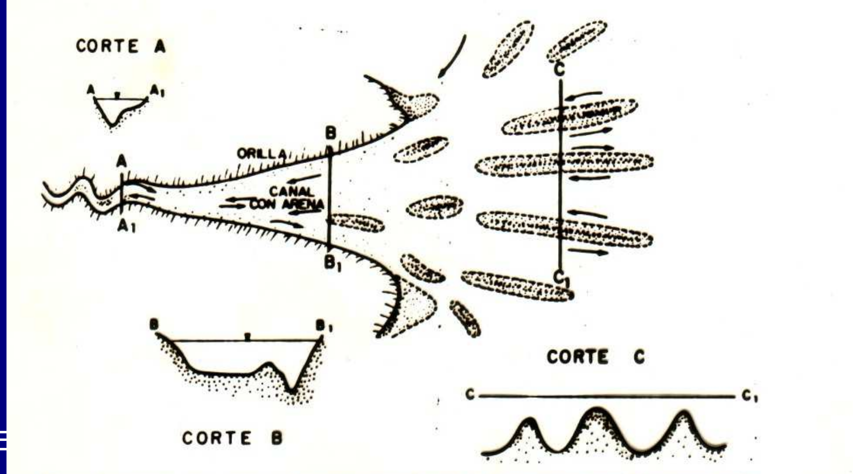


Fig. 13. Sedimentación teórica en la desembocadura de un río dominada por las mareas (según Wright, 1977).

EaE

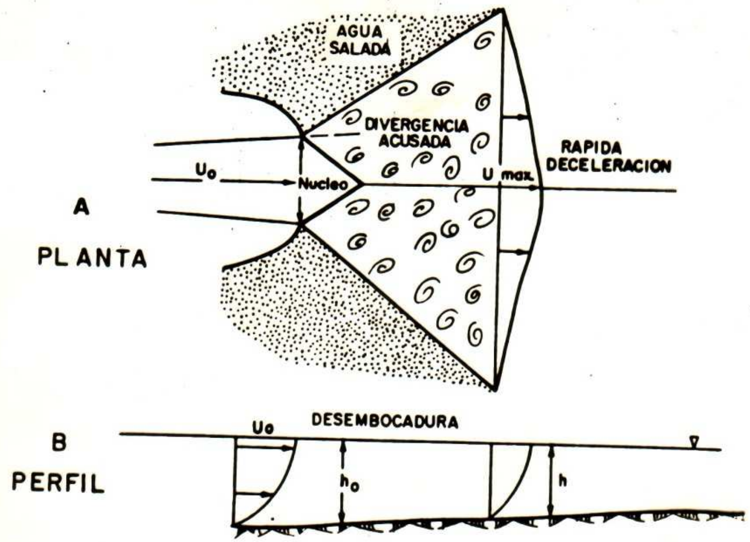


Fig. 7. Difusión y deceleración de un efluyente dominado por la fricción (flujo hiperpícnico) (según Wright, 1977).

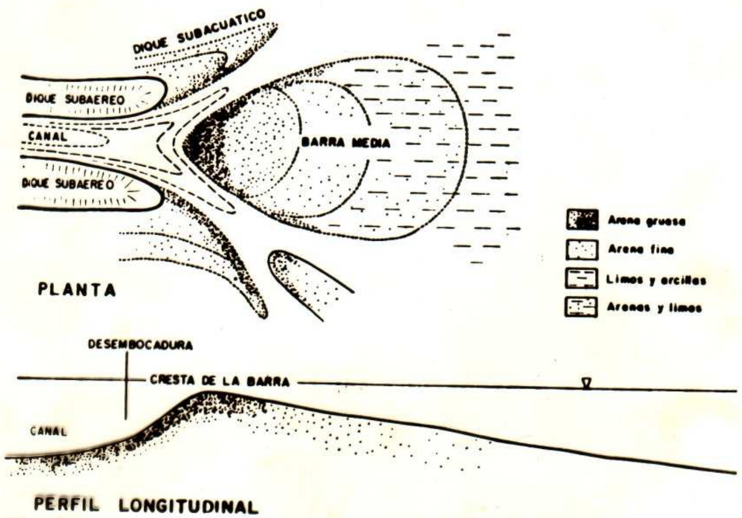


Fig. 8. Sedimentación teórica en la boca de un efluyente dominado por la fricción (según Wright, 1977).

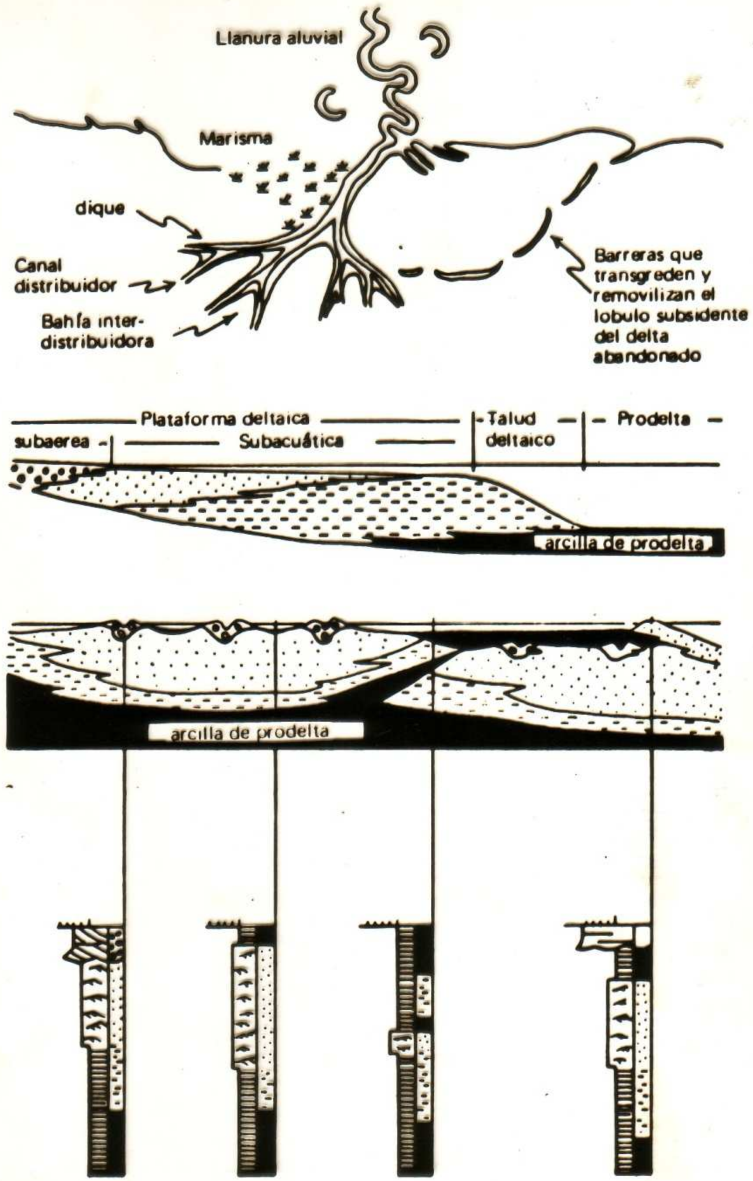


Figura 5.1. Ilustración de la geomorfología y facies sedimentarias de un delta actual. Adviértase la complejidad de secciones verticales que pueden resultar.

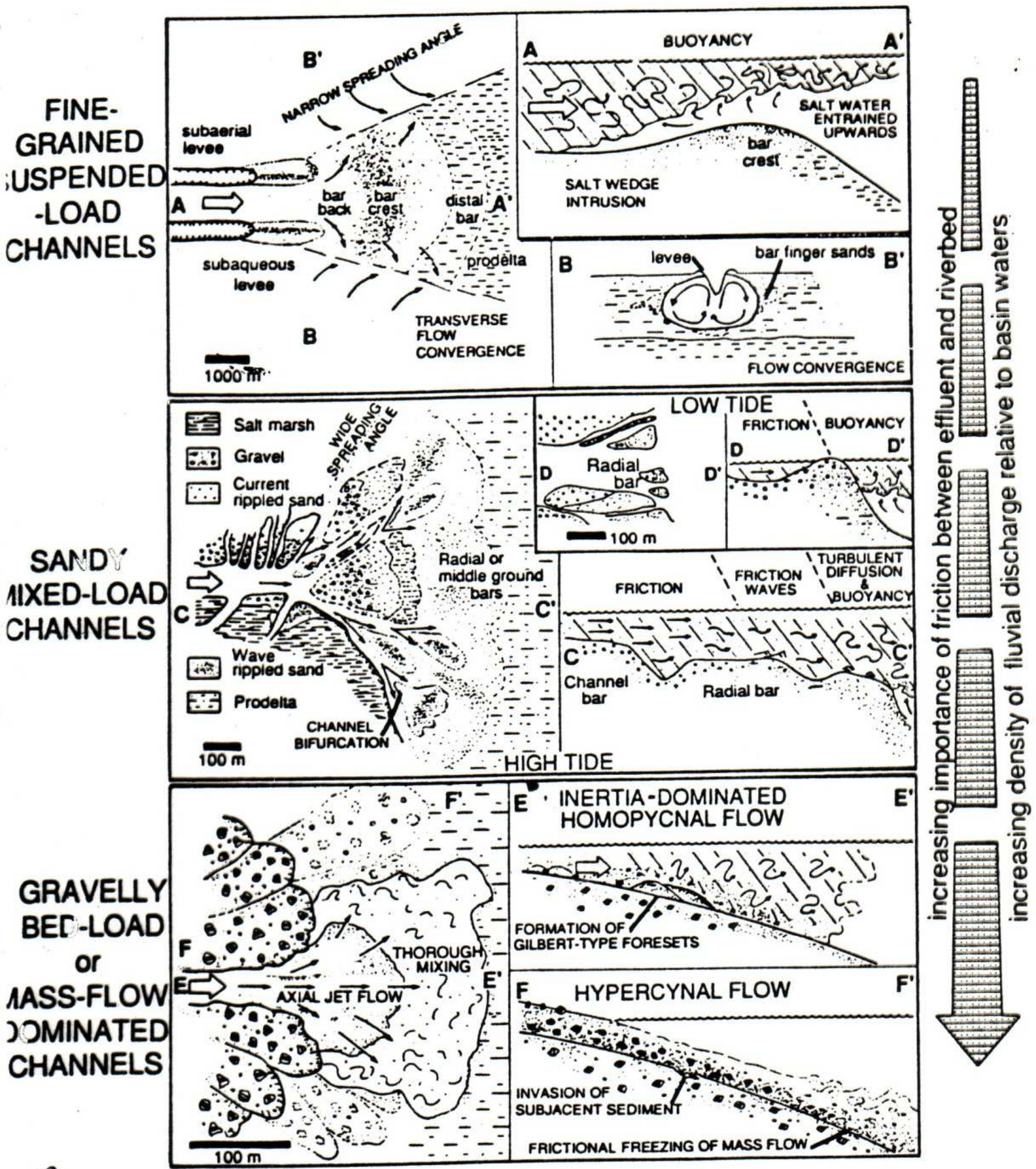
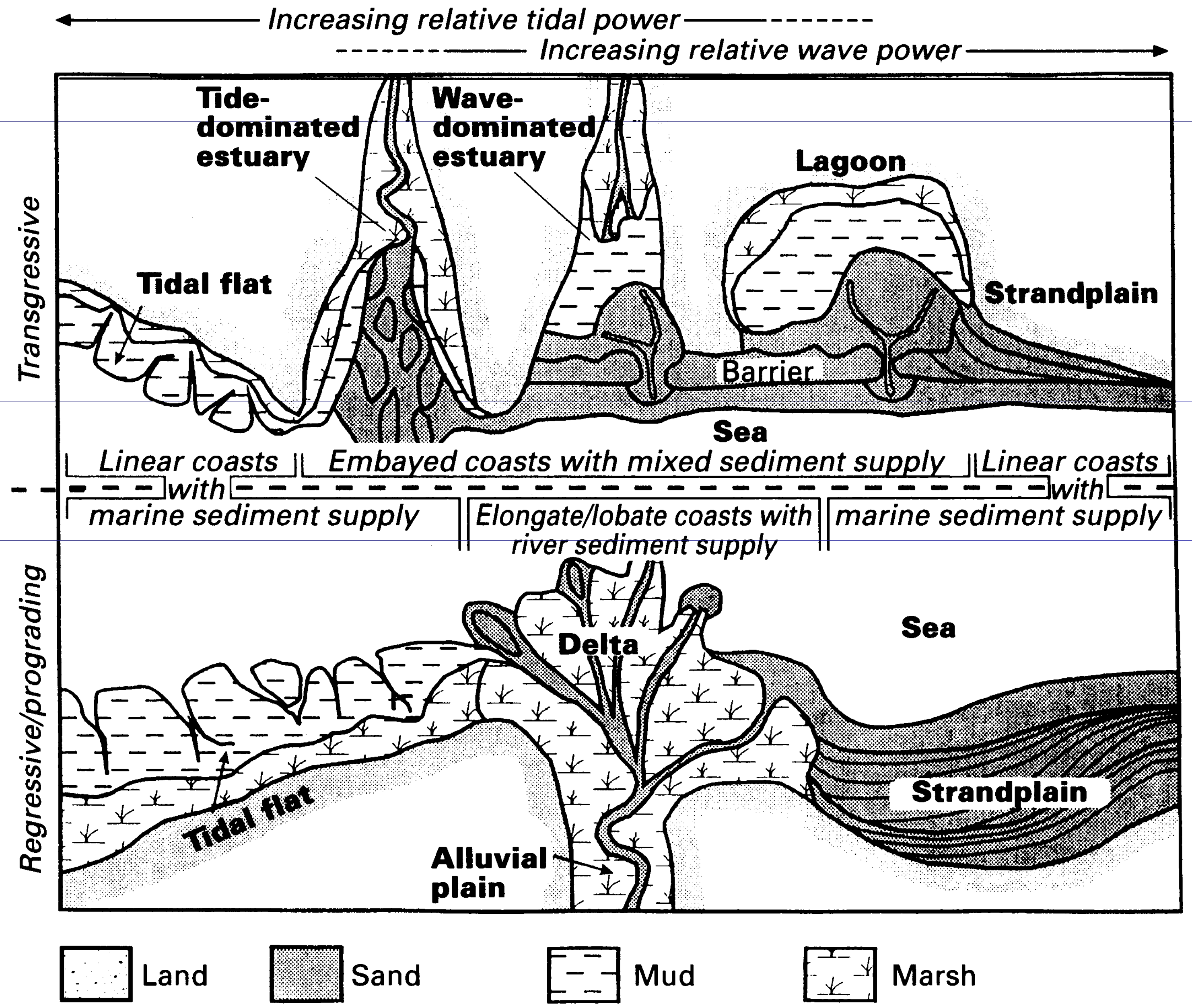


Fig. 12 Control of grain size on mixing behaviour at the river mouth. Suspended- and mixed load examples based on the Mississippi (Wright, 1977) and Bella Coola rivers (Kostaschuk, 1985), respectively. Gravelly river mouth is hypothetical. Note different horizontal scales.


PLAYAS,
ISLAS
BARRERAS –
LAGOON,
ESTUARIOS

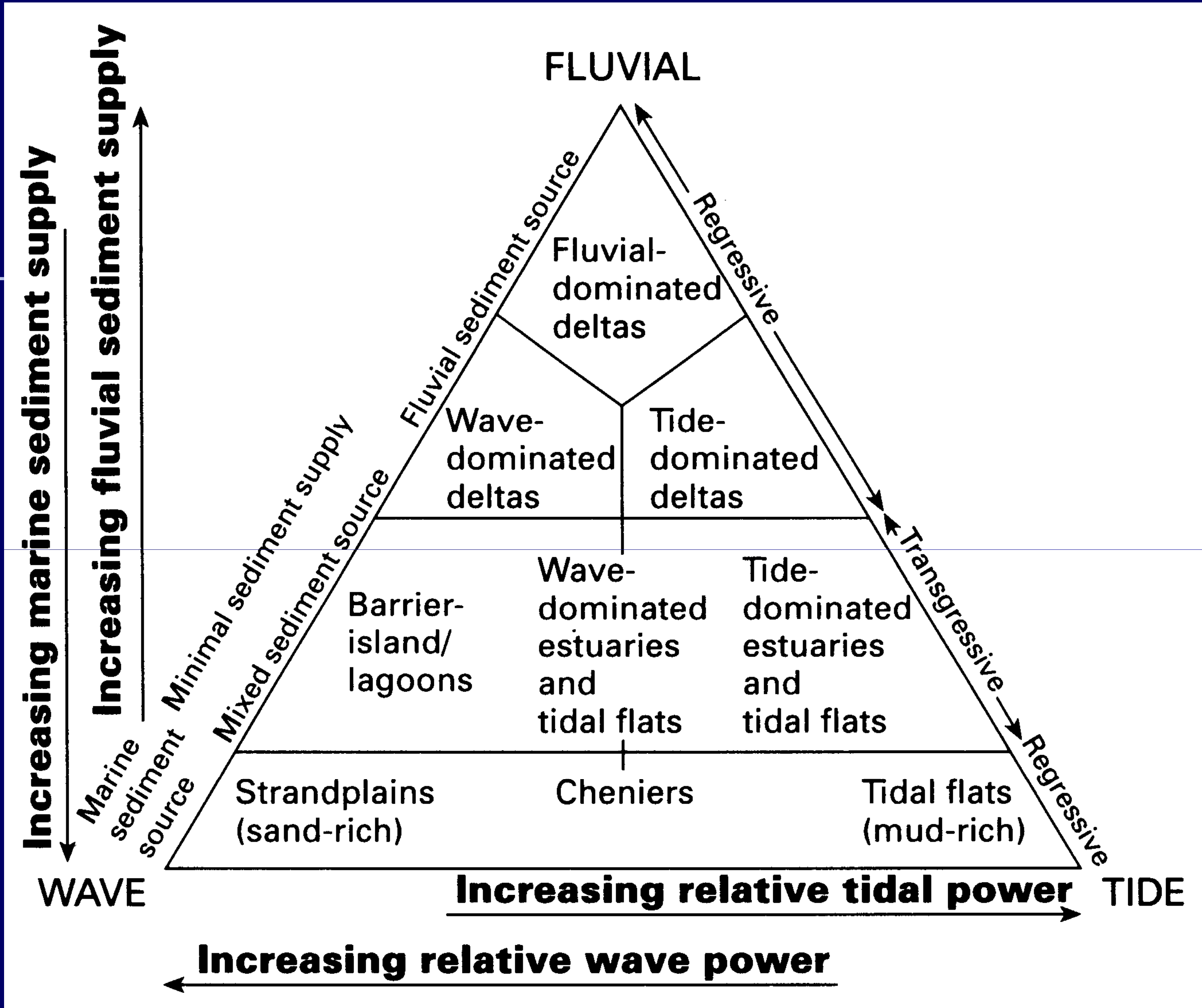


Increasing relative tidal power
Increasing relative wave power
Transgressive
Tide-dominated estuary
Wave-dominated estuary
Lagoon
Tidal flat
Strandplain
Barrier
Sea
Linear coasts with marine sediment supply
Embayed coasts with mixed sediment supply
Linear coasts with marine sediment supply
Elongate/lobate coasts with river sediment supply
Regressive/prograding
Delta
Sea
Strandplain
Tidal flat
Alluvial plain
Land
Sand
Mud
Marsh

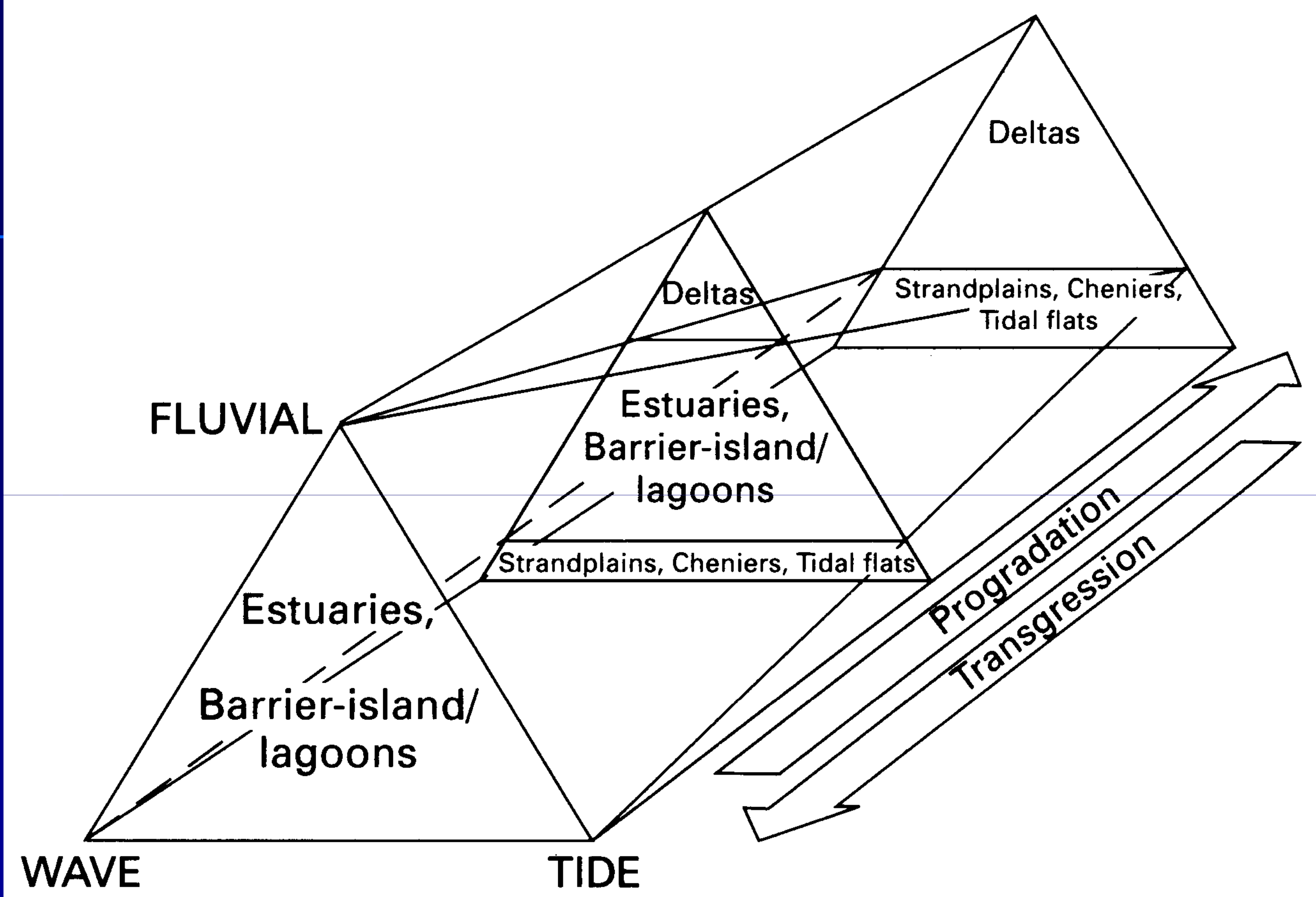
Coastal environments

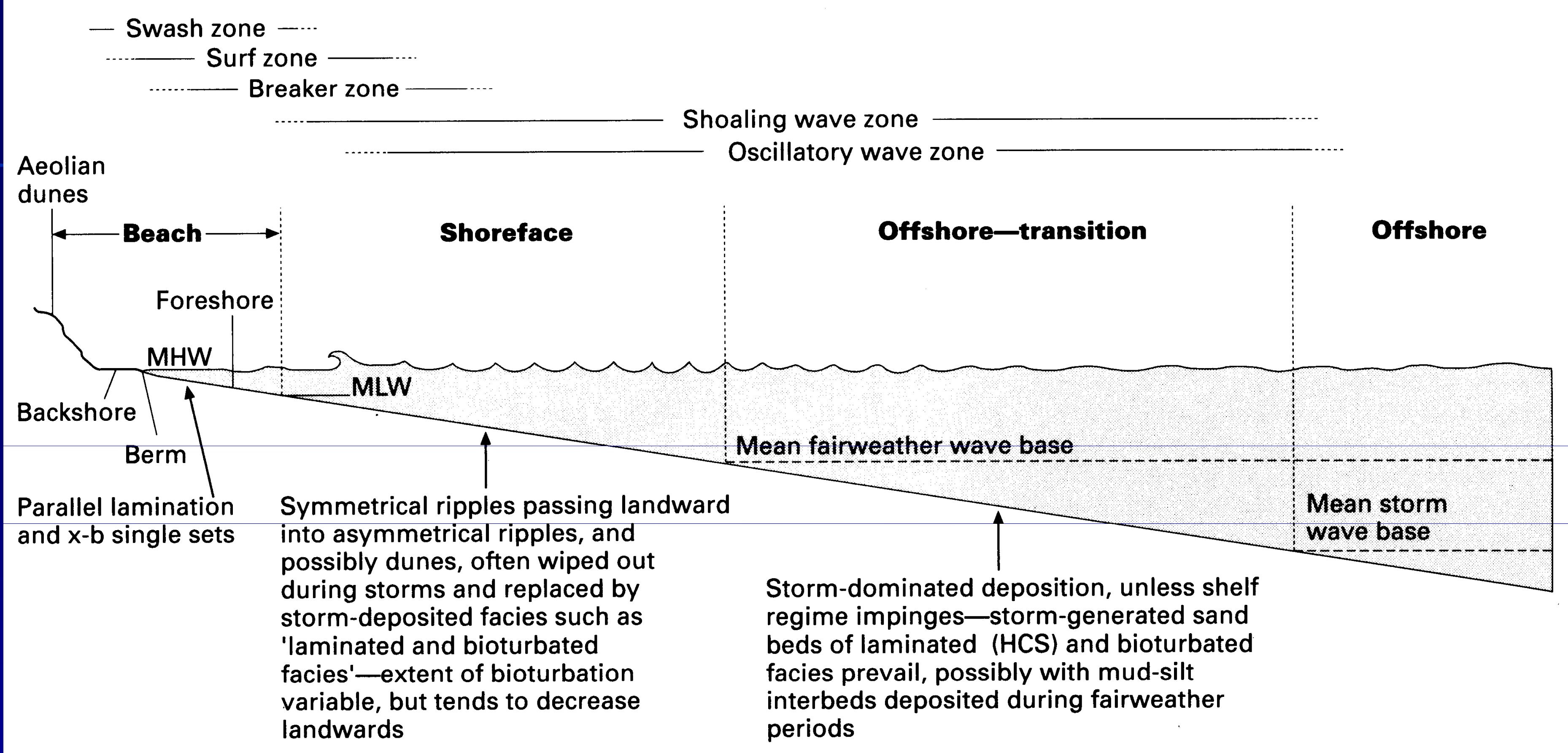
- The classification of deltas can be extended to include those depositional coastal environments that are in large part fed by marine sediments
  - Wave-dominated shorelines
  - Tide-dominated shorelines

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



FLUVIAL
Fluvial-dominated deltas
Wave-dominated deltas
Tide-dominated deltas
Barrier-island/ lagoons
Wave-dominated estuaries and tidal flats
Tide-dominated estuaries and tidal flats
Strandplains (sand-rich)
Cheniers
Tidal flats (mud-rich)
Fluvial sediment source
Minimal sediment supply
Mixed sediment source
Marine sediment source
Regressive
Transgressive
Regressive
Increasing marine sediment supply
Increasing fluvial sediment supply
WAVE
TIDE
Increasing relative tidal power
Increasing relative wave power

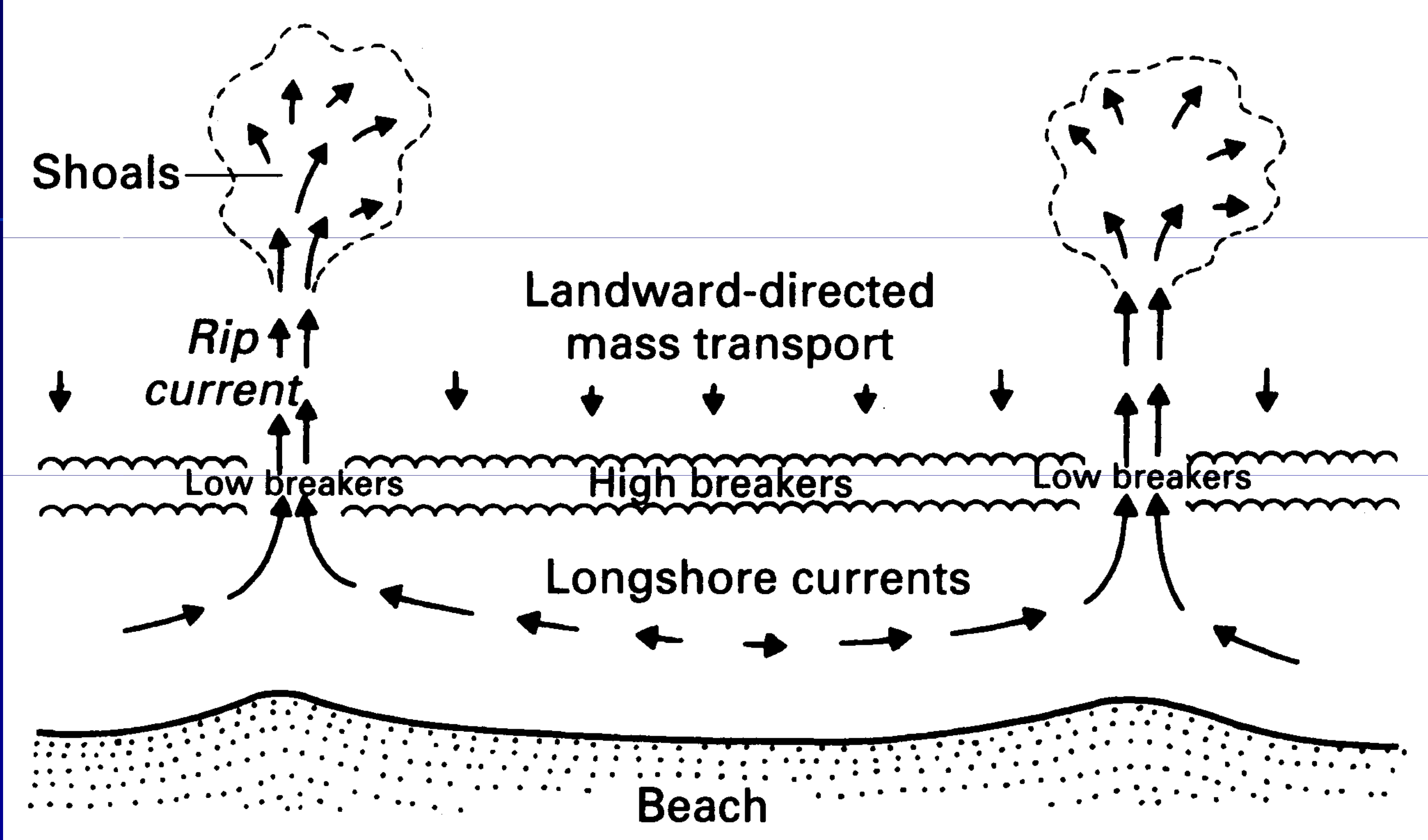

Deltas
Deltas
Strandplains, Cheniers,
Tidal flats
FLUVIAL
Estuaries,
Barrier-island/
lagoons
Strandplains, Cheniers, Tidal flats
Estuaries,
Barrier-island/
lagoons
Progradation
Transgression
WAVE
TIDE



Swash zone
Surf zone
Breaker zone
Shoaling wave zone
Oscillatory wave zone
Aeolian dunes
Beach
Shoreface
Offshore—transition
Offshore
Foreshore
MHW
MLW
Backshore
Berm
Mean fairweather wave base
Mean storm wave base
Parallel lamination and x-b single sets
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)

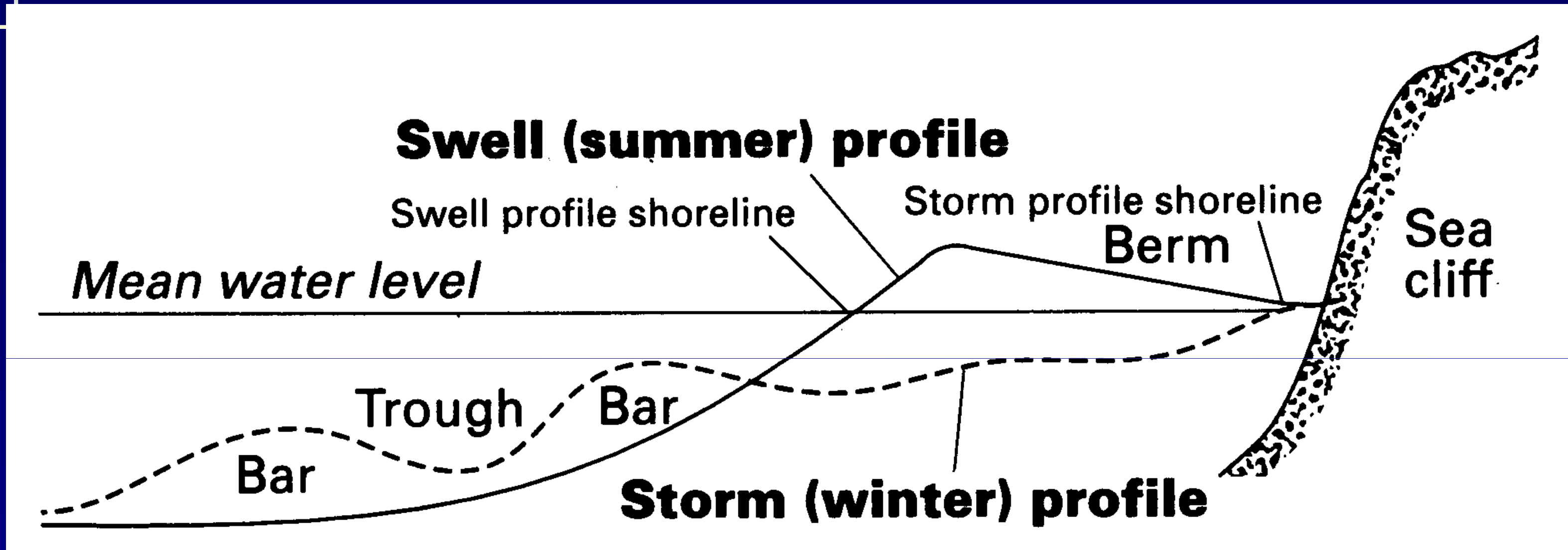

Shoals
Landward-directed
mass transport
Rip
current
Low breakers
High breakers
Low breakers
Longshore currents
Beach

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)


Swell (summer) profile
Swell profile shoreline
Storm profile shoreline
Berm
Mean water level
Sea
cliff
Trough
Bar
Bar
Storm (winter) profile

Coastal environments

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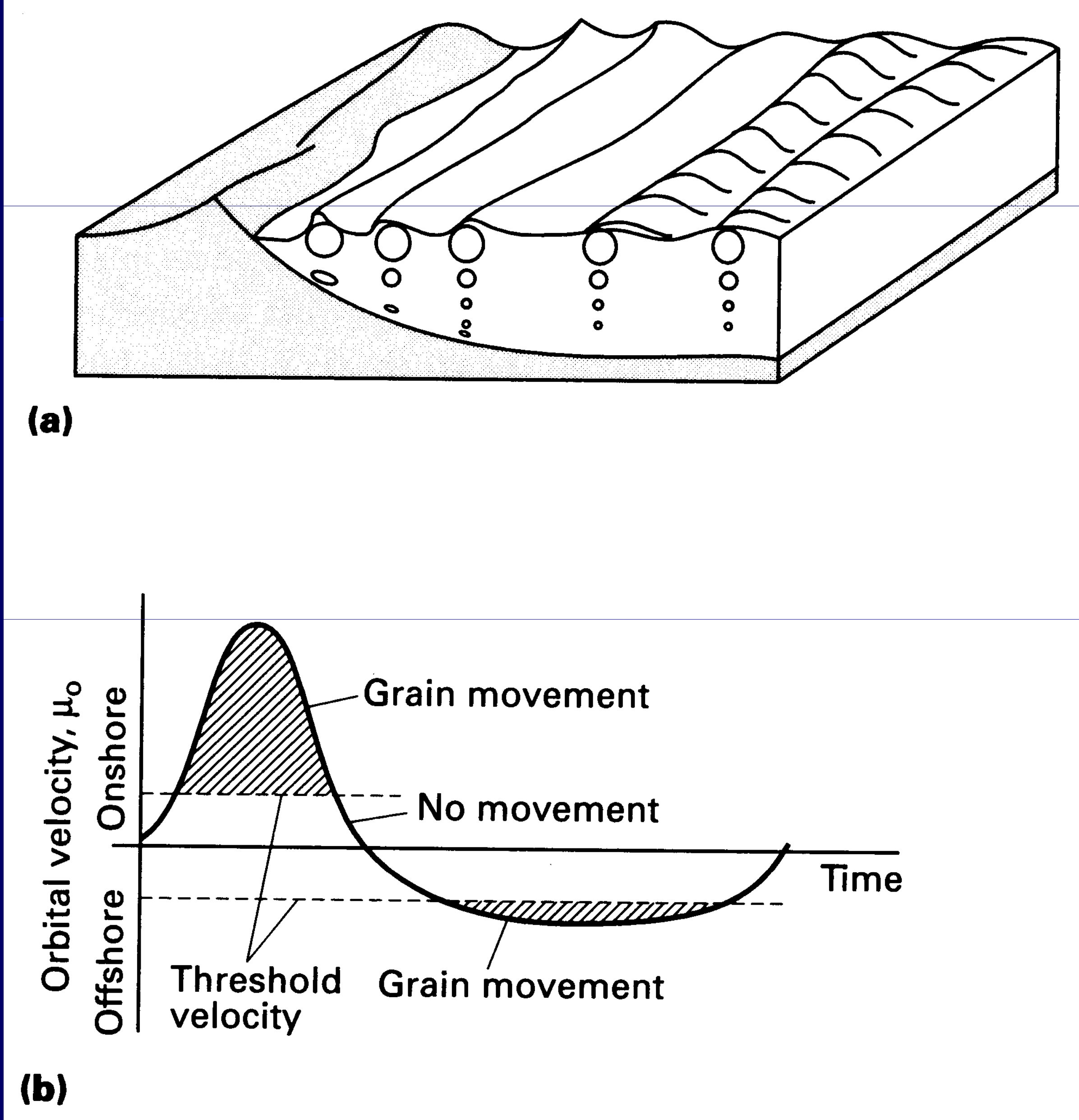
(a)
Grain movement
No movement
Time
Orbital velocity, μo
Onshore
Offshore
Threshold velocity
Grain movement
(b)

Coastal environments

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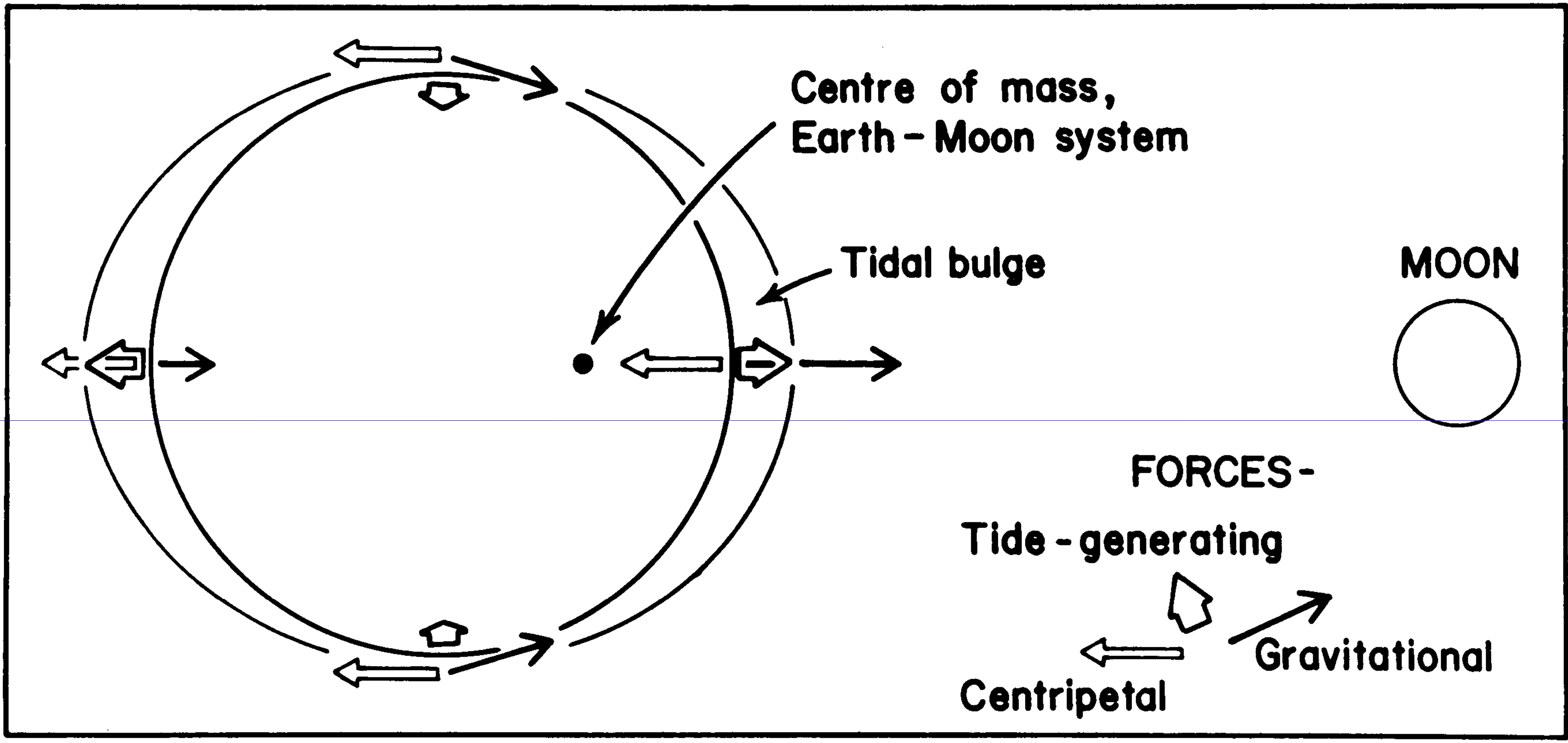
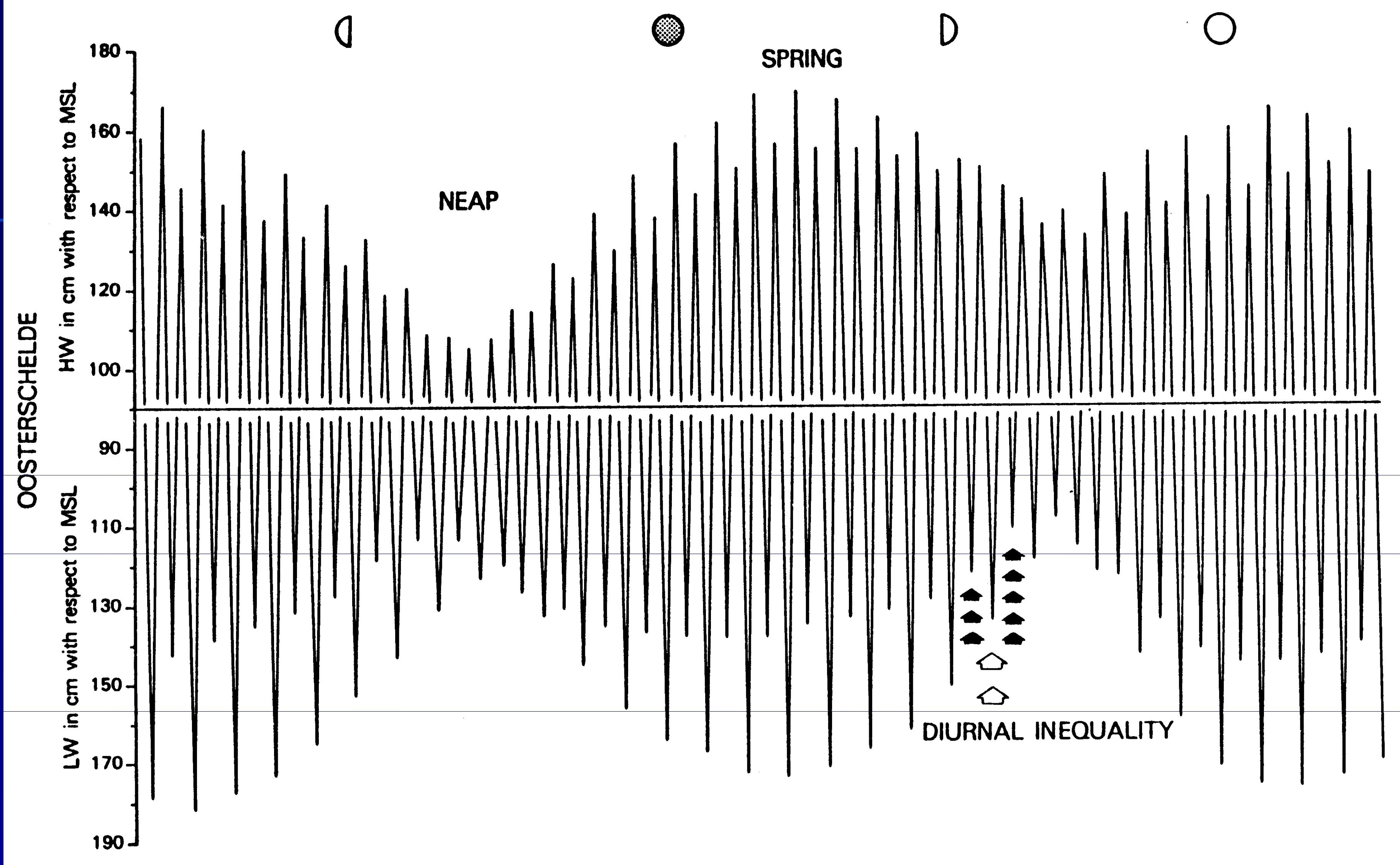

Centre of mass,
Earth - Moon system
Tidal bulge
MOON
FORCES -
Tide - generating
Gravitational
Centripetal

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


SPRING
NEAP
DIURNAL INEQUALITY
OOSTERSCHELDE
HW in cm with respect to MSL
LW in cm with respect to MSL
180
160
140
120
100
90
110
130
150
170
190

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
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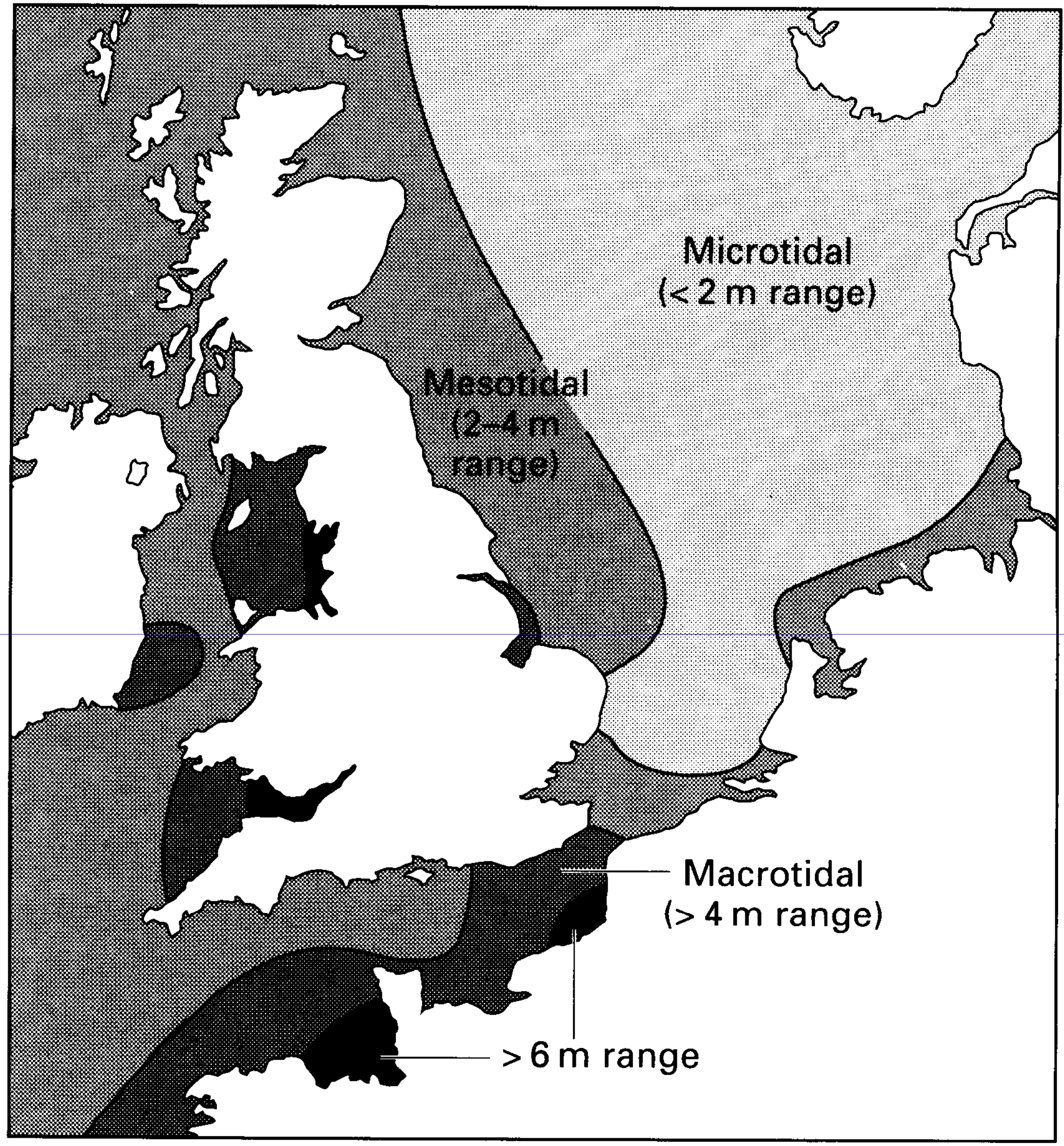
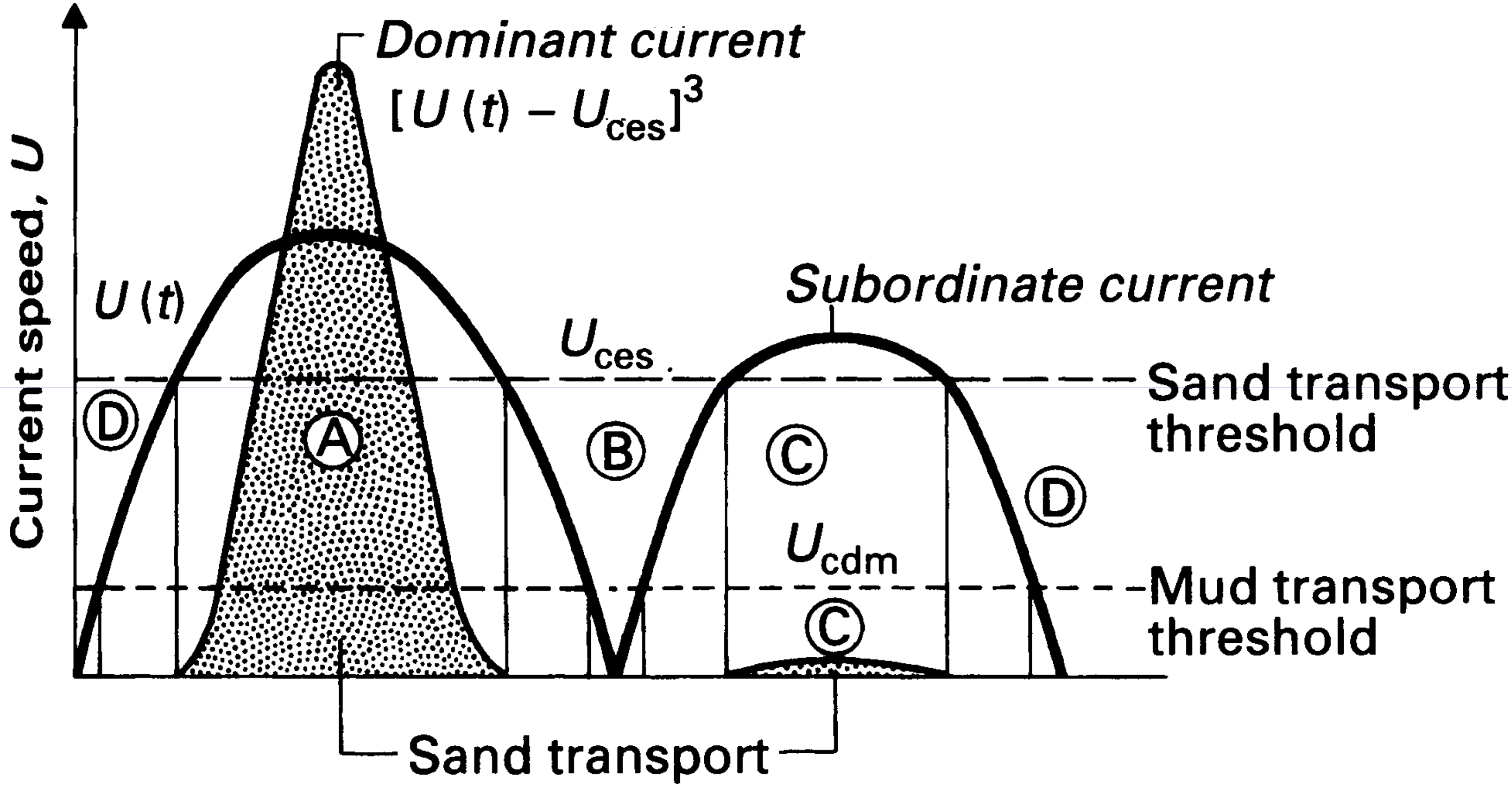

Microtidal
(< 2 m range)
Mesotidal
(2–4 m
range)
Macrotidal
(> 4 m range)
> 6 m range

Tidal cycle with equivalent sand/mud depositional sequence

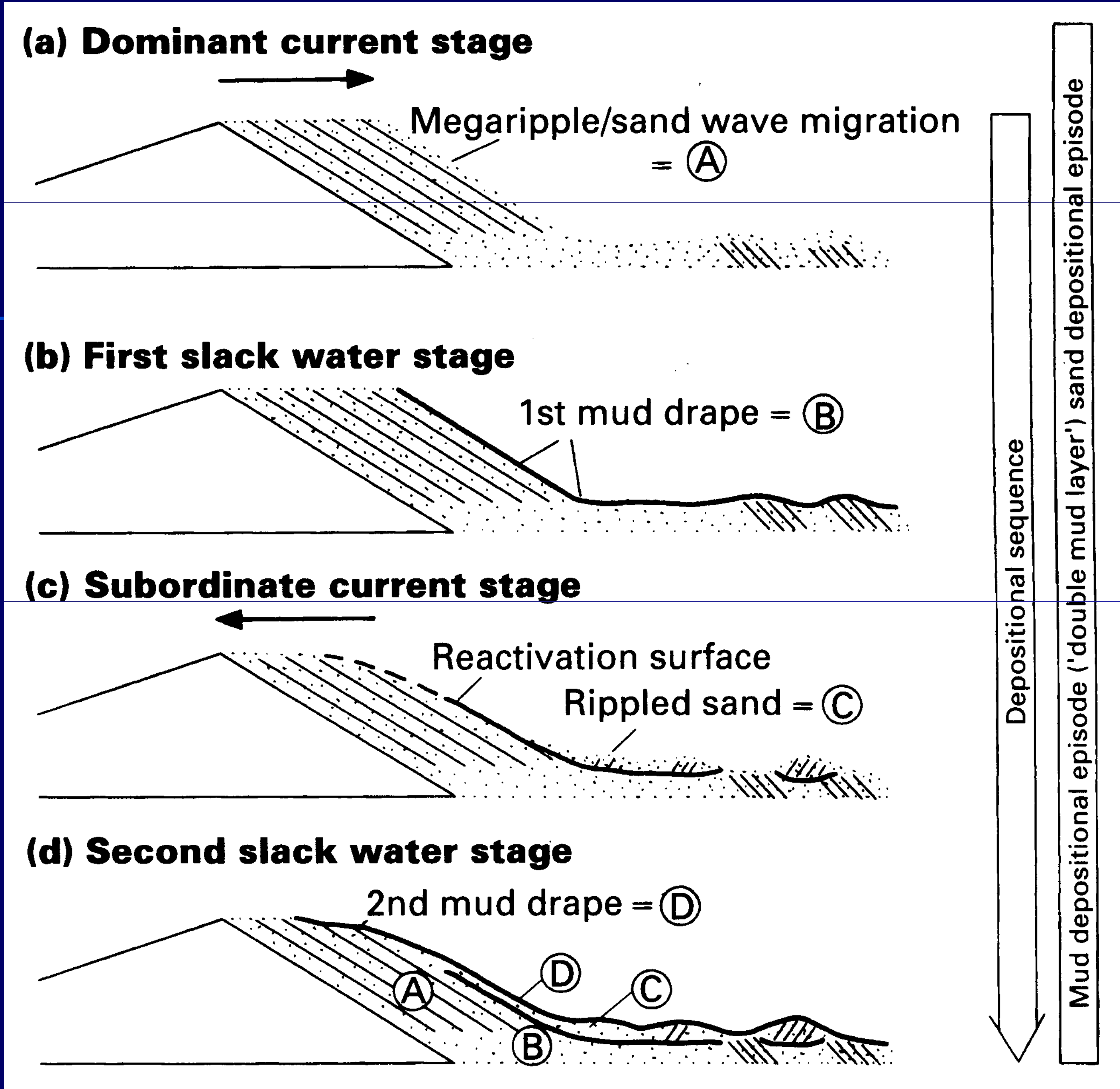


Coastal environments

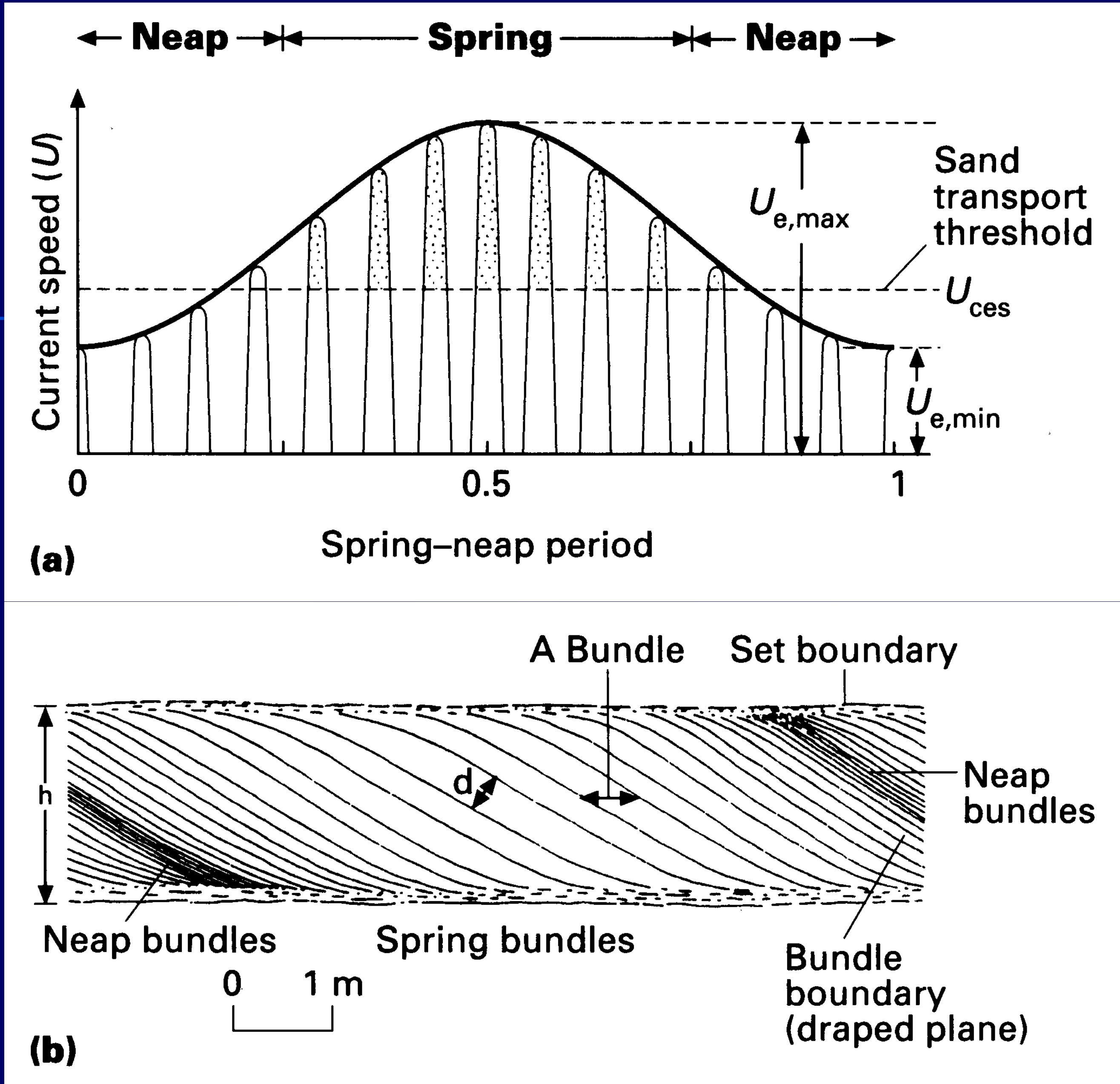
- Tide-influenced sedimentary structures can take different shapes:
  - **Herringbone cross stratification** indicates bipolar flow directions, but it is rare
  - Mud-draped cross strata are much more common, and are the result of alternating bedform migration during high flow velocities and mud deposition 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 = (A)
(b) First slack water stage
1st mud drape = (B)
(c) Subordinate current stage
Reactivation surface
Rippled sand = (C)
(d) Second slack water stage
2nd mud drape = (D)
(A)
(B)
(C)
(D)
Depositional sequence
Mud depositional episode ('double mud layer') sand depositional episode



← Neap →|← Spring →|← Neap →
Current speed (U)
Sand transport threshold
$U_{e,max}$
U_{ces}
$U_{e,min}$
0
0.5
1
Spring–neap period
(a)
A Bundle
Set boundary
Neap bundles
h
d
Neap bundles
Spring bundles
Bundle boundary (draped plane)
0
1 m
(b)

Coastal environments

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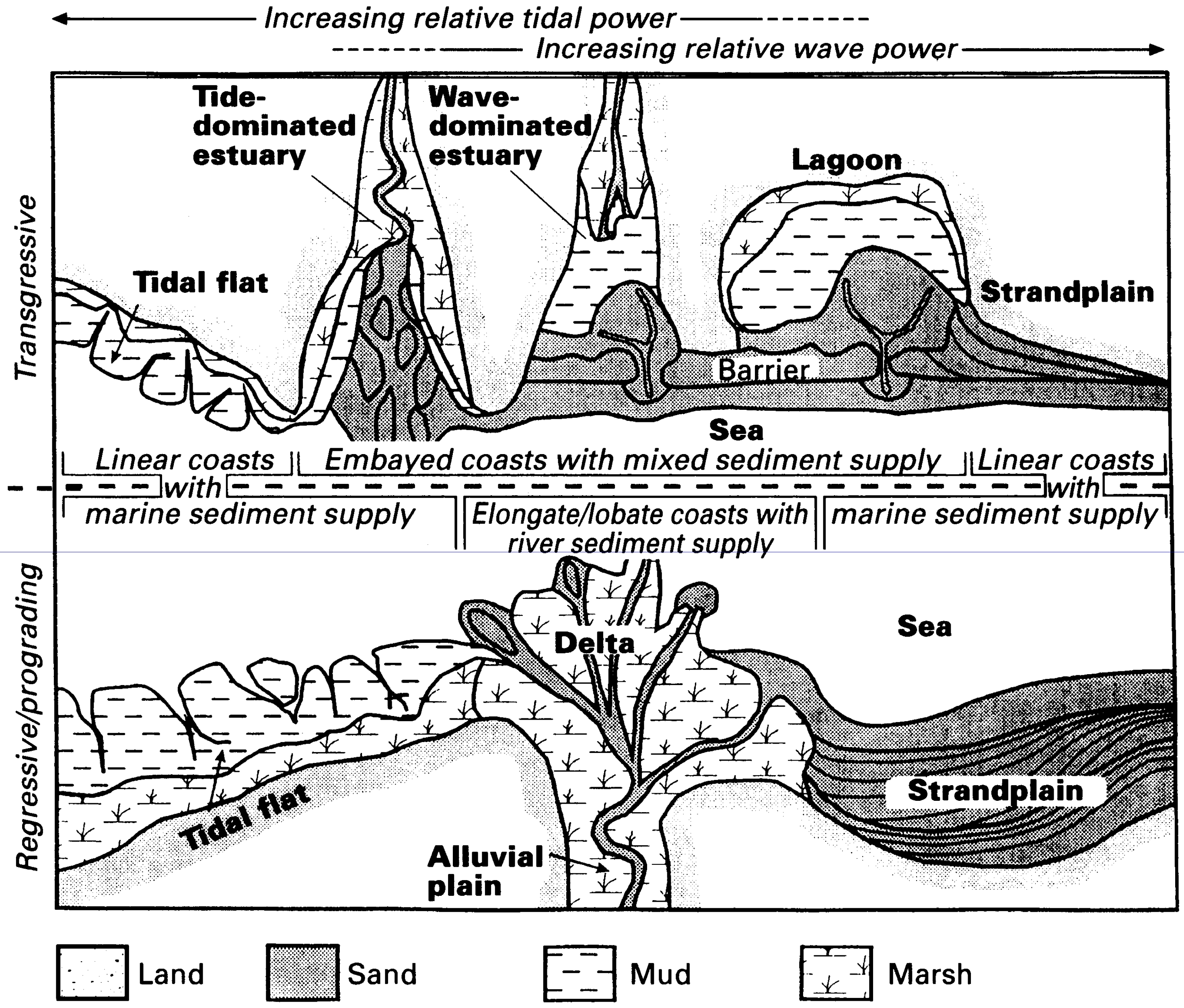
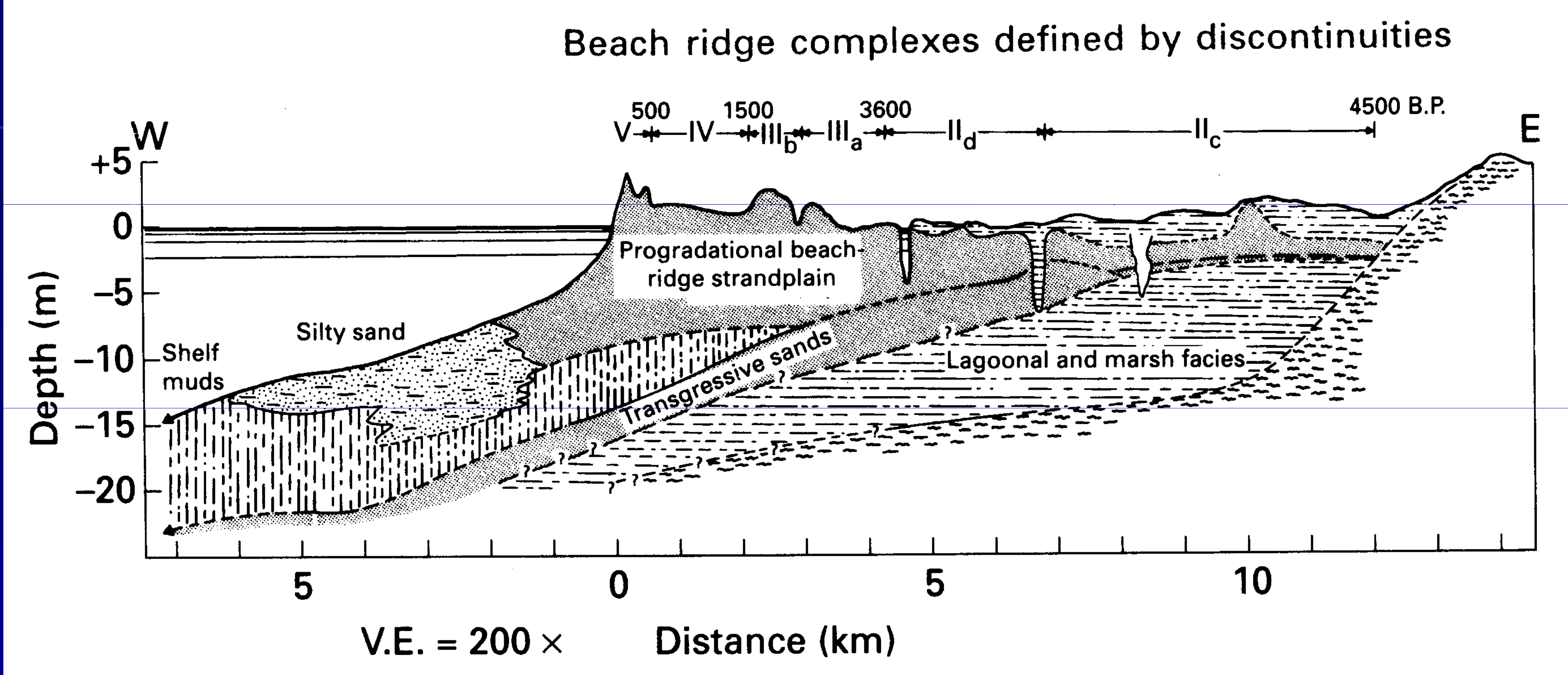
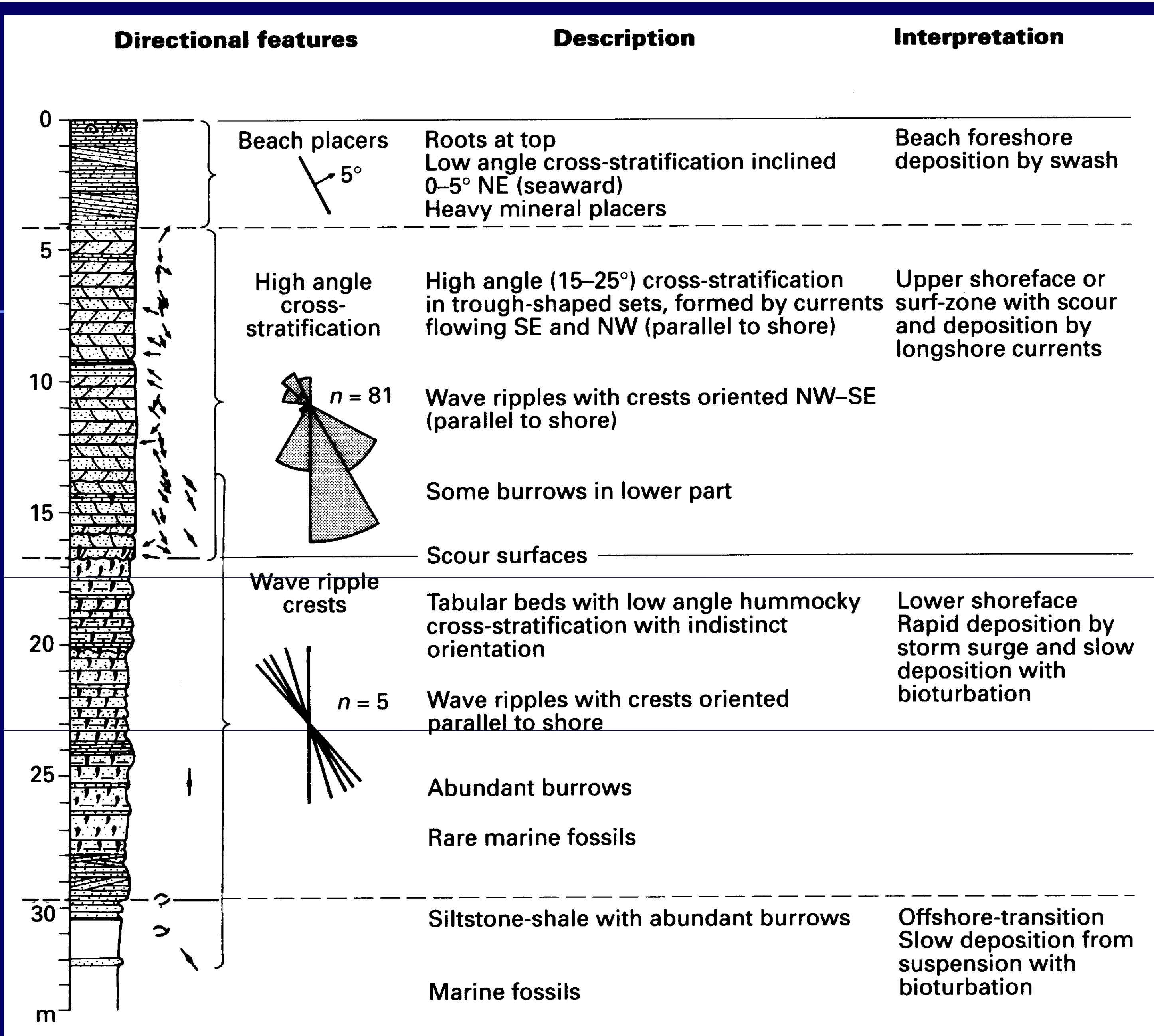

Increasing relative tidal power
Increasing relative wave power
Transgressive
Tide-dominated estuary
Wave-dominated estuary
Lagoon
Tidal flat
Strandplain
Barrier
Sea
Linear coasts with marine sediment supply
Embayed coasts with mixed sediment supply
Linear coasts with marine sediment supply
Elongate/lobate coasts with river sediment supply
Regressive/prograding
Delta
Sea
Strandplain
Tidal flat
Alluvial plain
Land
Sand
Mud
Marsh

Coastal environments

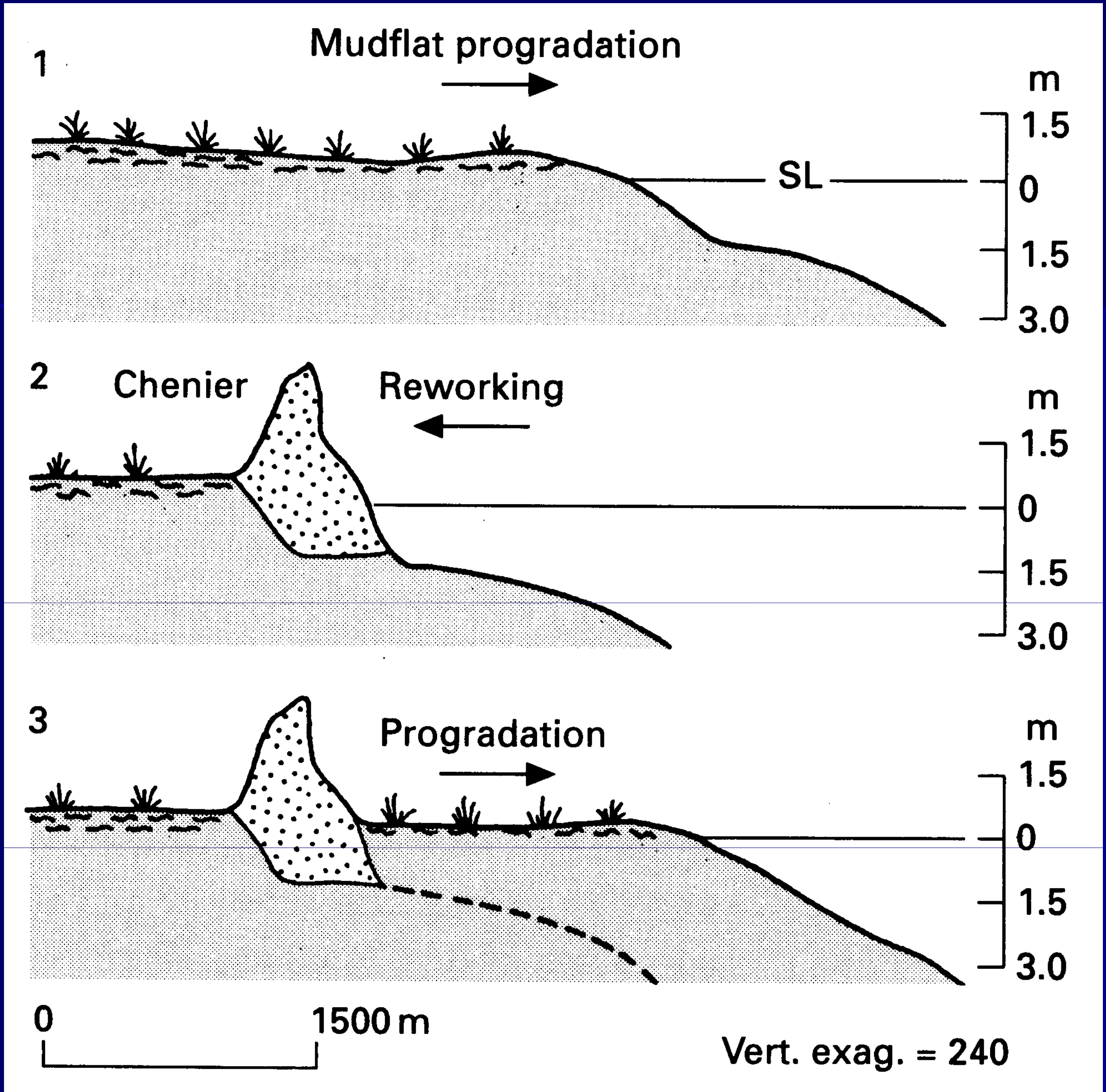
- **Beach-ridge strandplains** and **chenier plains** result from coastal progradation in sand- and mud-dominated settings respectively; both are dominantly fed by sediments transported by long-shore currents

- **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
500
1500
3600
4500 B.P.
V
IV
IIIb
IIIa
IId
IIc
W
E
+5
0
−5
−10
−15
−20
Depth (m)
Shelf muds
Silty sand
Progradational beach-ridge strandplain
Transgressive sands
Lagoonal and marsh facies
5
0
5
10
V.E. = 200 ×
Distance (km)



Directional features
Description
Interpretation
0
5
10
15
20
25
30
m
Beach placers
5°
Roots at top
Low angle cross-stratification inclined
0–5° NE (seaward)
Heavy mineral placers
Beach foreshore
deposition by swash
High angle
cross-
stratification
High angle (15–25°) cross-stratification
in trough-shaped sets, formed by currents
flowing SE and NW (parallel to shore)
Upper shoreface or
surf-zone with scour
and deposition by
longshore currents
n = 81
Wave ripples with crests oriented NW–SE
(parallel to shore)
Some burrows in lower part
Scour surfaces
Wave ripple
crests
Tabular beds with low angle hummocky
cross-stratification with indistinct
orientation
Lower shoreface
Rapid deposition by
storm surge and slow
deposition with
bioturbation
n = 5
Wave ripples with crests oriented
parallel to shore
Abundant burrows
Rare marine fossils
Siltstone-shale with abundant burrows
Offshore-transition
Slow deposition from
suspension with
bioturbation
Marine fossils


1
Mudflat progradation
m
1.5
SL
0
1.5
3.0
2
Chenier
Reworking
m
1.5
0
1.5
3.0
3
Progradation
m
1.5
0
1.5
3.0
0
1500 m
Vert. exag. = 240

Coastal environments

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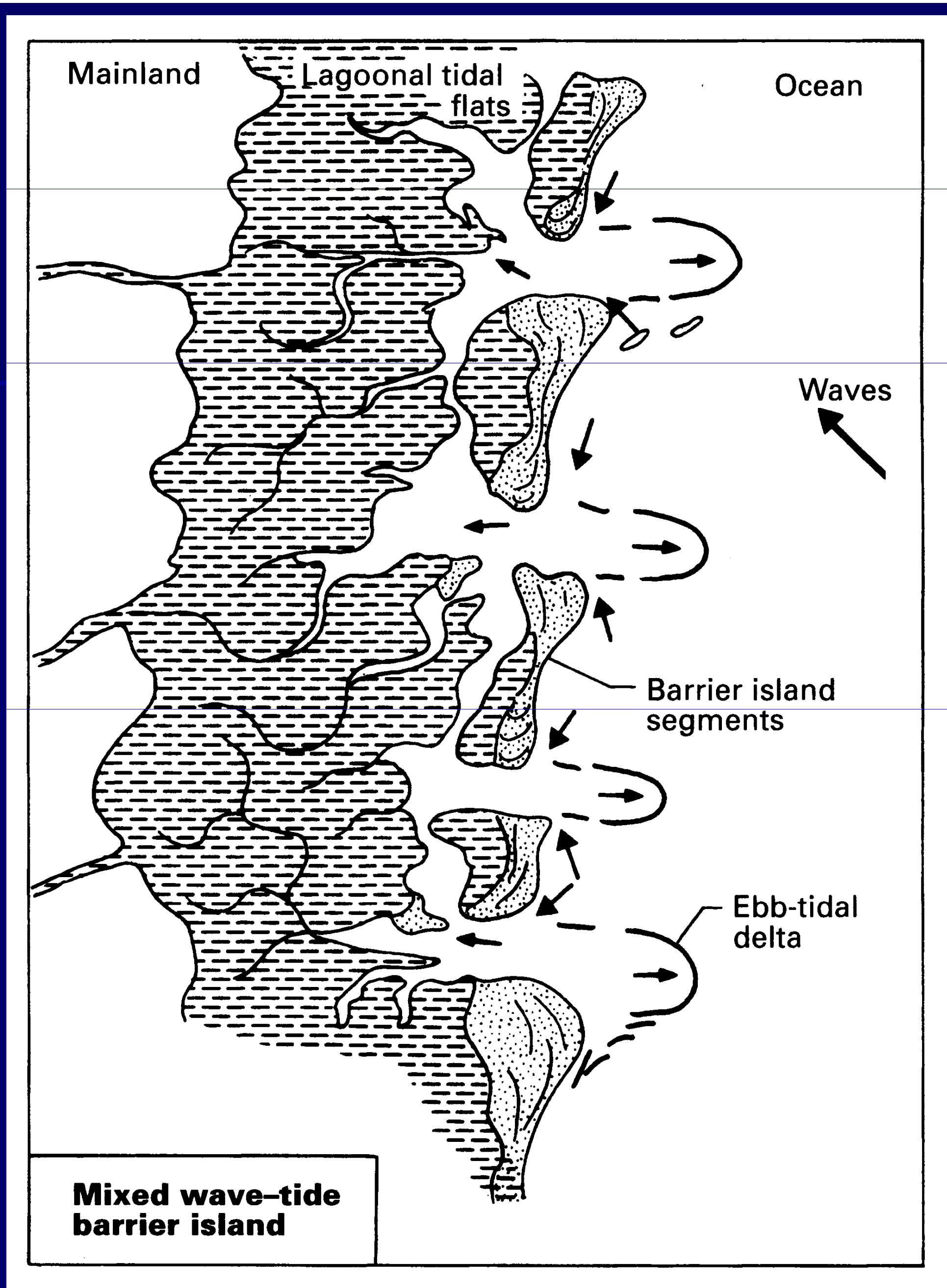
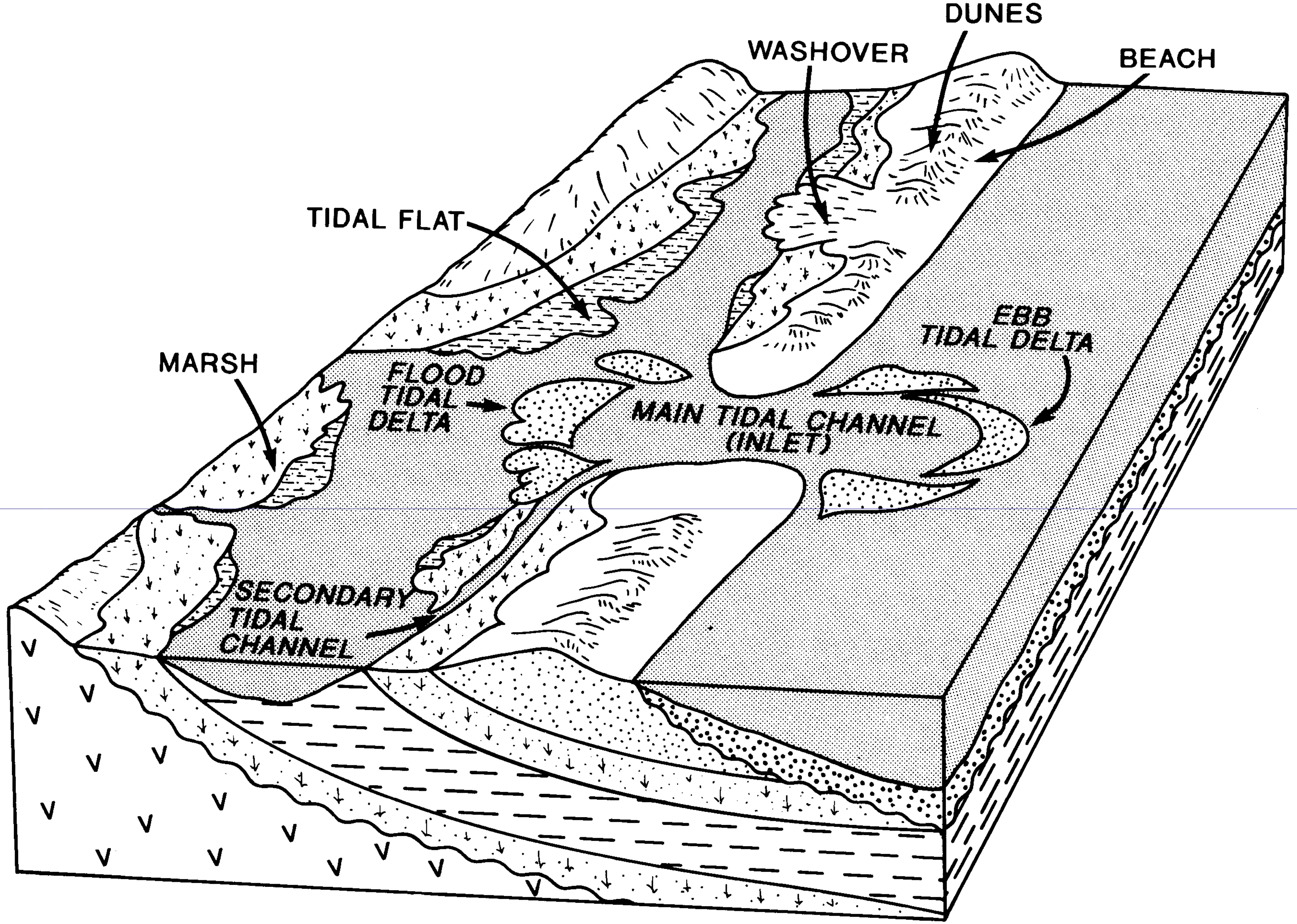
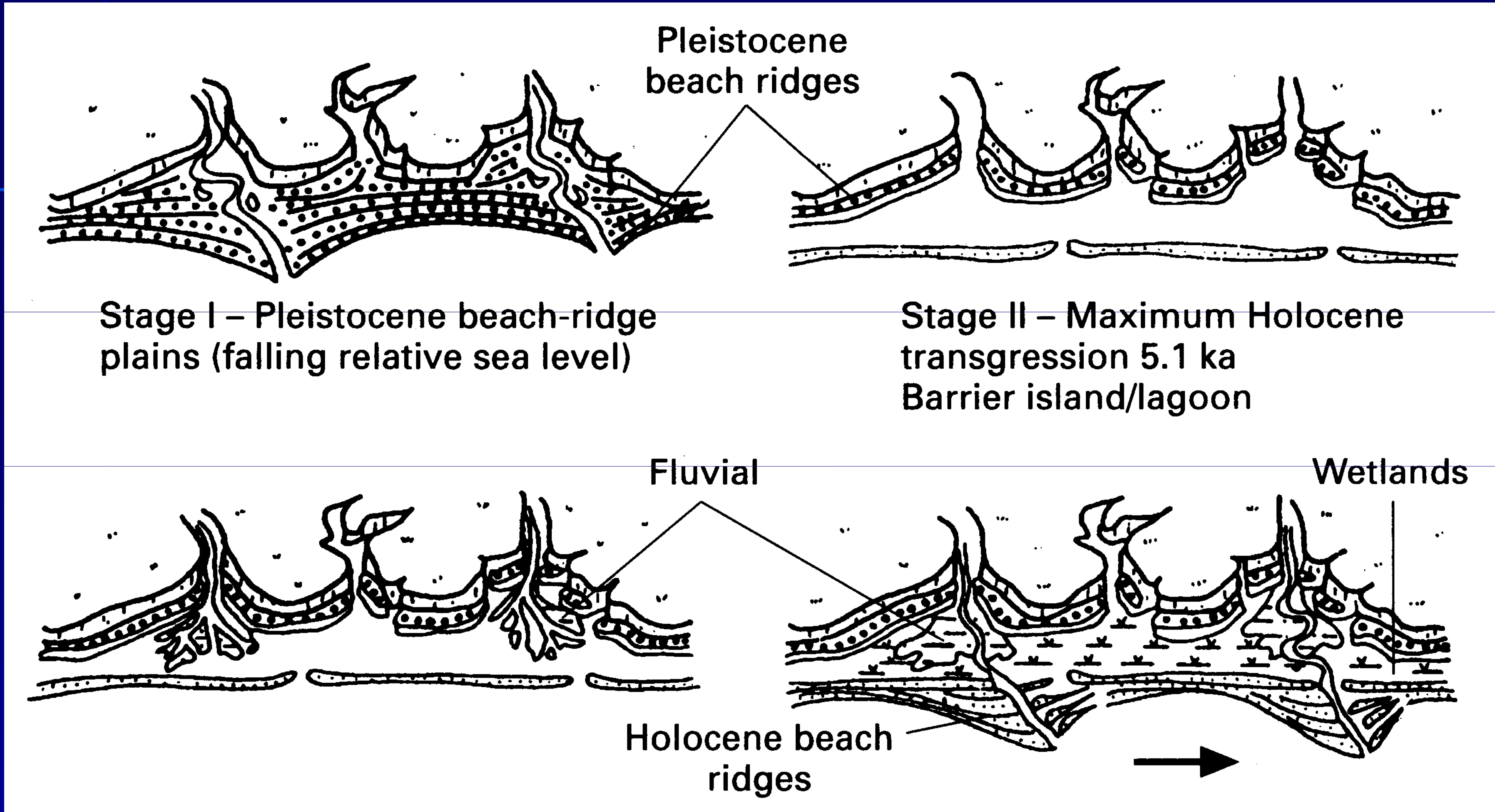

Mainland
Lagoonal tidal flats
Ocean
Waves
Barrier island segments
Ebb-tidal delta
Mixed wave–tide barrier island

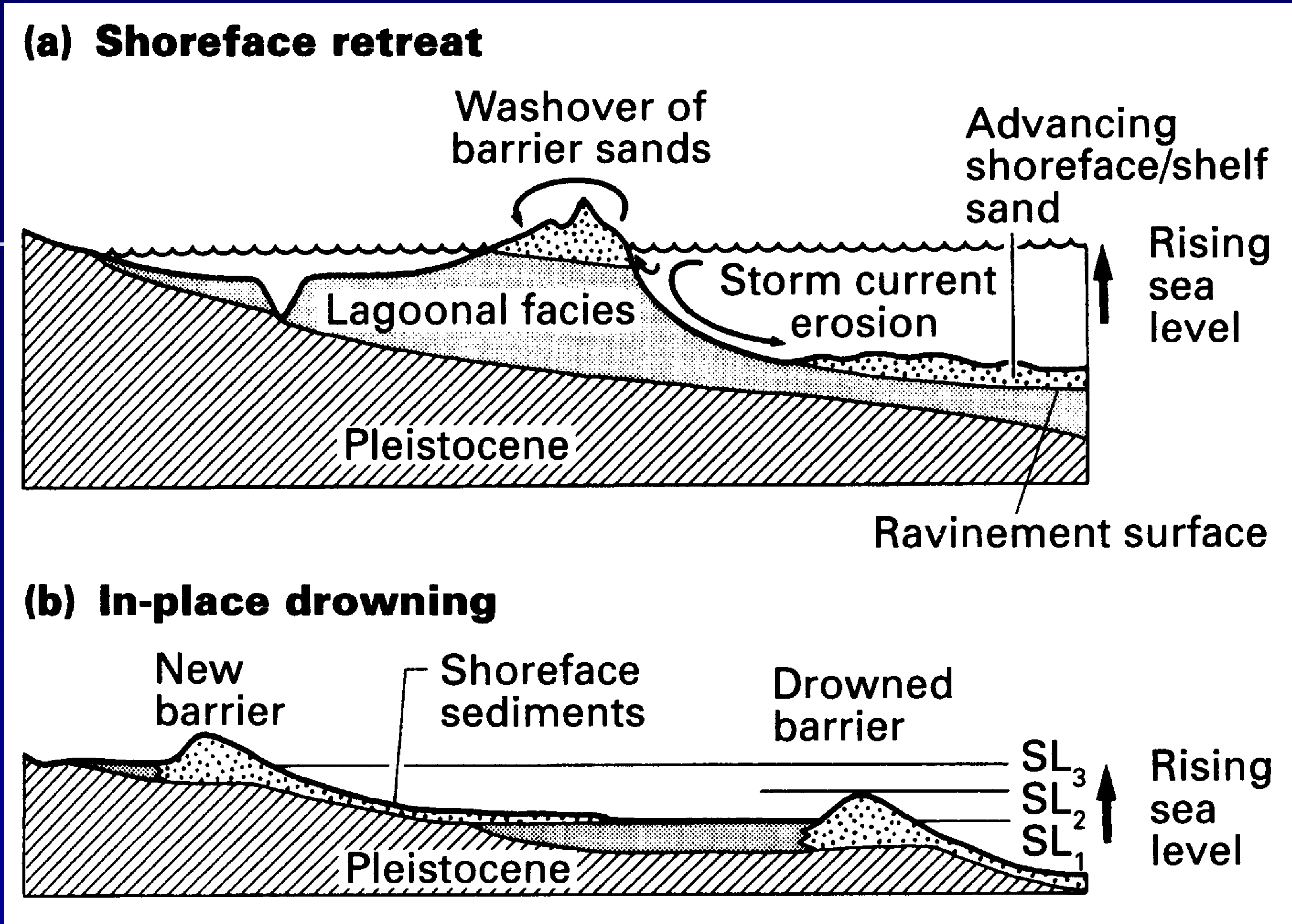

DUNES
WASHOVER
BEACH
TIDAL FLAT
EBB
TIDAL DELTA
MARSH
FLOOD
TIDAL
DELTA
MAIN TIDAL CHANNEL
(INLET)
SECONDARY
TIDAL
CHANNEL

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


Pleistocene
beach ridges
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
Rising sea level
Storm current erosion
Lagoonal facies
Pleistocene
Ravinement surface
(b) In-place drowning
New barrier
Shoreface sediments
Drowned barrier
SL3
SL2
SL1
Rising sea level
Pleistocene

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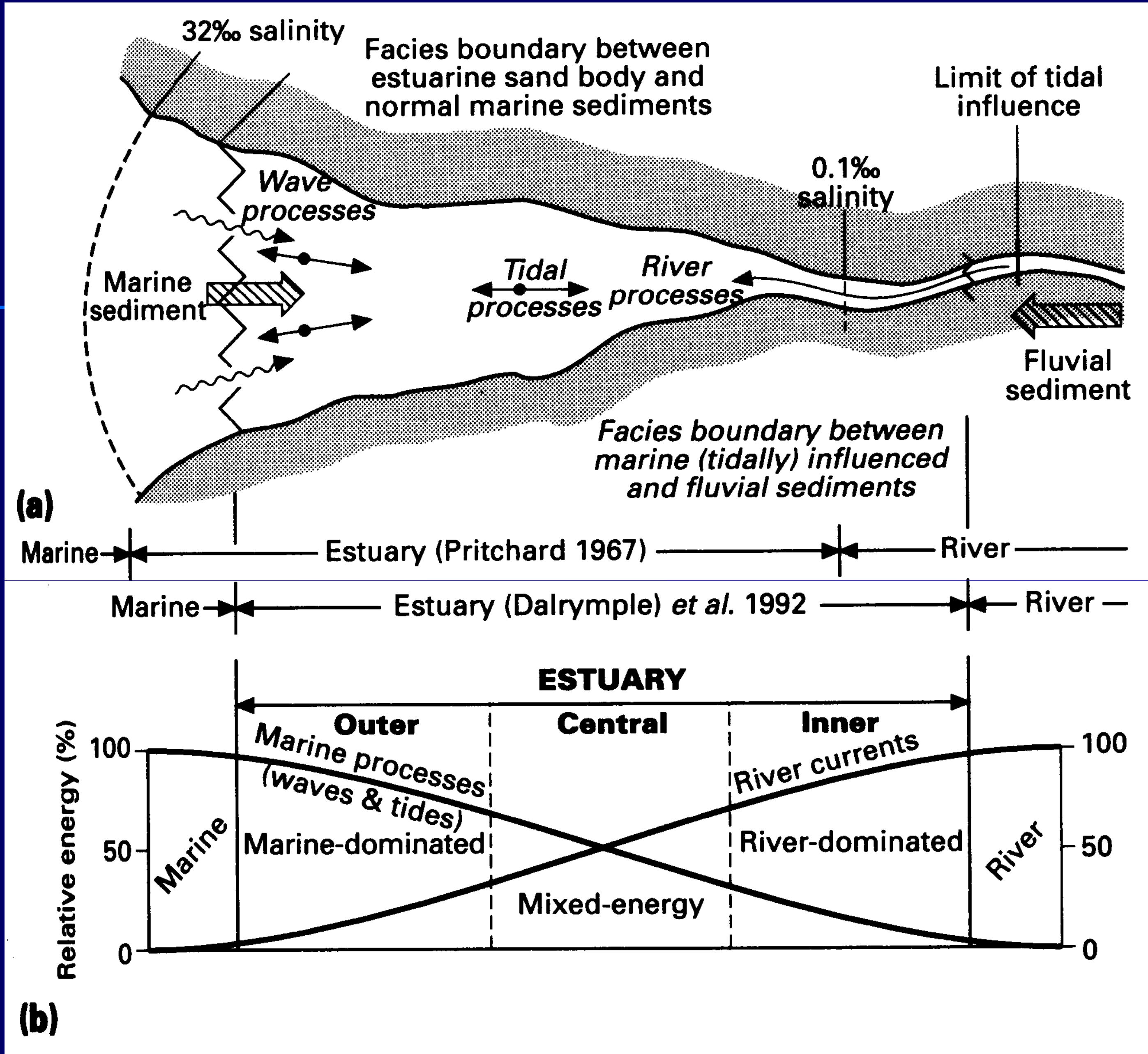
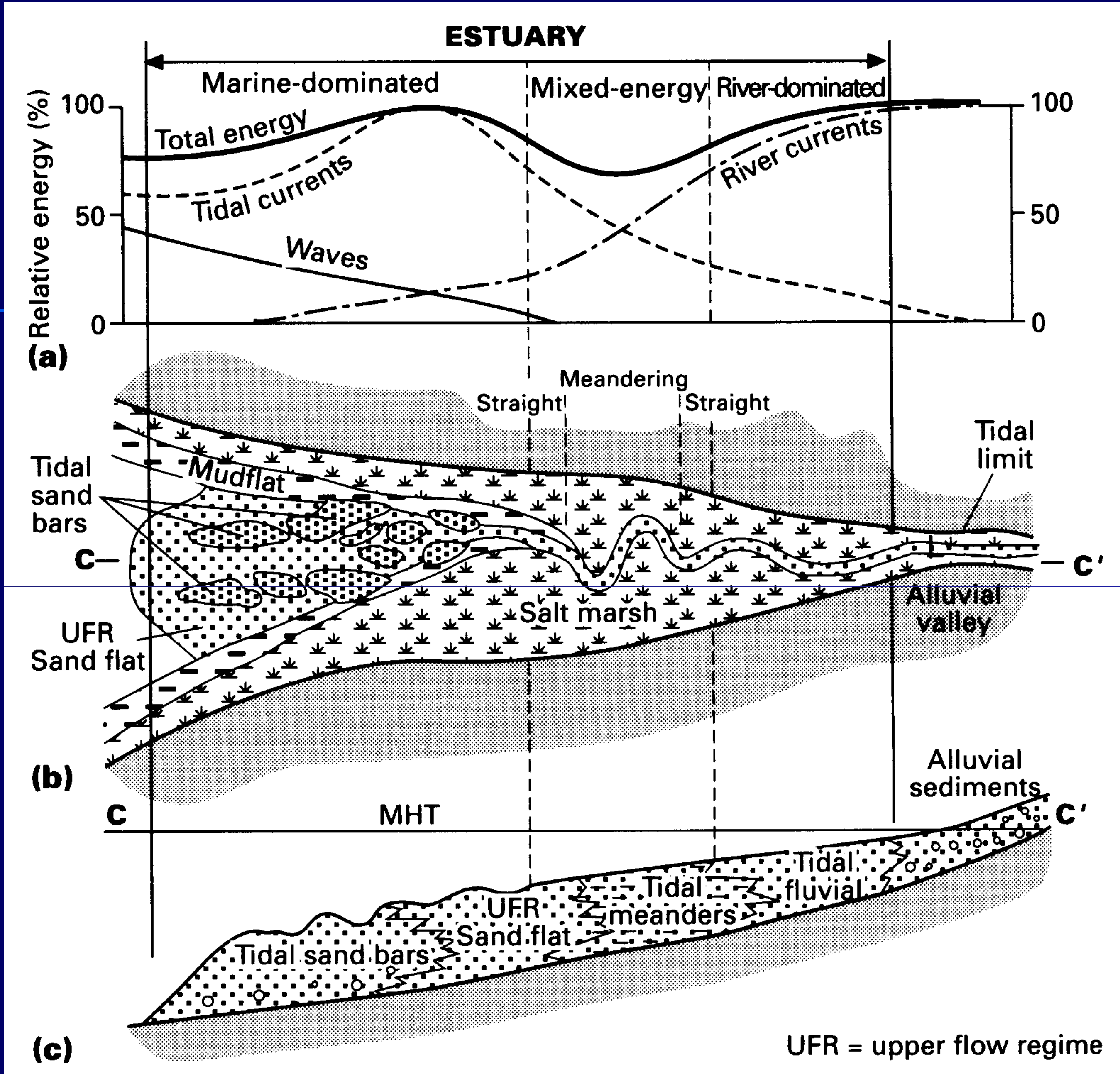

32‰ salinity
Facies boundary between estuarine sand body and normal marine sediments
Limit of tidal influence
Wave processes
0.1‰ salinity
Marine sediment
Tidal processes
River processes
Fluvial sediment
Facies boundary between marine (tidally) influenced and fluvial sediments
(a)
Marine
Estuary (Pritchard 1967)
River
Marine
Estuary (Dalrymple) et al. 1992
River
ESTUARY
Outer
Central
Inner
Marine processes (waves & tides)
River currents
Marine
Marine-dominated
Mixed-energy
River-dominated
River
Relative energy (%)
100
50
0
(b)

- **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


ESTUARY
Marine-dominated
Mixed-energy
River-dominated
Relative energy (%)
100
50
0
Total energy
Tidal currents
Waves
River currents
(a)
Meandering
Straight
Straight
Tidal sand bars
Mudflat
Tidal limit
C
C′
Salt marsh
Alluvial valley
UFR Sand flat
(b)
Alluvial sediments
C
MHT
C′
Tidal fluvial
Tidal meanders
UFR Sand flat
Tidal sand bars
(c)
UFR = upper flow regime

Coastal environments

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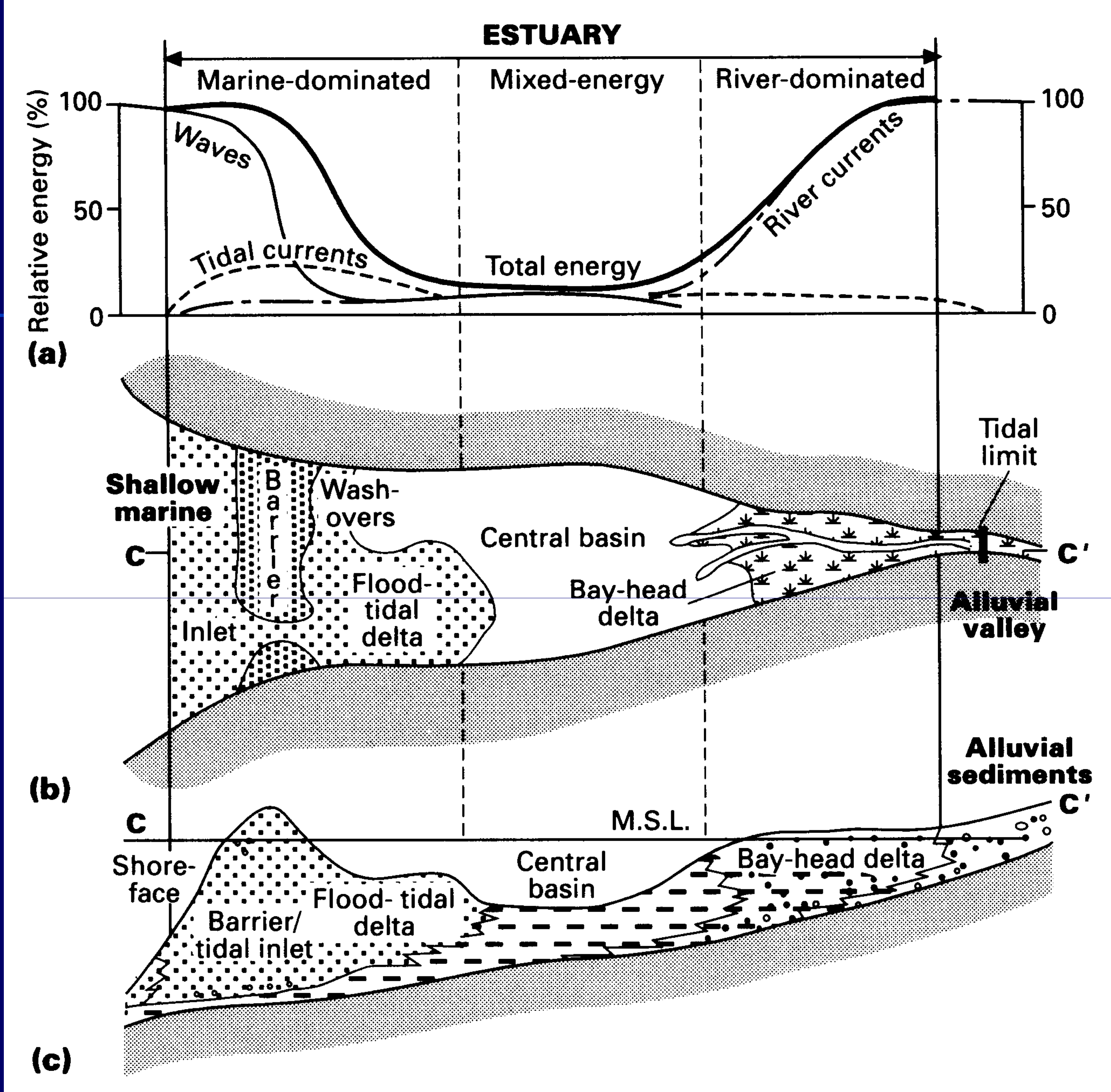
ESTUARY
Marine-dominated
Mixed-energy
River-dominated
Relative energy (%)
100
50
0
Waves
Tidal currents
Total energy
River currents
(a)
Shallow marine
Barrier
Wash-overs
Central basin
Tidal limit
C
C′
Flood-tidal delta
Inlet
Bay-head delta
Alluvial valley
(b)
Alluvial sediments
C
M.S.L.
C′
Shore-face
Barrier/ tidal inlet
Flood- tidal delta
Central basin
Bay-head delta
(c)

Coastal environments

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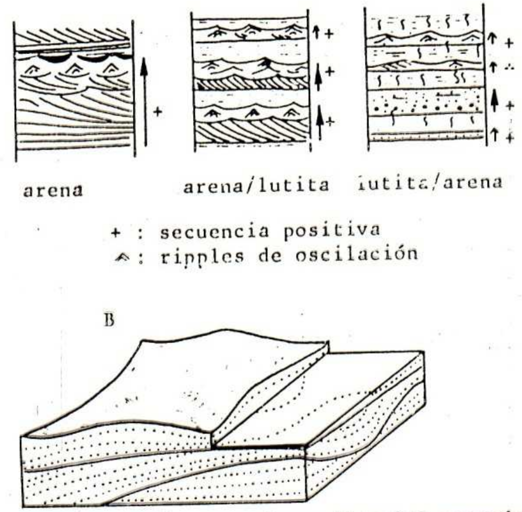


Figura 5-6.—Arriba, secuencias positivas (+) generadas por tormentas en el *shoreface*. La primera consiste en arena con laminación paralela de régimen de flujo alto, estratificación cruzada debida a *megaripples* de oscilación, laminación cruzada de *ripples* de oscilación y *flasers* de lutita que 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 indicadoras de una menor energía del oleaje que la anterior. La tercera consiste en lutita bioturbada y arenas gradadas o con laminación cruzada, que incluyen microsecuencias positivas, indicadora de una débil acción del oleaje sobre el fondo durante las tormentas. Abajo, estratificación cruzada «hummocky».

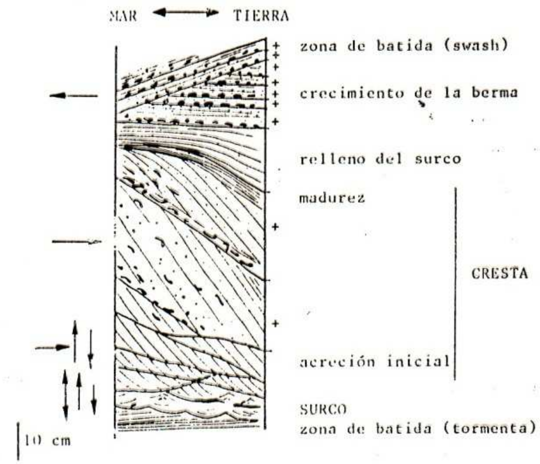


Figura 5-3.—Secuencia ideal producida por la migración de un sistema de cresta y surco (*ridge and runnel*) en el *foreshore*. La estratificación cruzada de gran escala formada por la migración de la cresta, apunta hacia tierra, pero las direcciones de corriente en el surco suelen apuntar paralelamente a la costa al igual que las crestas de los *ripples* de oscilación. Las láminas de la parte alta de la secuencia se inclinan hacia el mar. Obsérvense las secuencias positivas (+) de tamaño de grano decreciente a techo y del espesor de las láminas comprendidas entre las superficies erosivas en la facies de cresta.

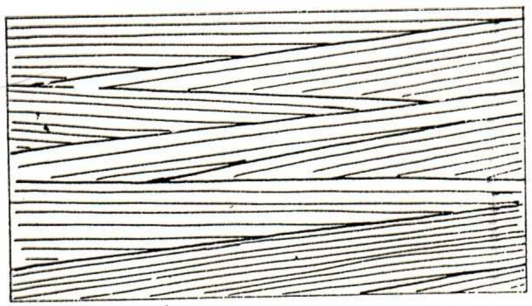


Figura 5-7.—Laminación paralela típica del *foreshore* (zona de batida). Obsérvense los *sets* de láminas separados por superficies de discordancia. Arenas de Neurath, Mioceno (Alemania).

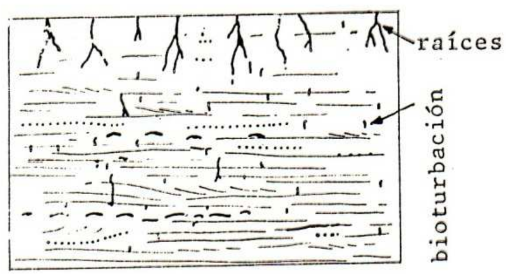


Figura 5-9.—Esquema de la estructura interna de los sedimentos de *backshore*, integrada por laminación paralela difusa y alguna cruzada, niveles de conchas y de acumulación de minerales pesados y bioturbación producida por animales y raíces de plantas.

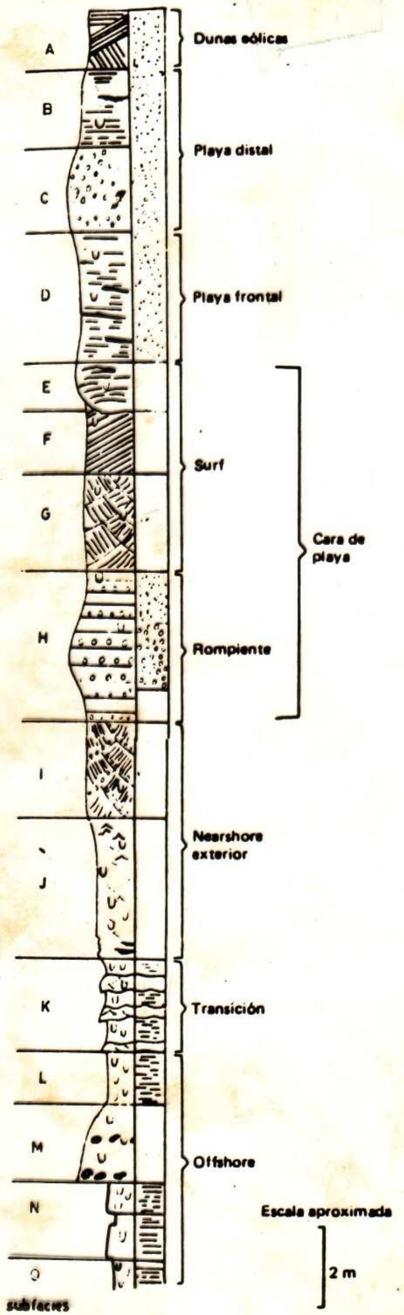


Fig. 64 – **Perfil teórico de progradación en depósitos marinos poco profundos y litorales.**

A. Eolianitas costeras.

B. Zona de mezcla eólica-ácuea. Estrat. Plana. Algunas entrecruzadas hacia el continente. Escasos concentrados de pesados, ondulitas varias, costilla y surco, m de escurrimiento, costras salinas y pelíticas.

C. Berma y cresta de playa; tehco con estrecruzamiento 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 acreción 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 subácuea. Entrecruzados tabulares unimodales hacia la costa (ondas de arena).

G. Barras longitudinales. Entrecruzados en artesa unimodales paralelos a la costa. Canales de corr. de retorno con artesas orietadas hacia el mar.

H. Barra de rompiente. Estratificación plana; hacia arriba ondulitas paralelas al tren de olas; interna gradada.

I. Megaóndulas arqueadas. Artenas con interna gradada; unidireccionales a la costa u oblicuas, también bimodales transversales u oblicuas.

J. Ondulitas asimétricas discontinuas bipolares con moda ppal. hacia la costa. Bioturbación. Hacia abajo ondulitas continuas paralelas al tren de olas; intensa bioturbación.

K. Interestratificación psamita ondulítica y limolita. Flaser, ondulosa y lenticular. Bioturbación frecuente.

L. Limolitas con fuerte bioturbación.

M. Barra arenosa de offshore. Intraclastos pelíticos; entrecruzada tabular de gran escala, unidirec. paralela a la costa (ondas de arena); bioturbación.

N. Limolitas y arcillitas; laminación gradada; fuerte bioturbación.

O. Arcilitas con bioturbación.

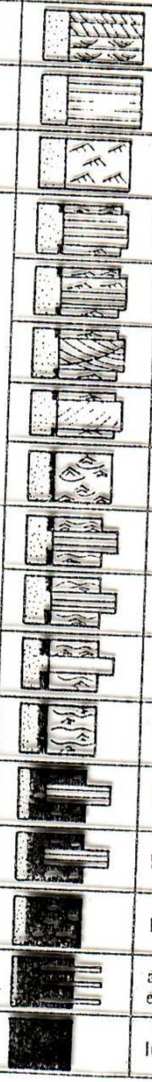
FACIES	SUBFACIES	COLUMNA	ESTRUCTURA INTERNA	% ARENA	ESPESOR	PROCESOS SEDIMENTARIOS Y OBSERVACIONES
FACIES DE ARENISCAS S	S_1 estratificación cruzada		estratificación cruzada tabular o en surco	90-100	20-200 cm.	Migración de *megaripples* de crestas rectas y sinuosas de escala variable.
	S_2 laminación paralela		laminación paralela o cruzada de ángulo bajo		Variable	Laminación formada por corrientes u olas con condiciones de alta energía.
	S_3 laminación cruzada		laminación cruzada		1-5 cm.	Migración de *ripples* de corriente, oscilación o combinados.
FACIES HETEROLITICAS H	H_1 arena dominante		laminación paralela	75-90	5-20 cm. máx. 200	Alternancias de capas de areniscas con laminación paralela y cruzada. Las capas más gruesas de arenisca pueden abarcar del 20 al 90 por 100. Frecuentes amalgamaciones. La arena se deposita como carga de fondo y desde la suspensión, con retrabajado de intensidad variable por *ripples* de corriente y de oscilación. La arena se deposita durante las tormentas fuertes y puede contener restos de conchas transportados. La bioturbación aumenta en las intercalaciones de grano fino.
			laminación paralela y cruzada		5-20 cm. máx. 200	
			laminación paralela y cruzada en surco		5-20 cm. máx. 50	
			estratificación cruzada tabular aislada		5-20 cm. máx. 50	
			laminación flaser en arena		1-5 cm.	
	H_2 mezclas de arena y lutita		laminación paralela	50-75	1-10 cm.	Esencialmente areniscas con laminación cruzada y lutitas con capas subordinadas de areniscas con laminación paralela (10-15 por 100). Laminación cruzada variable según el tipo de *ripple* (corriente, oscilación o combinado). Pueden reconocerse los depósitos de buen tiempo y tormenta. La parte alta de las capas de areniscas está bioturbada.
			de laminación paralela a laminación cruzada		1-10 cm.	
			laminación de bajo ángulo		1-10 cm.	
			laminación flaser y ondulada		1-3 cm.	
	H_3 lutita dominante		laminación paralela	10-50	1-5 cm.	Esencialmente laminación lenticular con algunas capas de areniscas laminadas (5-10 por 100). Las lentes de arena se forman por corrientes u olas. Las areniscas, por suspensión durante tormentas. En buen tiempo, depósito de finos en suspensión que luego suelen ser intensamente bioturbados.
			laminación paralela y cruzada		1-5 cm.	
			laminación lenticular		1-3 cm.	
FACIES DE LUTITAS M	M_1		arenas gradadas o capas ricas en conchas	0-10	0,1-2 cm.	Lutitas y alguna capita de areniscas. Depósito de suspensión. Olas y corrientes sólo actúan durante las tormentas muy fuertes. Bioturbación intensa. Faunas bentónicas *in situ* o casi.
	M_2		lutitas		Menor de 0.5 cm.	

Fig. 20. Principales litofacies depositadas en ambientes someros siliciclásticos (modificado de Johnson, 1978, y Boersma, 1975).