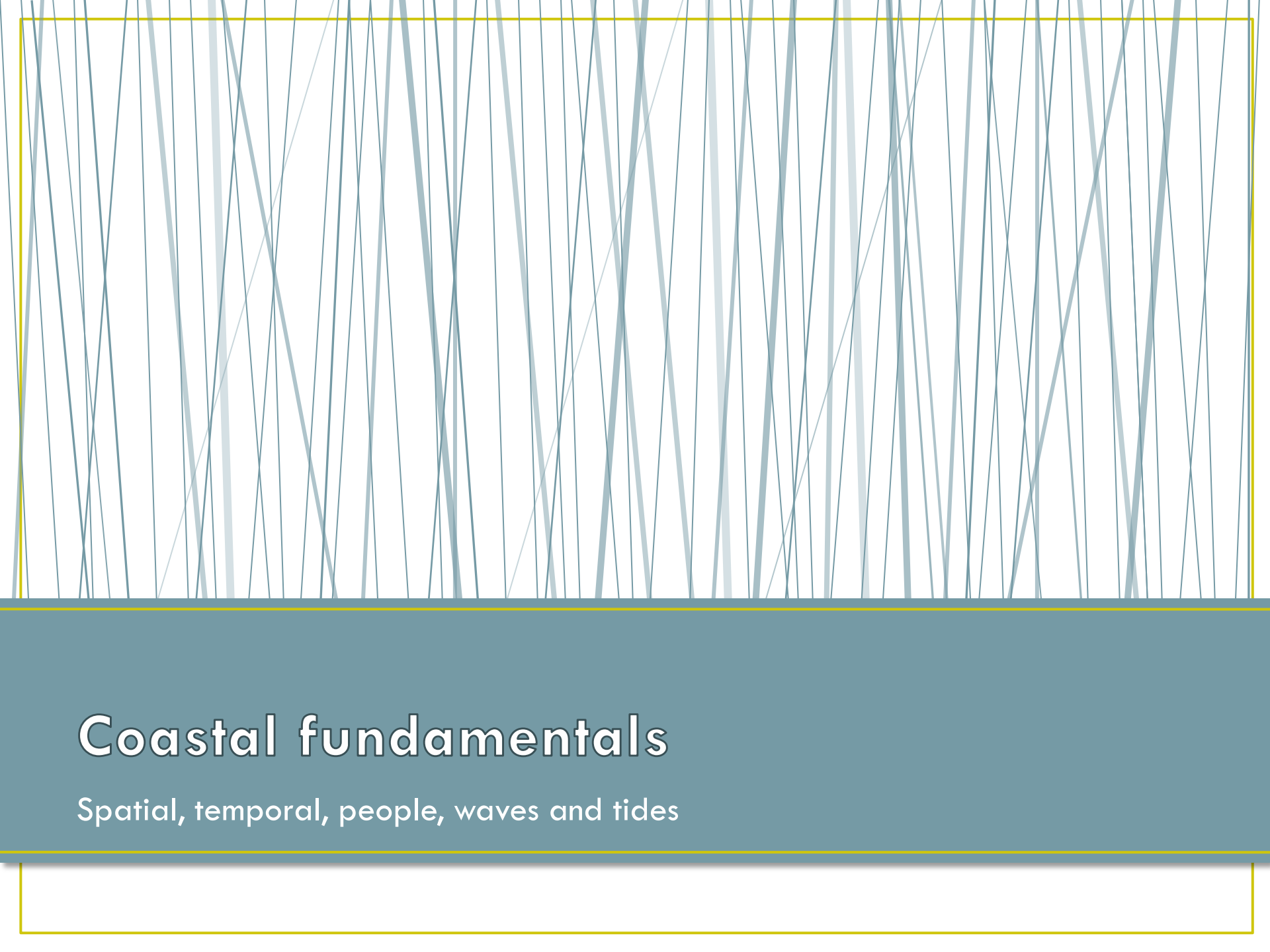


Coastal Geomorphology

A determinant of environmental
conservation



Katsushika Hokusai
Hokusai was a Japanese
painter and printmaker from the
1700's.



Coastal fundamentals

Spatial, temporal, people, waves and tides

Introduction

- Coasts are temporary structures, often subject to rapid change.
- The location of a coast depends on tectonic activity and the level of water in the ocean.
- The shape of a coast is a product of many processes.
- Human interference in coastal processes rarely increases the long-term stability of a coast.
- The shape of a coast is a product of many processes.



Time

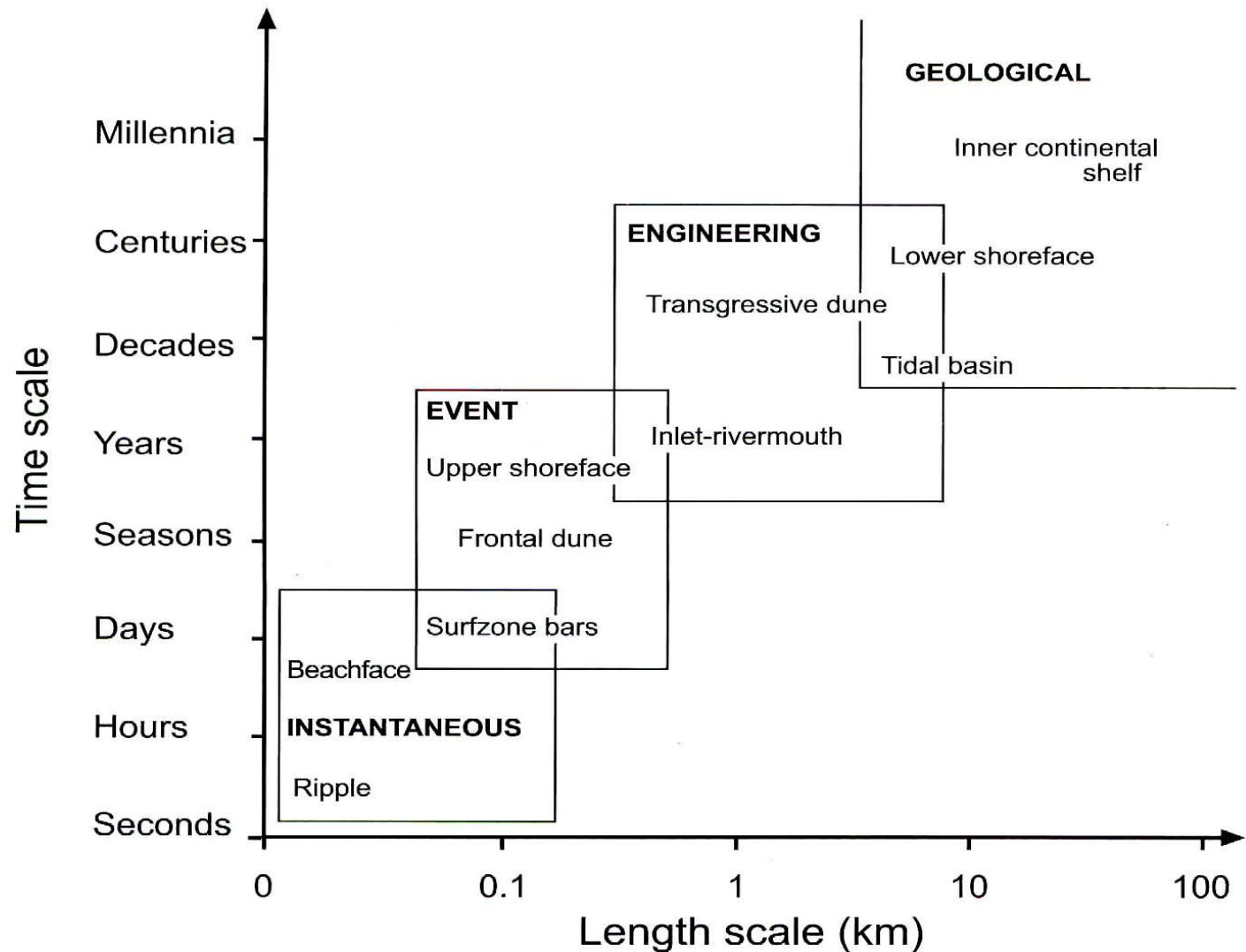
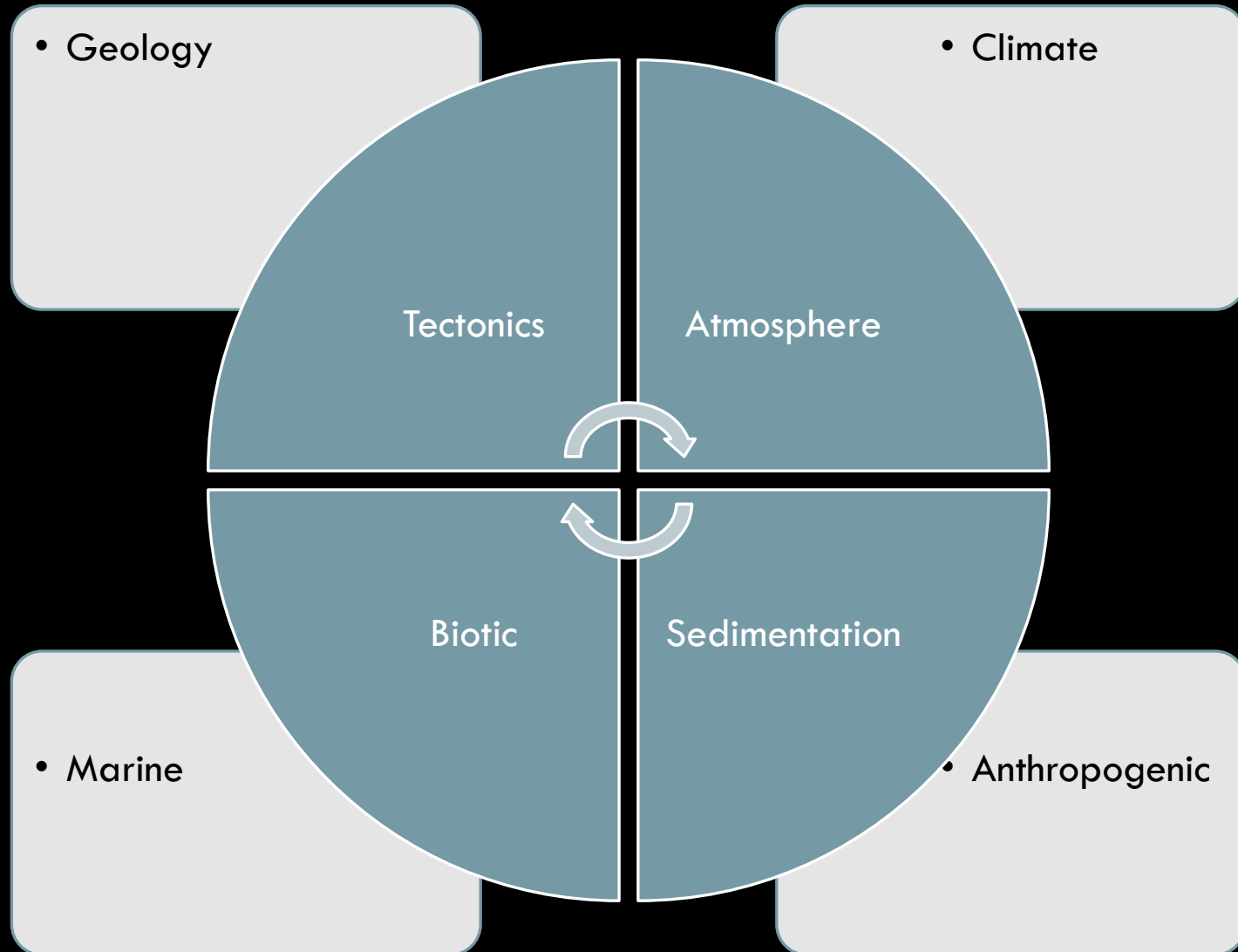


Figure 1.2 – Definition of spatial and temporal scales involved in coastal evolution. Large-scale coastal landforms operate over long time scales, whereas small-scale coastal features respond over short time scales. [From Cowell and Thom, 1994.] [Copyright © 1994 Cambridge University Press, reproduced with permission.]

Coastal Importance

- Arguably the most intensely used of all habitats
- Arguably the largest biodiversity gradient on the planet
- 40% of the global pop. Live within 100km
- The CCSR (2006) report predicted that between 1995 and 2025 there will be a global 35% increase in population living within 60 miles of the sea which will be more than 75% of the total global population (Edgren, 1993).
- Changing population is not distributed equally due to the topography and proximity to the sea (Carter, 1988; Small and Nicholls, 2003)
- This dynamic coastal demography makes policy research crucial due to its impacts (Leatherman, 2001) on increased consumption of water, energy, production of waste and coastal infrastructure (Benoit and Comeau, 2005).
- Sea level rise (approx. 3mm/yr), delicate historical and ecological inheritance makes policy considerations particularly challenging (House & Phillips, 2011).
- Intergovernmental Panel on Climate Change (IPCC) coasts and climate change (Masselink, 2011)
- List the physical factors that influence the interface between terrestrial and marine environments.

Coastal factors



Eustatic SL Change

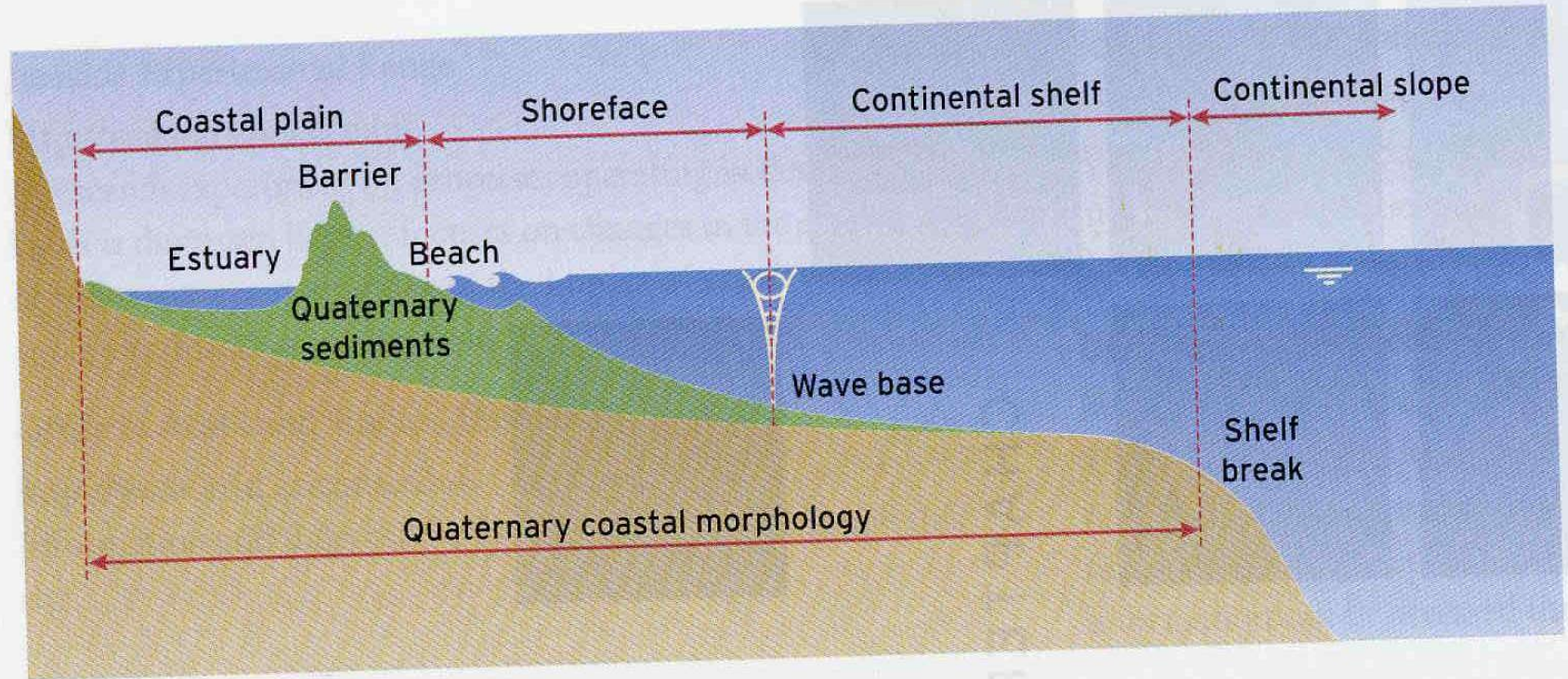
SEA-LEVEL RISE

It has become clear over the past few decades that global sea level is rising at an accelerated rate. Figure 17.2 shows the change in global sea level over the last 150 years reconstructed by Church and White (2006) from an extensive analysis of tide-gauge records and satellite altimeter data. The sea-level curve shows a modest rate of rise of about 1 mm yr^{-1} around 1850, increasing to about 3 mm yr^{-1} at present.

The Intergovernmental Panel on Climate Change (IPCC) has published its Fourth Assessment Report (AR4) which addresses at length the causes and implications of the current and future rise in sea level (IPCC, 2007a, 2007b). Four main contributing factors to the current sea-level rise have been identified: (1) thermal expansion of the ocean water due to an increase in the water temperature; (2) melting of mountain glaciers and ice caps; (3) melting of Greenland ice sheets; and (4) melting of Antarctic ice sheets.

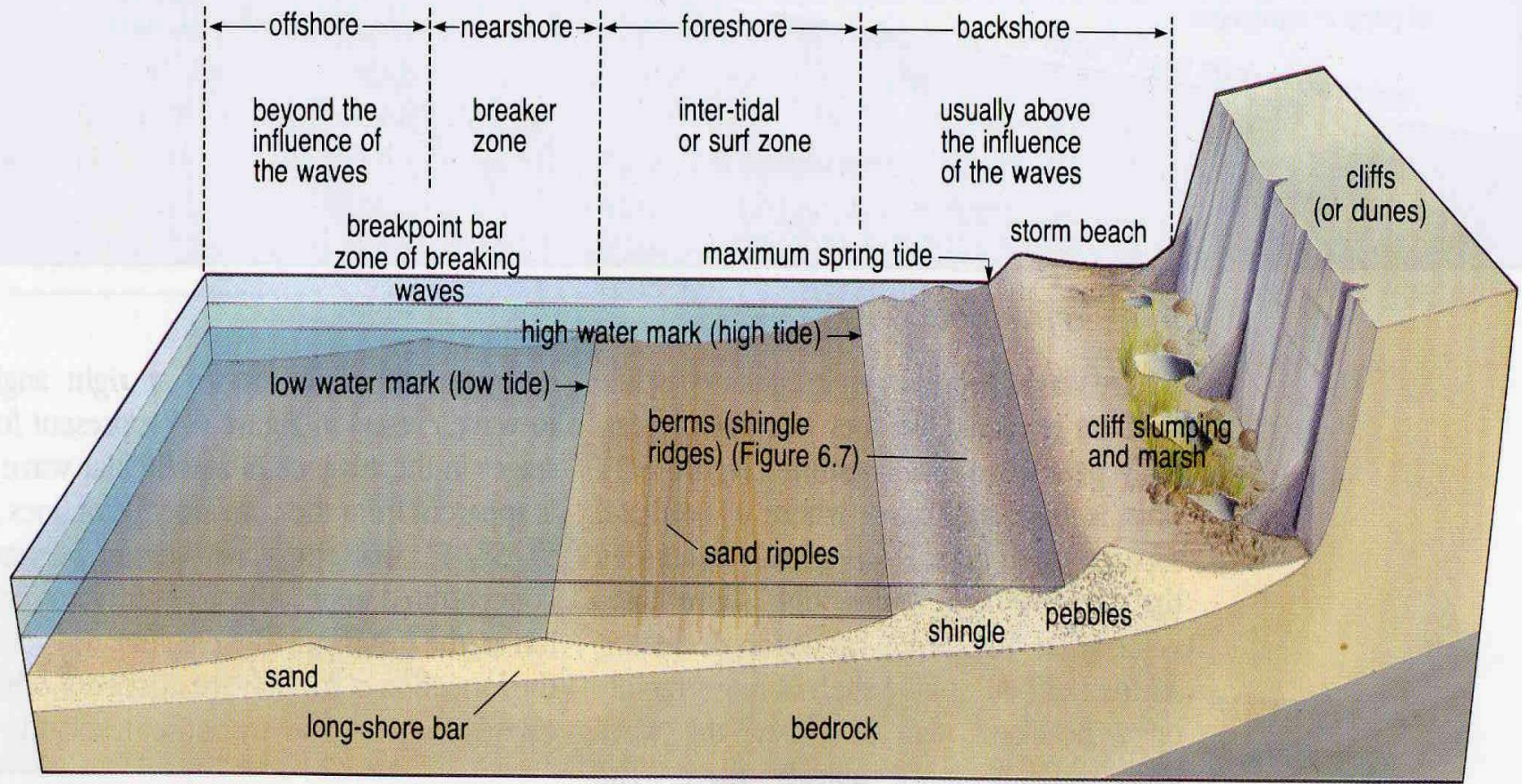
These contributions have been quantified and are listed in Table 17.1. For the observed sea-level rise from 1961 to 2003 (1.8 mm yr^{-1}), the cumulative effect of these four factors still left about 0.7 mm yr^{-1} unexplained. However, the use of more sophisticated and comprehensive monitoring has brought to light that melting of Greenland and Antarctic ice sheets has contributed considerably to the observed sea-level rise from 1993 to 2003 (3.1 mm yr^{-1}), leaving only

Coastal Zone Boundaries (Masselink & Hughes, 2003)

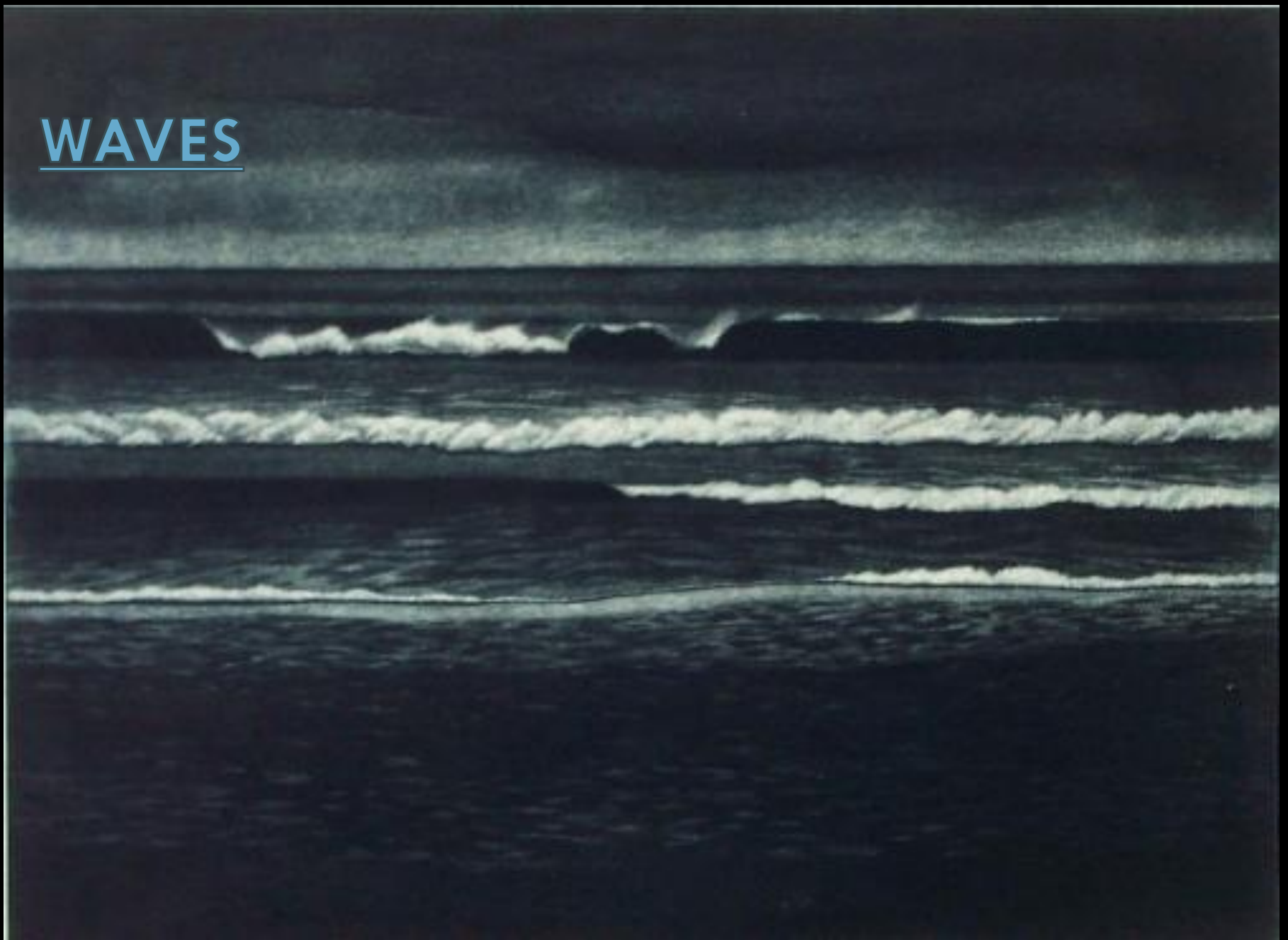


Quaternary coastal morphology

Shoreface: Beach Morphology (King, 1980)



WAVES



Waves

- Wind energy (Except Tsunamis) due to friction
 - Waves from distant storm- Swell
 - Waves from wind in juxtaposition -sea waves
- Deep water waves
- Swell linked to fetch

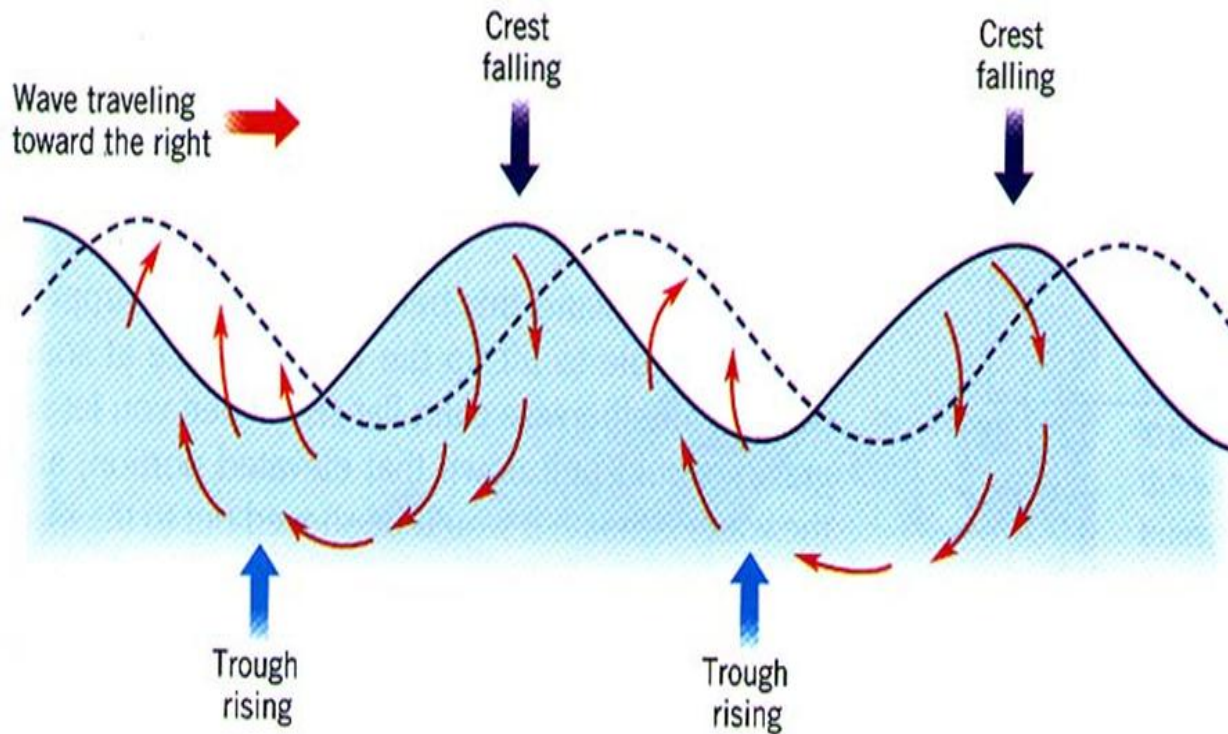
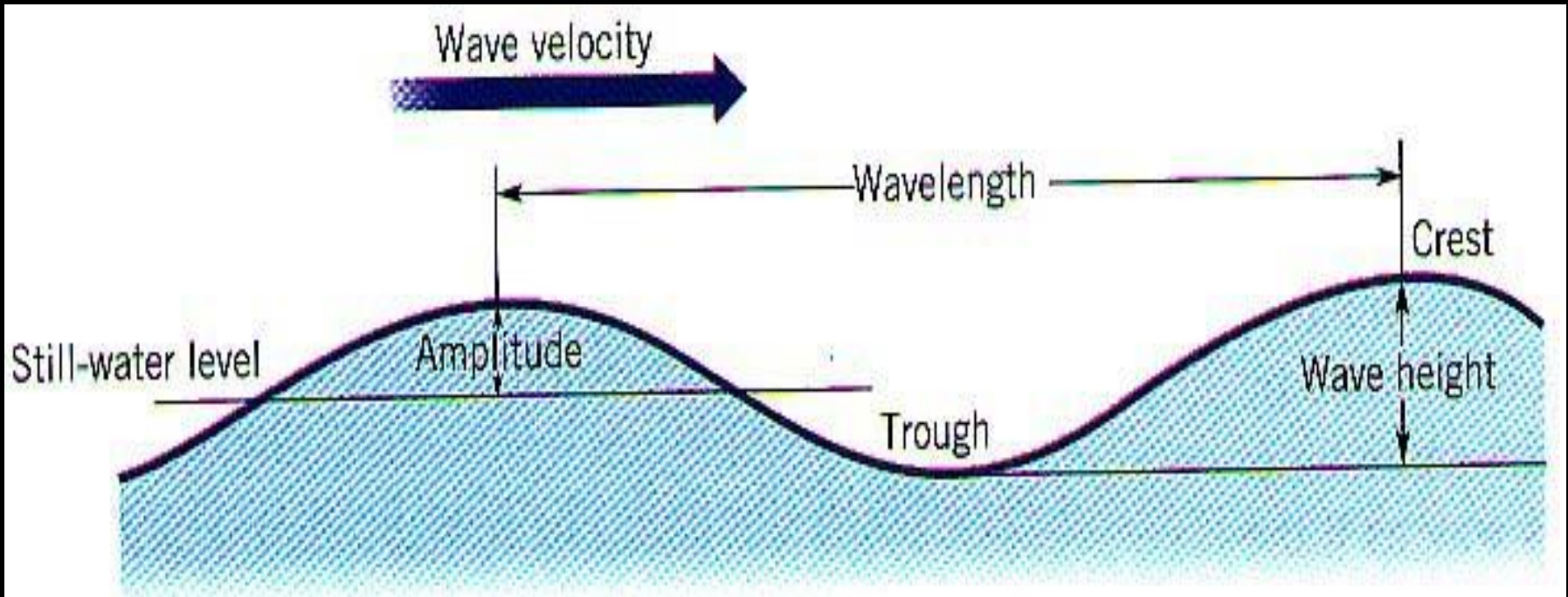


Figure 9.10

Waves travel because gravity pulls the water in the crests downward. Forced out from beneath the falling crests, the falling water pushes the former troughs upward, and the wave moves to a new position, as indicated. (Notice that the actual motion of the water itself beneath these waves is circular or *orbital*, which confirms our experience that we are carried up and forward as the wave approaches, and down and back as it passes.)

Terminology

- Velocity **C** (crest movement in time generally max. 6m)
- Height **H**
- Period Between successive Waves) **T**
- Length (dist. Successive crests) **L**
- Energy **E** (Mean 11 tonnes per m²)
- Steepness **H/L** (Cannot exceed $1:7 = 0.14$)



Linear wave theory

- Deep water: Orbital/sinusoidal symmetrical
- Shallow water: Elliptical (asymmetrical) imp. sediment

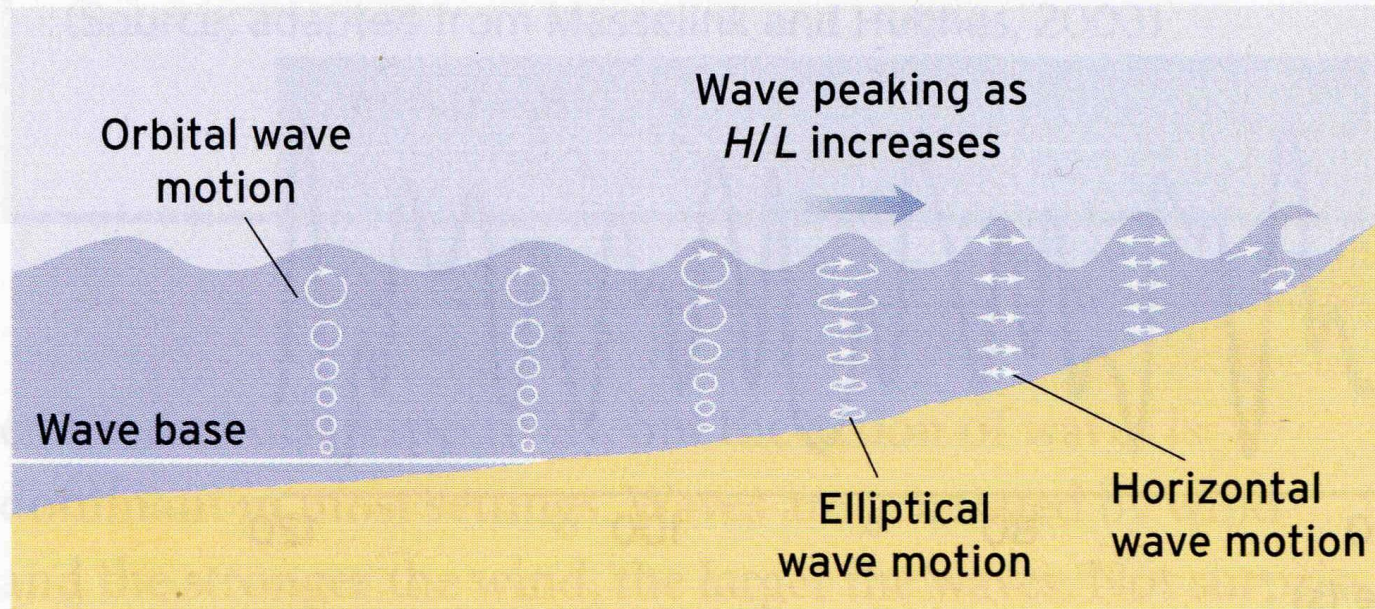
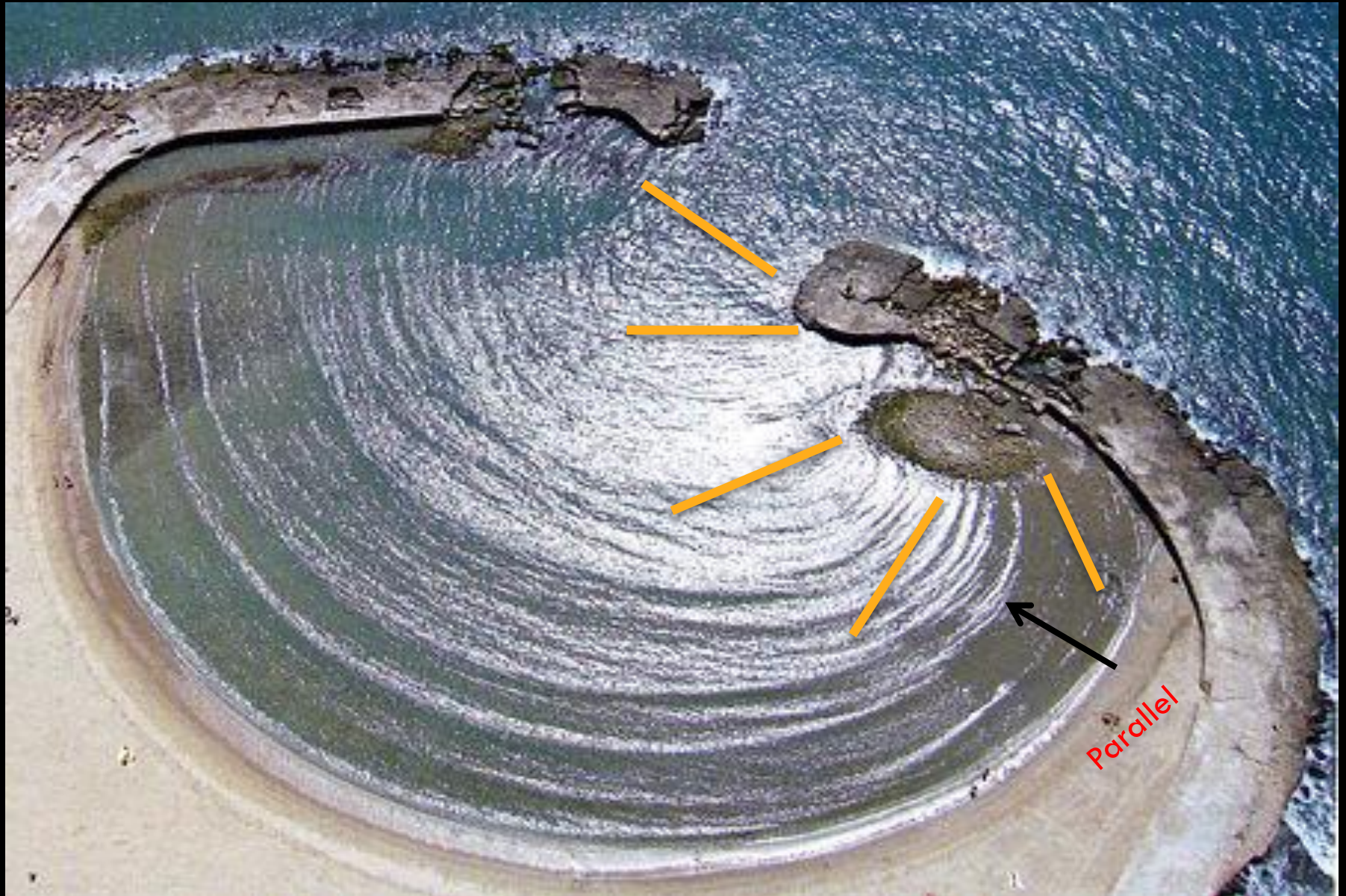
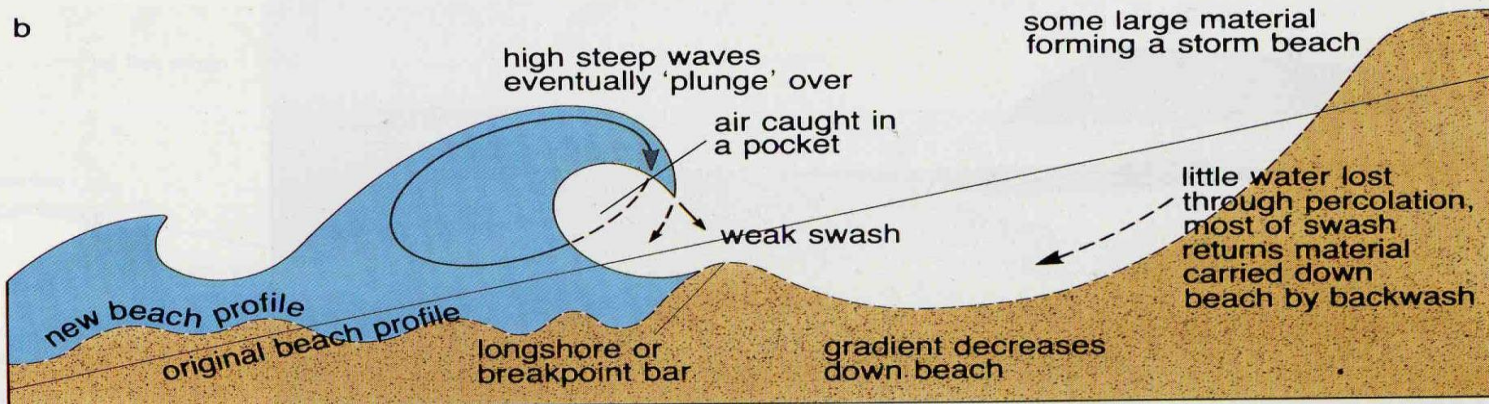
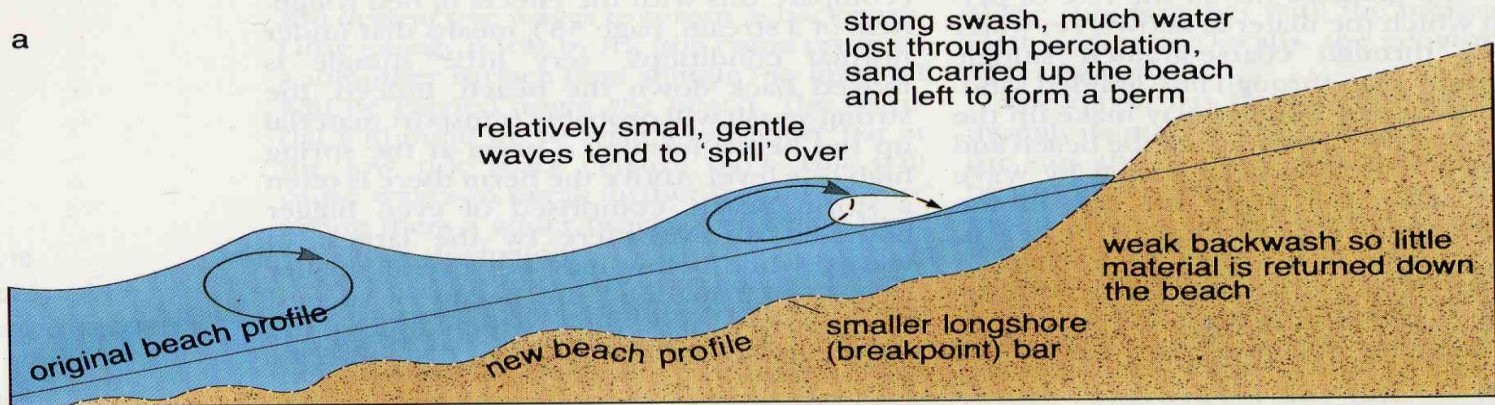


Figure 17.9 Motion of water particles under waves according to linear wave theory.

Wave characteristics



Shallow processes



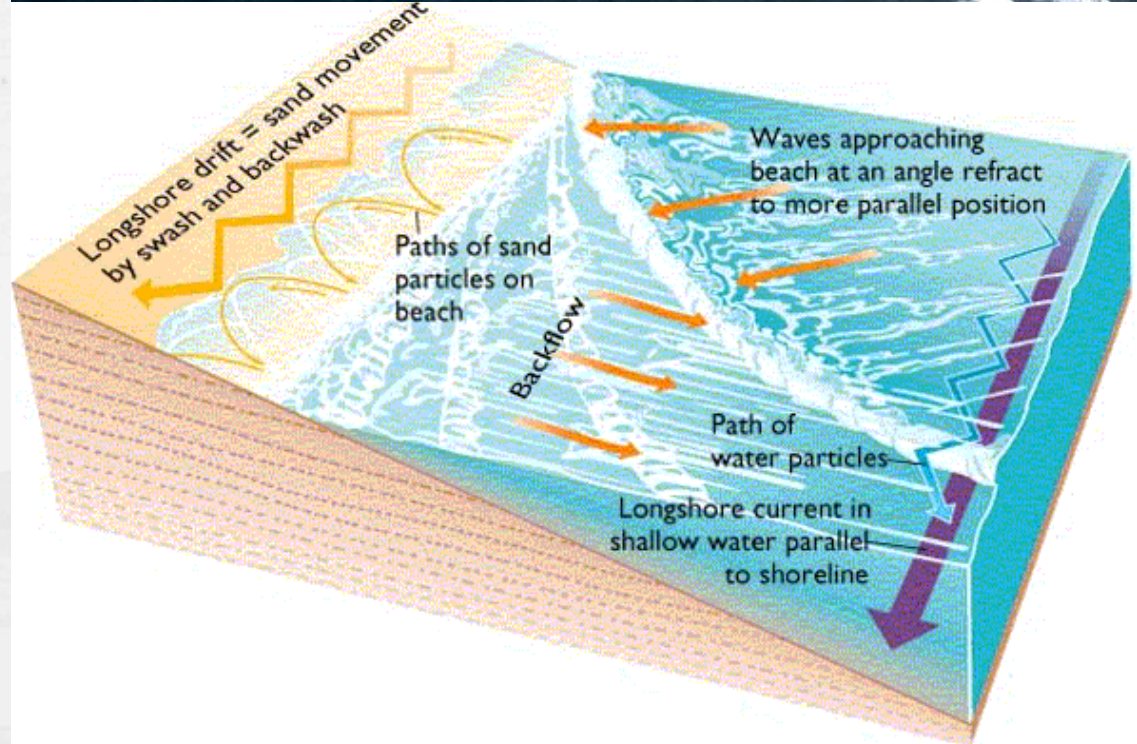
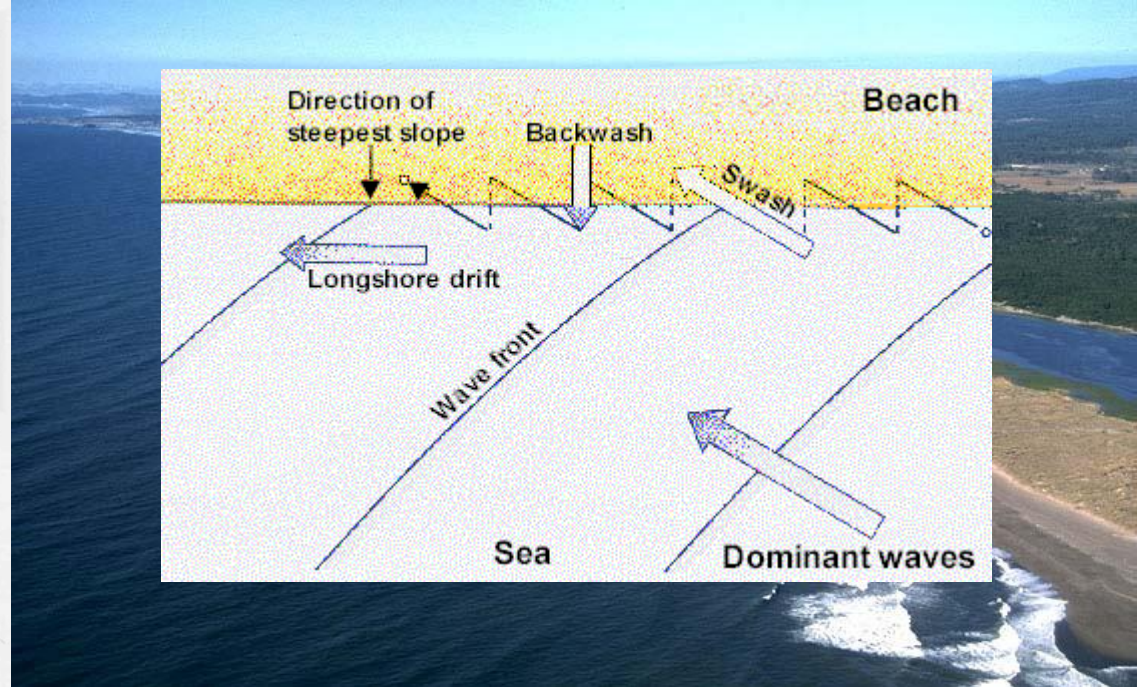
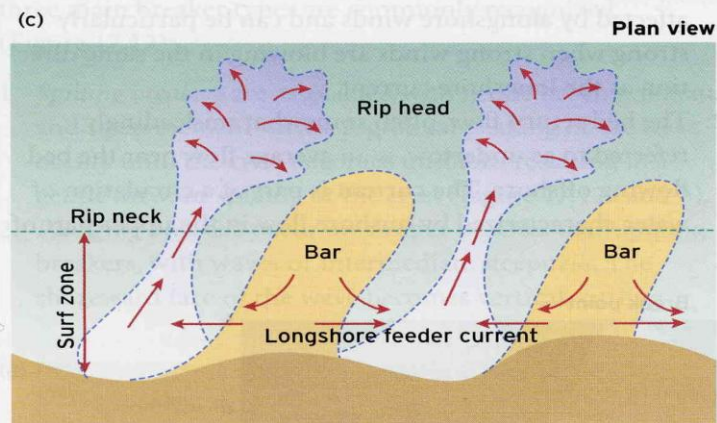
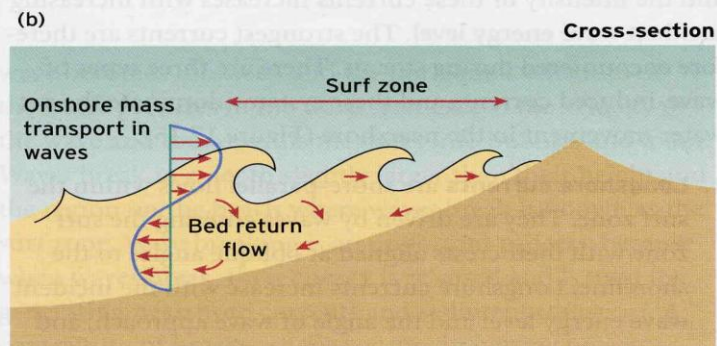
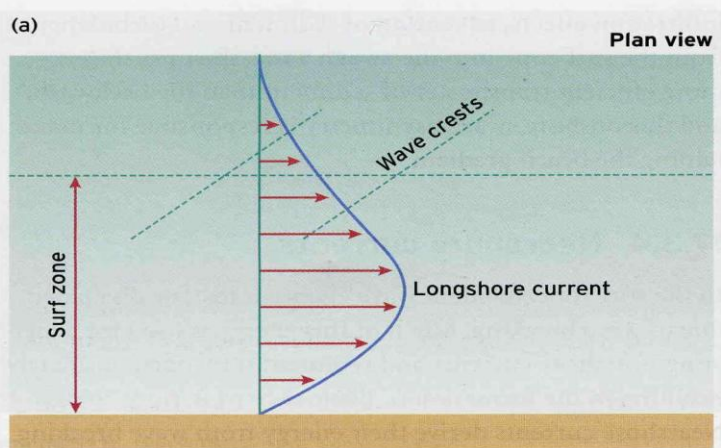


Figure 17.15 Quasi-steady currents in the surf zone: (a) shore-parallel longshore currents due to obliquely incident waves, (b) vertically segregated bed return flow or undertow and (c) horizontally segregated rip currents as part of the nearshore cell circulation system. (Source: after Masselink and Hughes, 2003)

TIDES

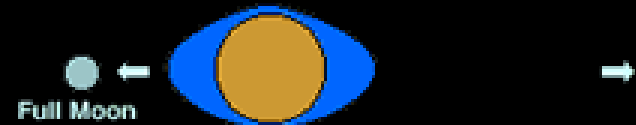
- Complicated (12.5 hours lunar component 12 hour solar)
- Tidal range (What is it for Swansea? Is this significant? Why?)
 - Twice daily
 - Micro <2m
 - Meso 2-4m
 - Macro >4m
- Spring
- Neap (moon around earth 28 days therefore neap to neap 14 days)

Tides

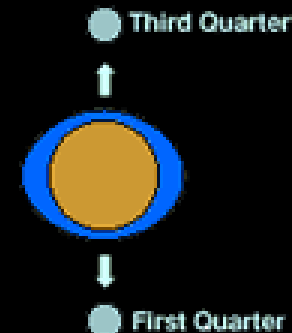
Spring Tide:
new moon



Spring Tide:
full moon



Neap Tides:
quarter phases of moon



The Moon has a 70% effect on the tides and the Sun has a 30% effect on the tides

Tidal Zones on a rocky ocean shore

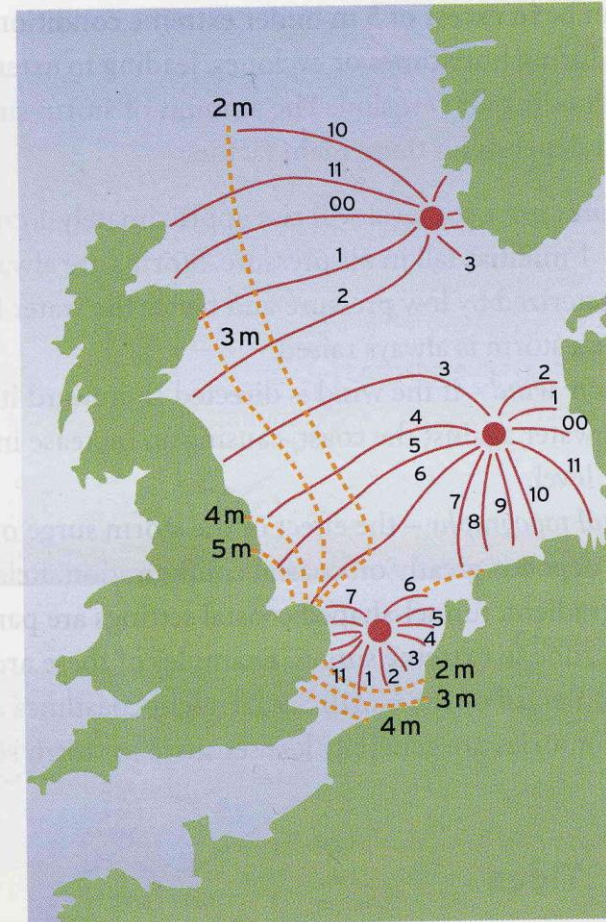
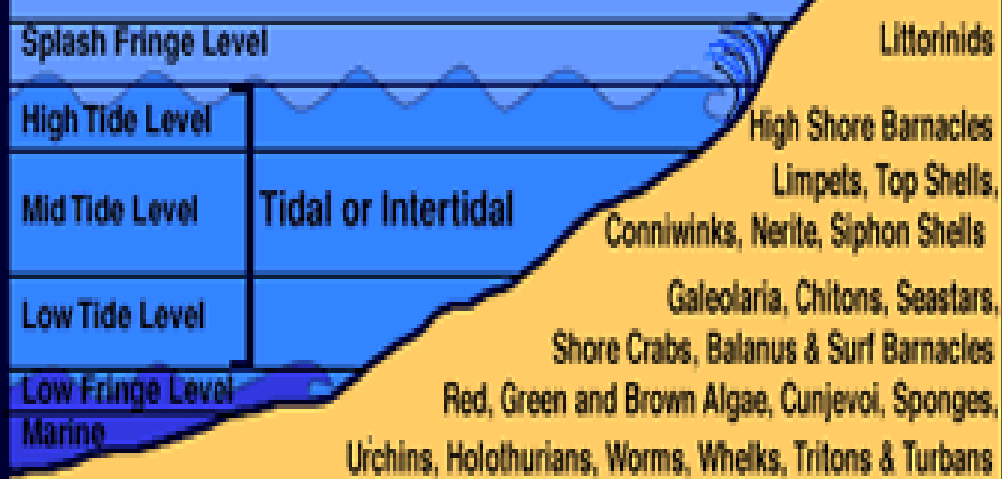


Figure 17.18 Map showing amphidromes in the North Sea. The dashed lines are lines of equal tidal range, whereas the solid lines show how the tidal wave propagates in an anticlockwise direction around the centre of the amphidrome. The numbers indicate where the tide is at the same stage in the tidal cycle (in hours). Along a line labelled '1', for example, the tide is one hour into the tidal cycle. (Source: Masselink and Hughes, 2003)

Storm Surge

- Higher sea level than expected high tide (5m)
- Why?
 - Low pressure (1cm rise for every 1 millibar fall)
 - Coastal topography (funnel e.g. Bay of Bengal)
 - Onshore winds
 - Hurricane
- February 1953 in the North Sea
- New York
- **What is the impact on coastal conservation?**
 - Habitat destruction and creation

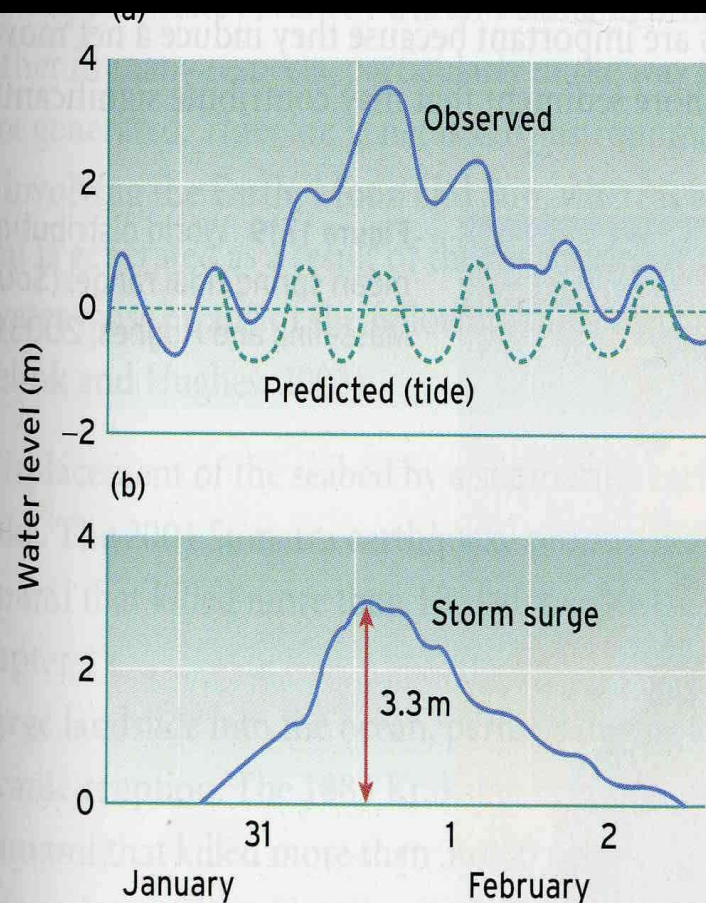


Figure 17.17 (a) Graph showing the predicted (dashed line) tidal water level and observed (solid line) water level at the Hook of Holland, January to February, 1953. (b) Graph showing the residual tide, which is attributed to storm surge, reached 3.3 m. (Source: Masselink and Hughes, 2003)

Tsunami

- Displacement of a body of water (Masselink, 2008)
 - Submarine earthquake (2004 Sumatra 100,000 dead, habitat destruction)
 - Landslide into the ocean (Krakatau, 1883 36,000, habitats changed and gave opportunity for recovery)
 - Impulse from meteorite impact (geological evidence of mega-tsunami (Bryant, 2001)
- **Open ocean:** long wavelength (100s km) and height $< 1\text{m}$ but typically speeds of 700km hour in depths of 5km
- **Continental shelf:** shoal and reduce wavelength, increase height
- **Shore:** tens of metres in height, devastation in a short period of time



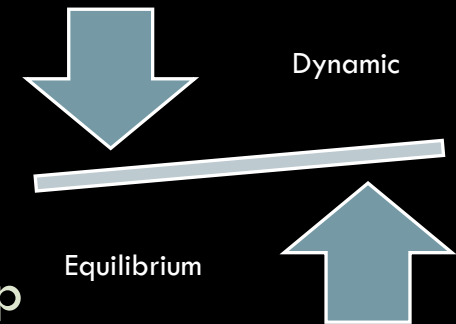
SYSTEMS

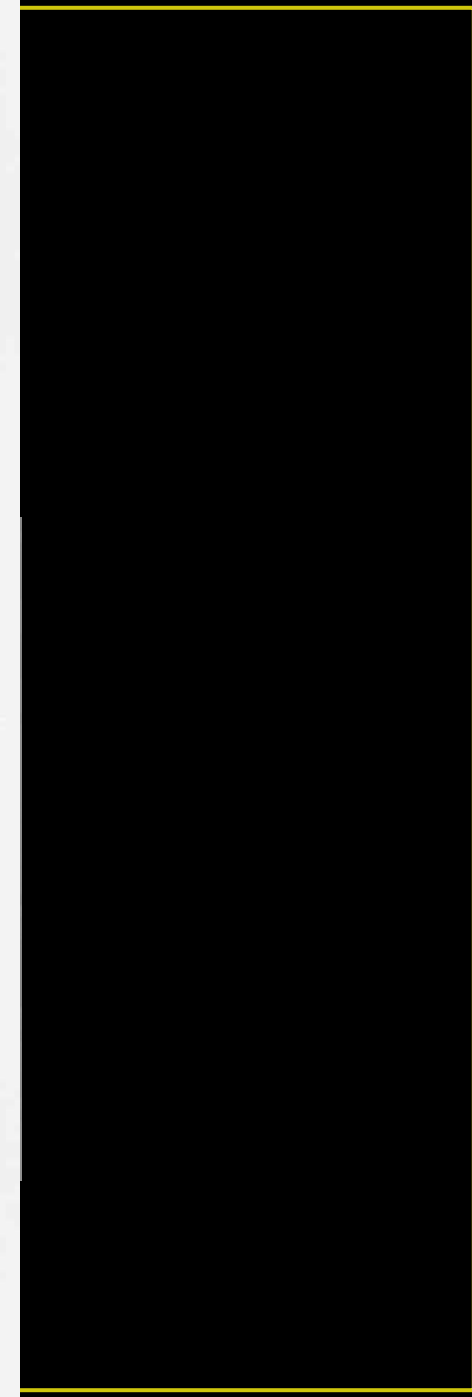
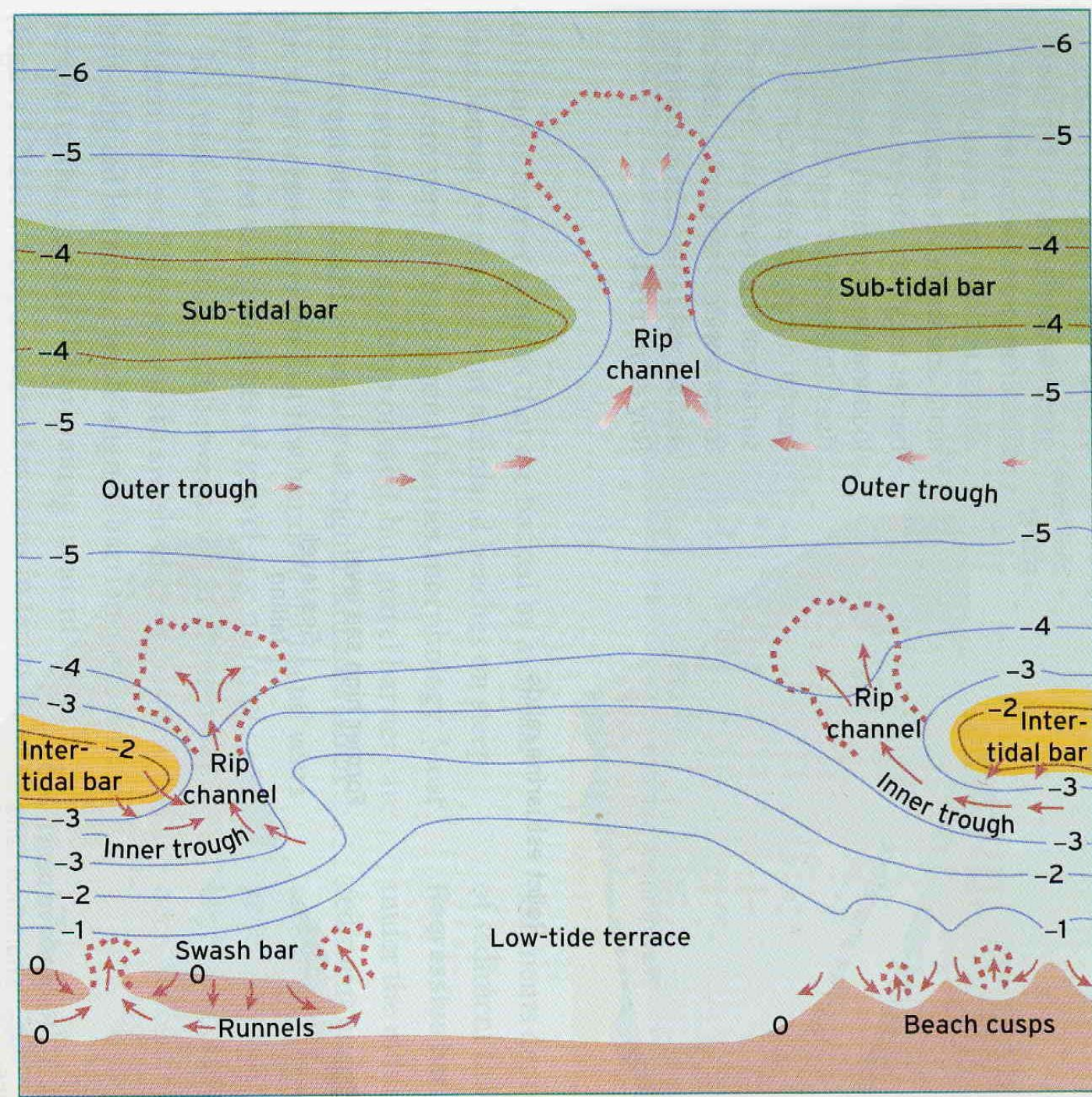
- 4 main factors in beach systems
 - Tide
 - Sediment (size)
 - Wave period (T)
 - Wave height



Beach type

- Described between: wide & flat to narrow & steep
- Wave dominated or tide dominated
- Sand Wet sand reduces percolation
 - Therefore limited energy loss (most of the energy returns in backwash)
 - Creates a longshore bar at low tide mark (hence waves break further from the shore=energy dissipation) **How could beach nourishment help coastal communities?**
 - If sand dries in prevailing/strong winds sand dunes form beyond backshore
- Dynamics between waves, sediment and beach profiles. Generally:
 - Destructive waves move material seawards (plunging/surfing) ($H > 1\text{m}$, L approx 20m, T 10-14 per min.)
 - Constructive move material landwards (surging/spilling) ($H < 1\text{m}$, L approx 100m, T 6-8 per min.)
 - Shingle beach moves material landwards
 - Sand moves material seawards





Sediment budgets

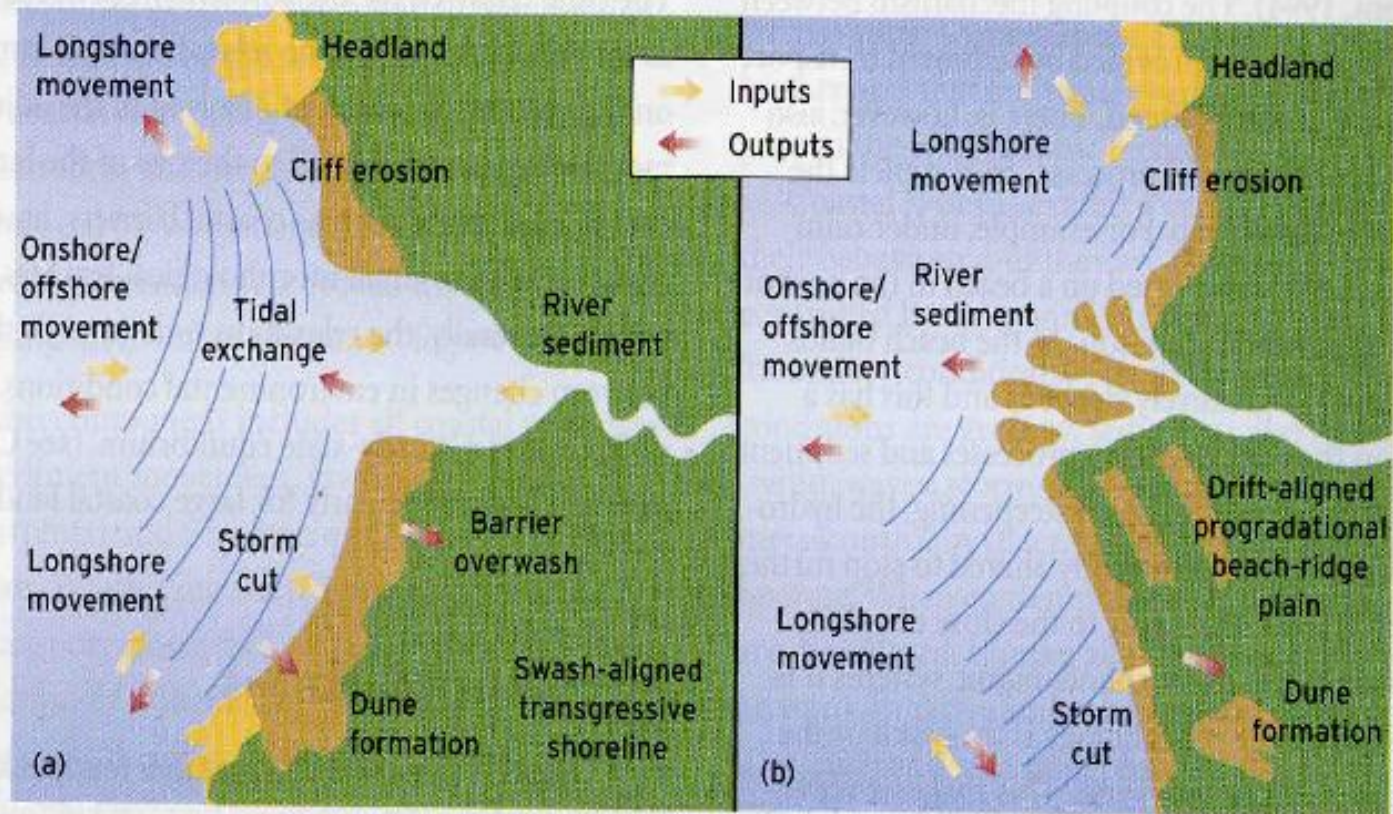
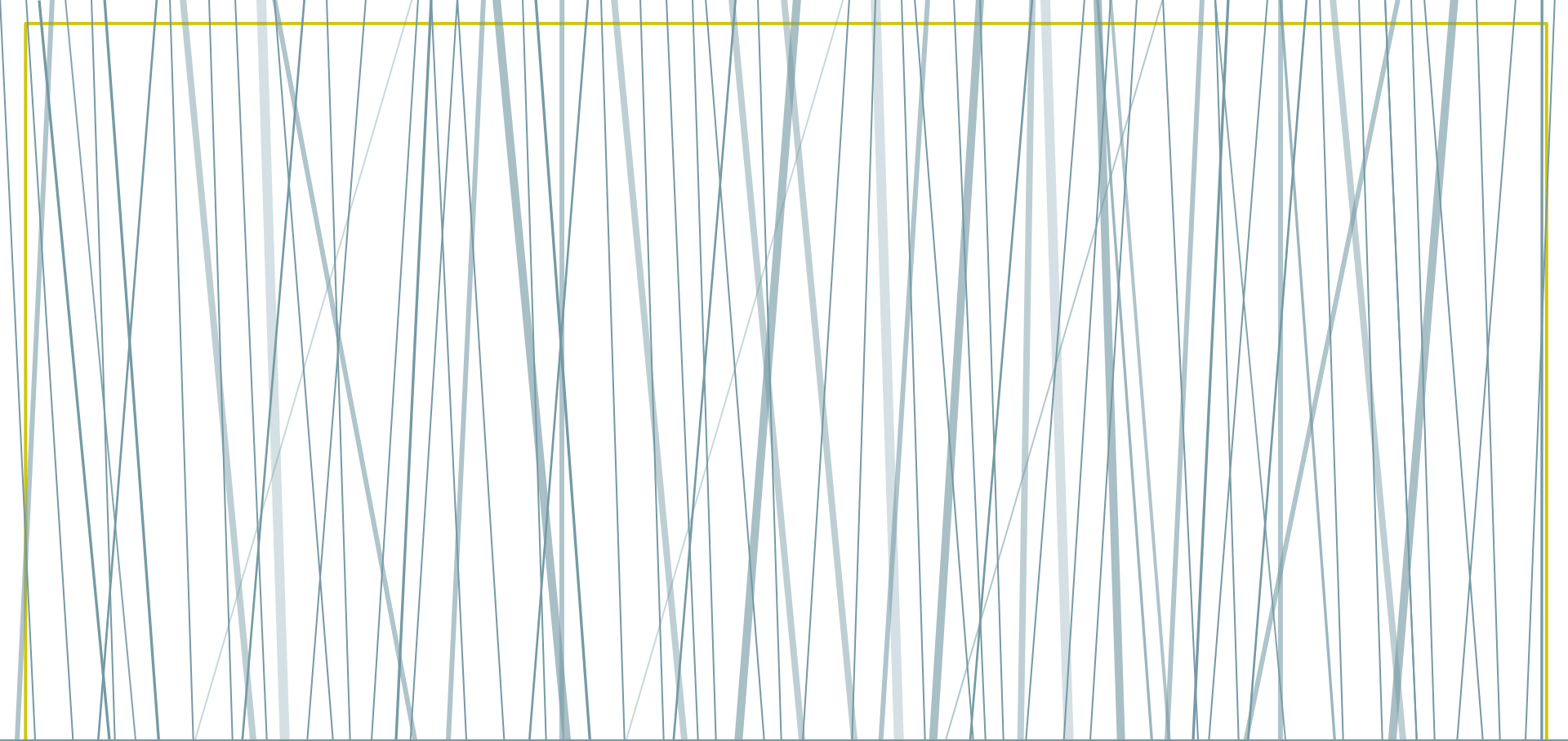


Figure 17.5 Qualitative examples of coastal sediment budgets. (a) Riverine sediment may be deposited into an estuarine embayment, which may also receive sediment from the seaward direction through tidal processes. (b) On a deltaic coast, riverine sediment contributes to the coastal sediment budget, and is moved up the drift-aligned coast, giving rise to a beach-ridge plain. (Source: adapted from Masselink and Hughes, 2003)

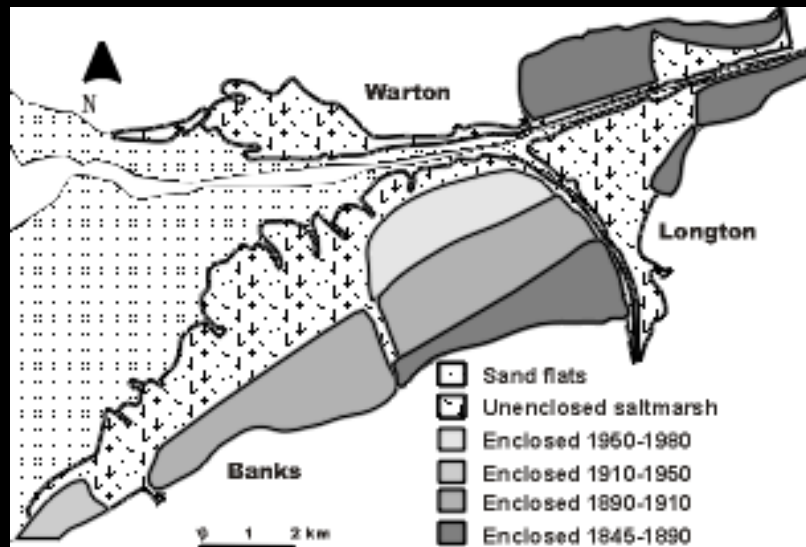


Erosion and deposition

Processes and landforms

EROSION

- The loss of land or encroachment by the sea through a combination of wave attack and, in the case of coastal cliffs, slope processes (e.g. high groundwater levels). This may include cliff instability, where coastal processes result in the periodic reactivation of landslide systems or promote rock falls. (DEFRA 2004)
- 70% of sandy coastlines are eroding (Bird, 1985)



Erosion

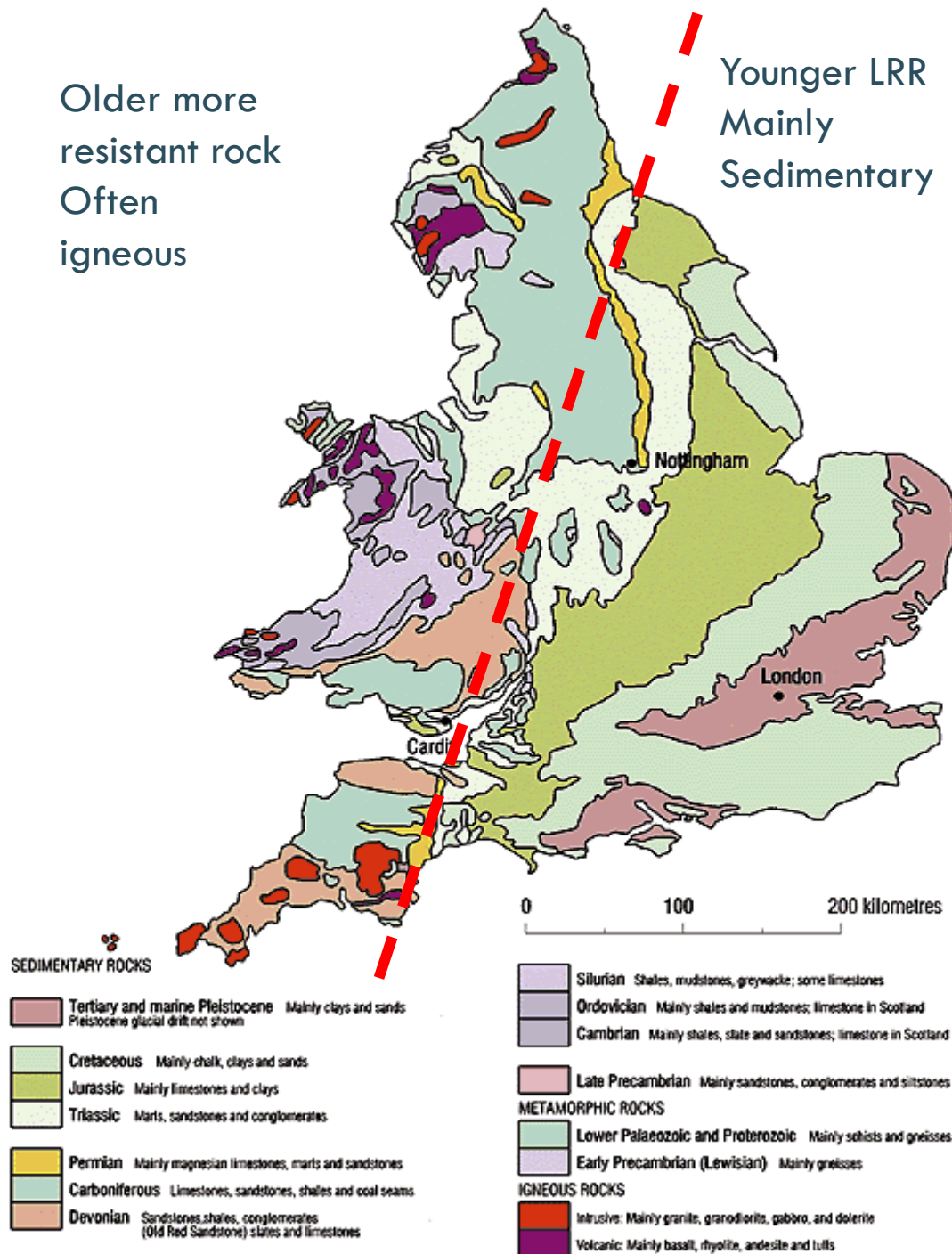
- *Hydraulic Action*
 - The waves hitting the cliffs apply pressure to the air in the cracks and pores within the rocks. This causes an increase in pressure in the pores and cracks causing them to implode.
- *Abrasion/ Corrasion*
 - Various sediment grades (LOAD) are used by the sea as a tool, the sediment is hurled at the base of the cliff by the sea, breaking off other sections of rock. (Esp. Exposed coasts)
- *Attrition*
 - Sediments colliding progressively reduce in size
- *Corrosion*
 - This occurs within granular rock, for example
 - The sandstone at Black Gang Chine., I of Wight. With the rise and fall of the tide the salt within the sea water crystallises within the pores and breaks the rock apart from the inside.
 - Chemical reaction e.g. Carbonic acid in L/S coasts
 - Also secretion from blue/green algae

Erosion cont'd

- *Wave Pounding*
 - *The action of the waves hitting the cliff base and breaking it up. (could be 30 tonnes per m² and seawalls may need replacing every 25yrs (Waugh, 2009))*
- *Sub-aerial*
 - *From above, water, freeze thaw etc. Leads to slope processes*
- *Anthropogenic*
 - *Especially influences rate and cost but the processes are the same.*

Older more
resistant rock
Often
igneous

Younger LRR
Mainly
Sedimentary



Erosional Landforms

- Headlands & bays

Plummer et al, 1985

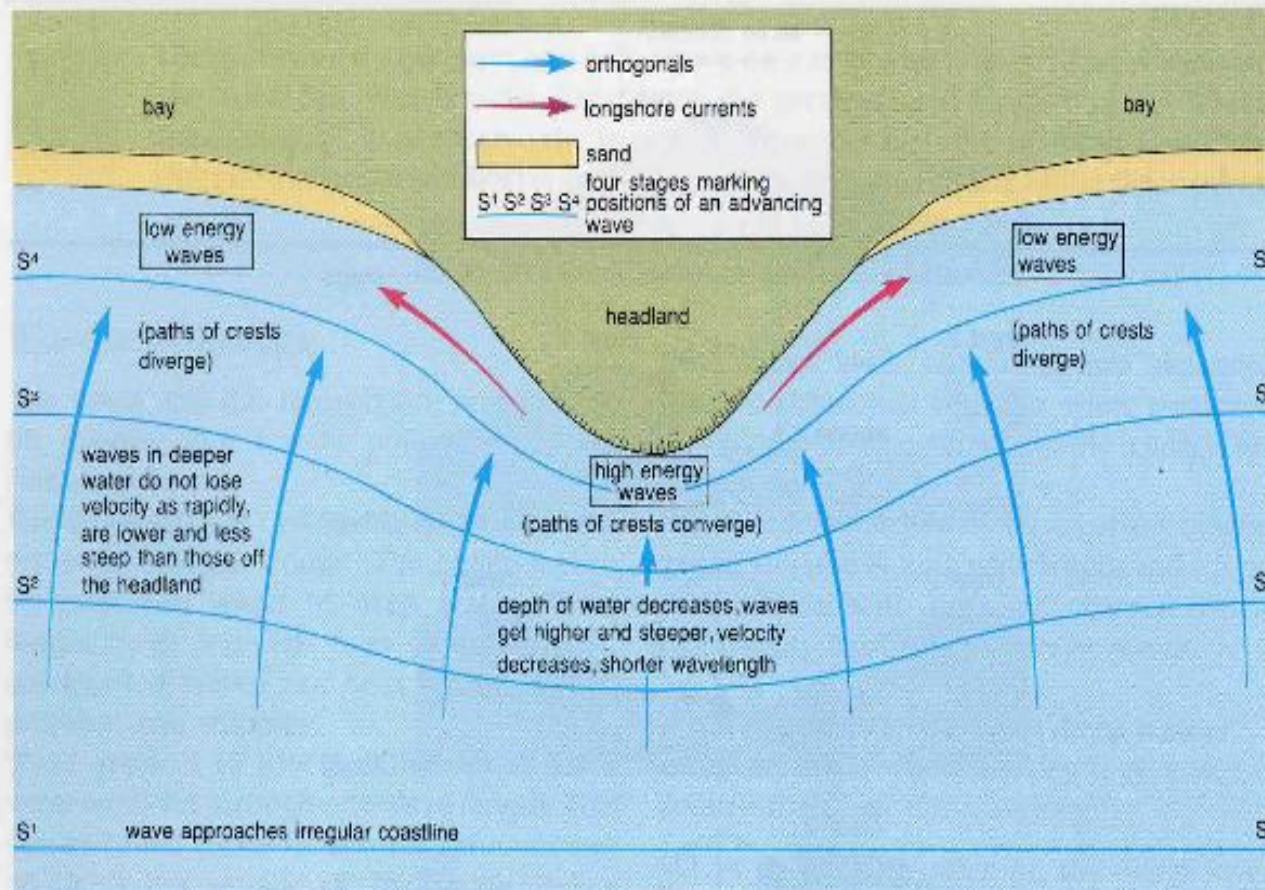
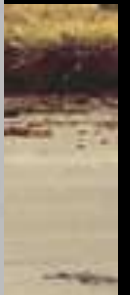
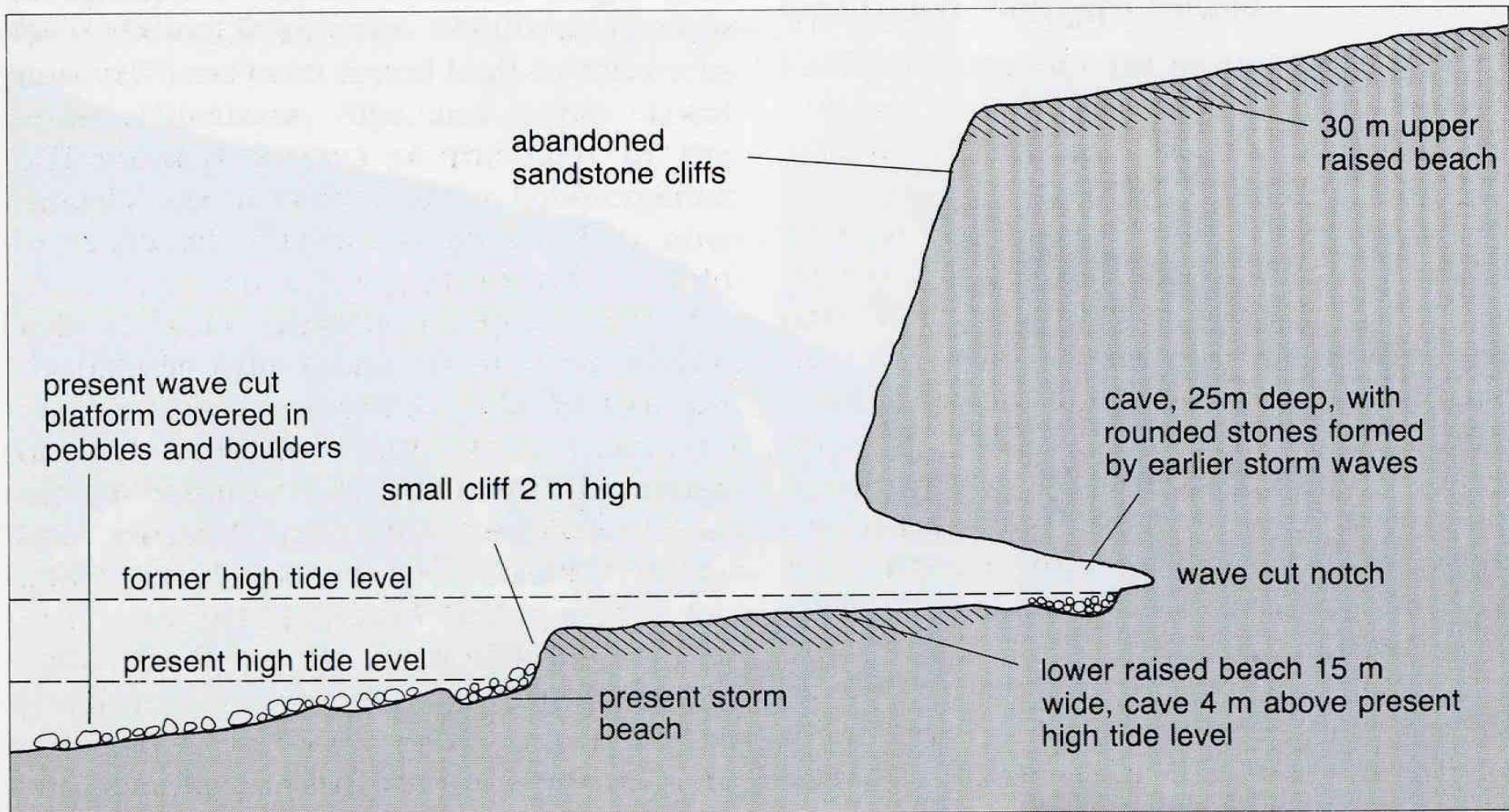


Figure 6.5

Wave refraction at a headland



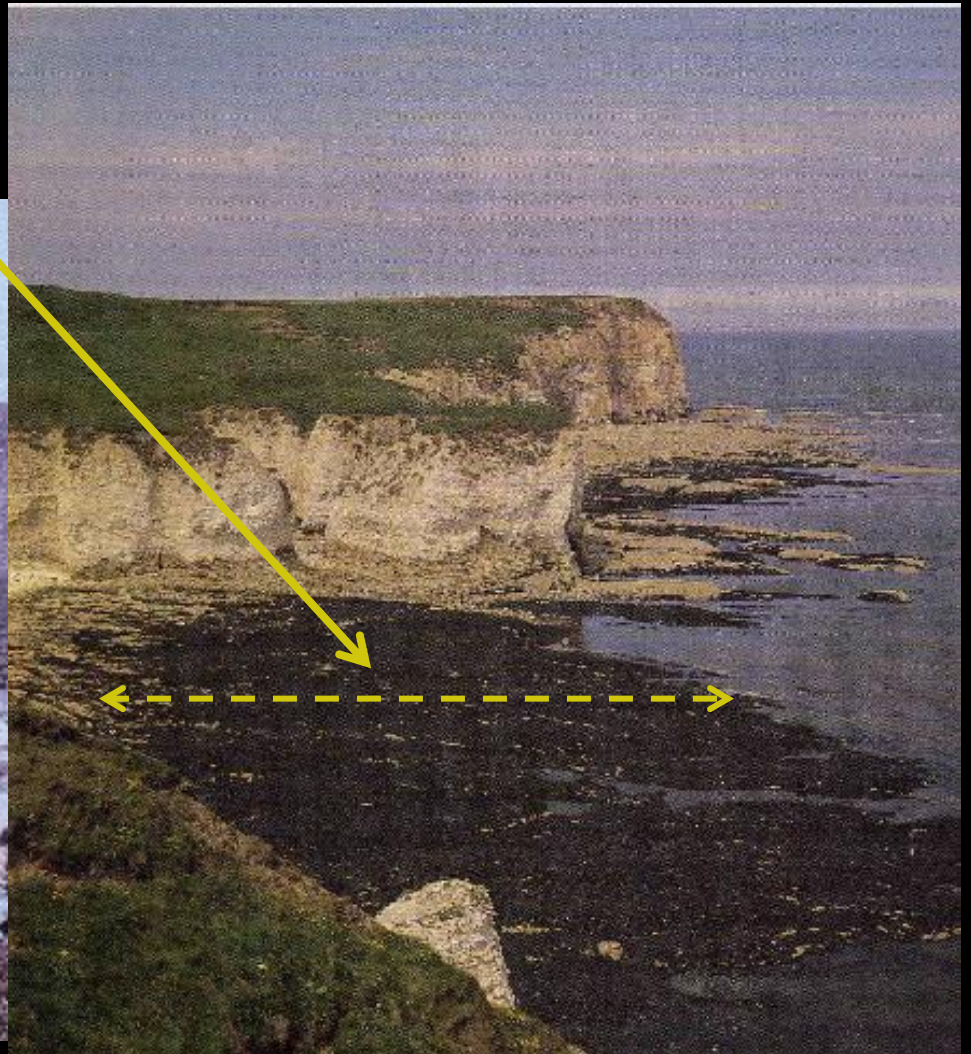
Notch



Flamborough Head, Yorks.

Wave cut notch

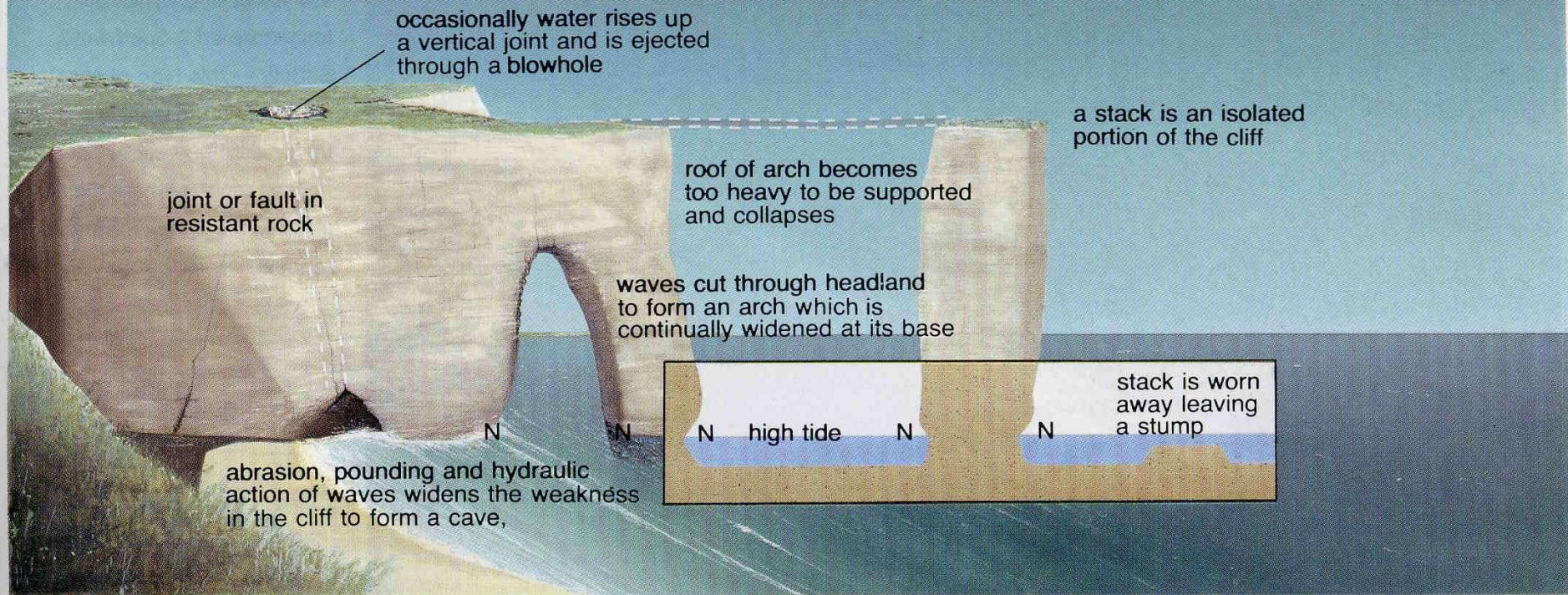
Wave cut platform





headland e.g. Flamborough Head

N = wave cut notches



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Cliffs (80% world's coasts Masselink, 2010)

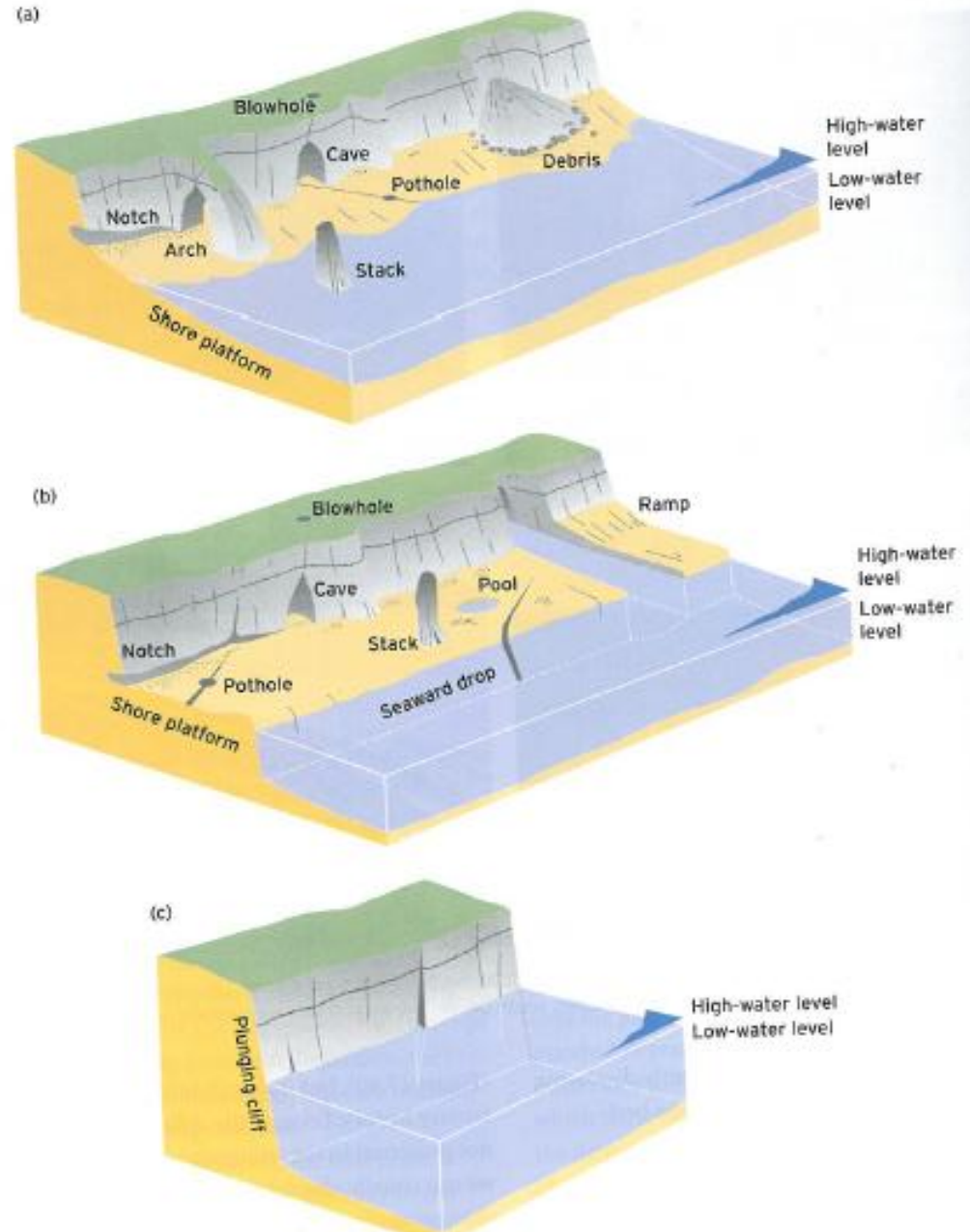
- Relative rates of sediment supply and removal
- Rate is principally associated with rock type & form
- Erosional coasts
 - Sloping shore platforms
 - Sub-horizontal shore platforms
 - Plunging cliff
- Processes
 1. Episodic Mass movement (slope processes)
 2. Rock break-down (coastal erosion processes)
 3. Marine rock removal (Marine processes)



Sunamura, (1992)

Morphology

- Major morphologies on rocky coasts.
Erosional features:
 - a) Sloping shore platform
 - b) sub-horizontal shore platform
 - c) plunging cliff(Sunamura, 1992;
Masselink, 2008)



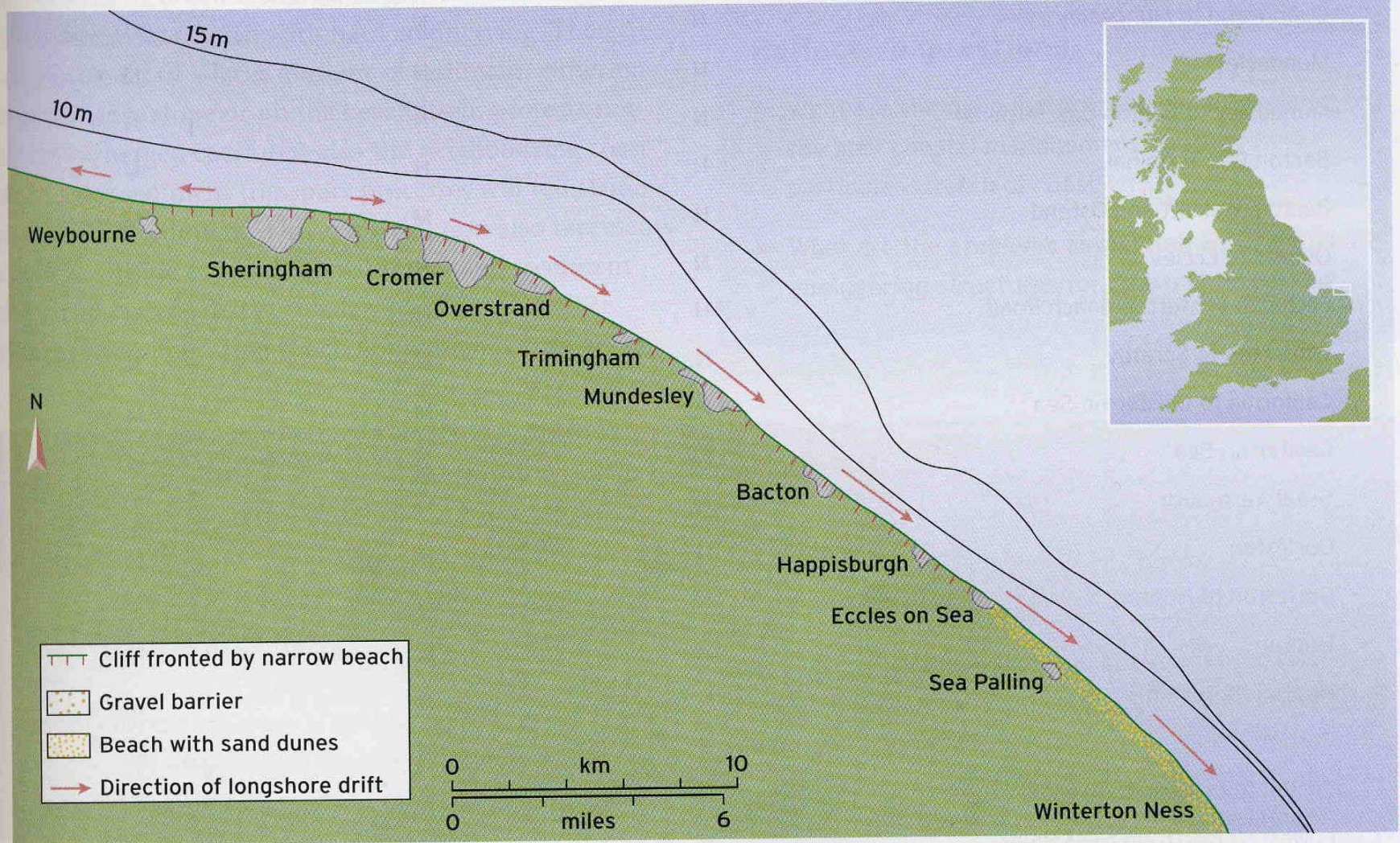


Figure 17.43 The north Norfolk coast is characterized by large littoral drift rates (up to $400\,000\text{ m}^3\text{ yr}^{-1}$) and rapidly eroding soft cliffs ($1\text{--}2\text{ m yr}^{-1}$). Holding the line is not sustainable and the preferred management option for most of this coastline is managed realignment.

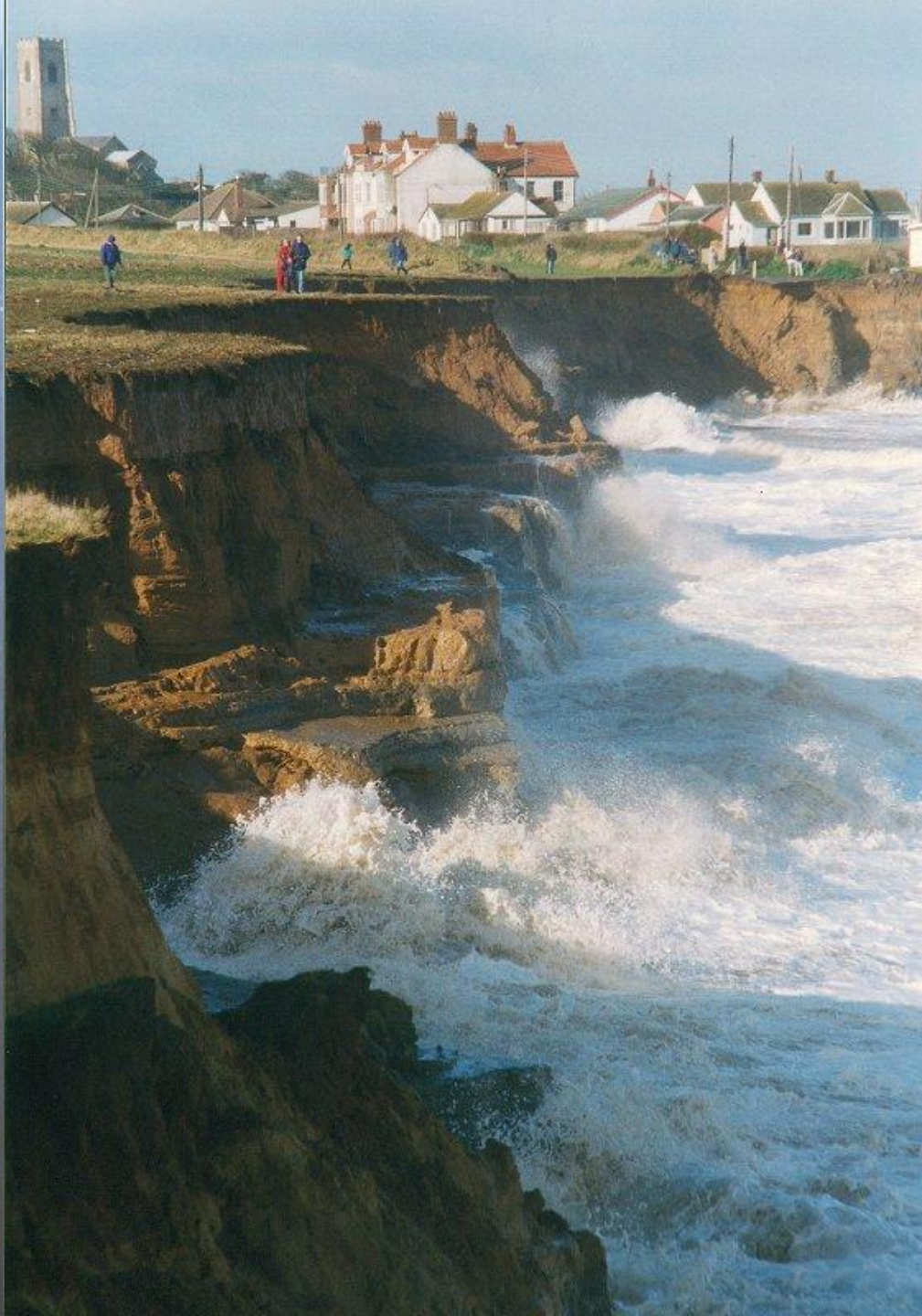




(C) Mike Page 31.05.2004



26.10.2004 (c) Mike Page



DEPOSITIONAL LANDFORMS

- Beaches
- Spits
- Dunes
- Saltmarsh
- Bars and tombolos
- Cuspate forelands (e.g. Dungeness) 2 LSD from opposite directions meet to produces ridges at 90° to each other
- Barrier beaches and islands
 - How do these depositional features influence habitat management?
 - Why is it important to study coastal processes for habitat management?
 - What maybe the influence of SL rise?



Queensland

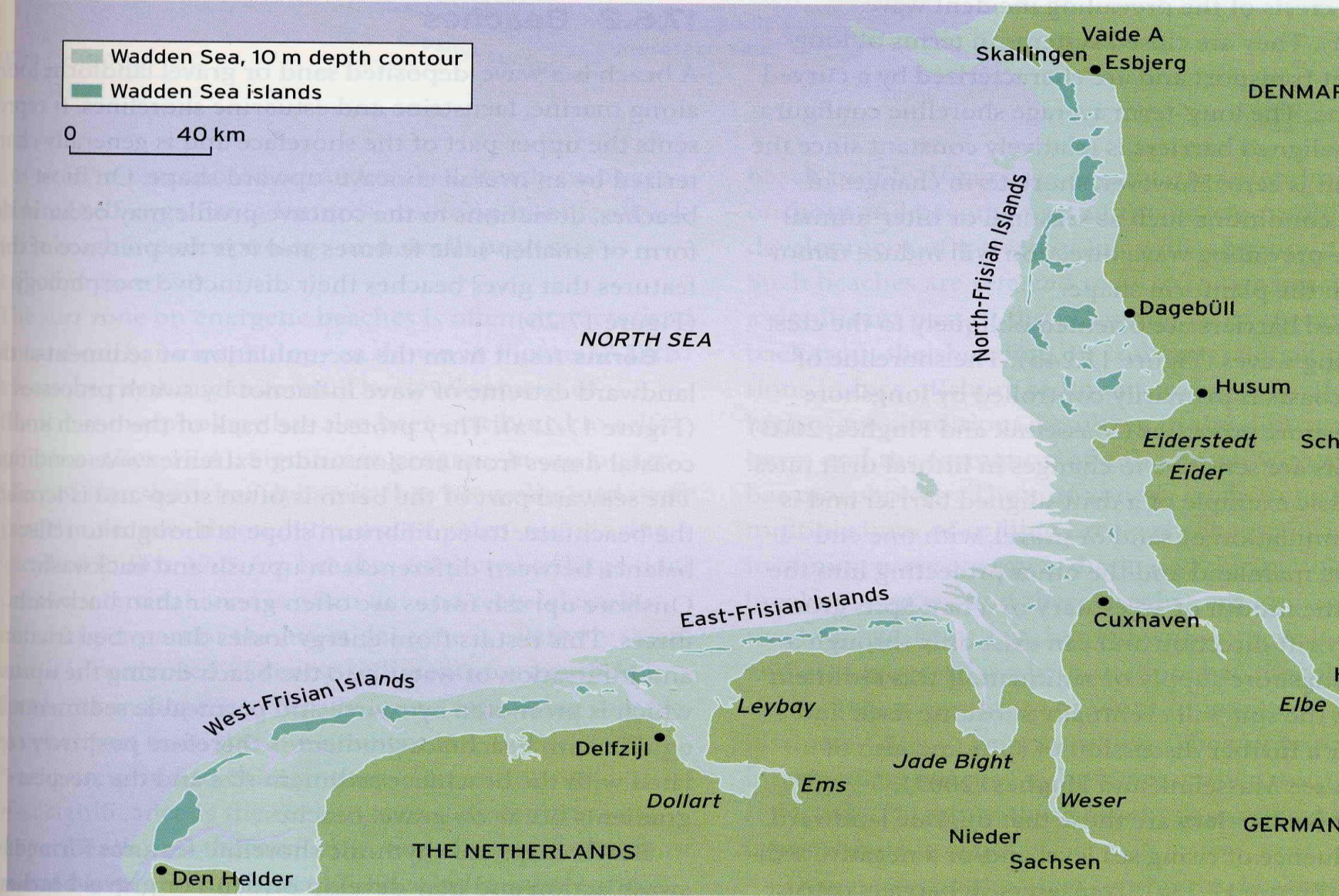
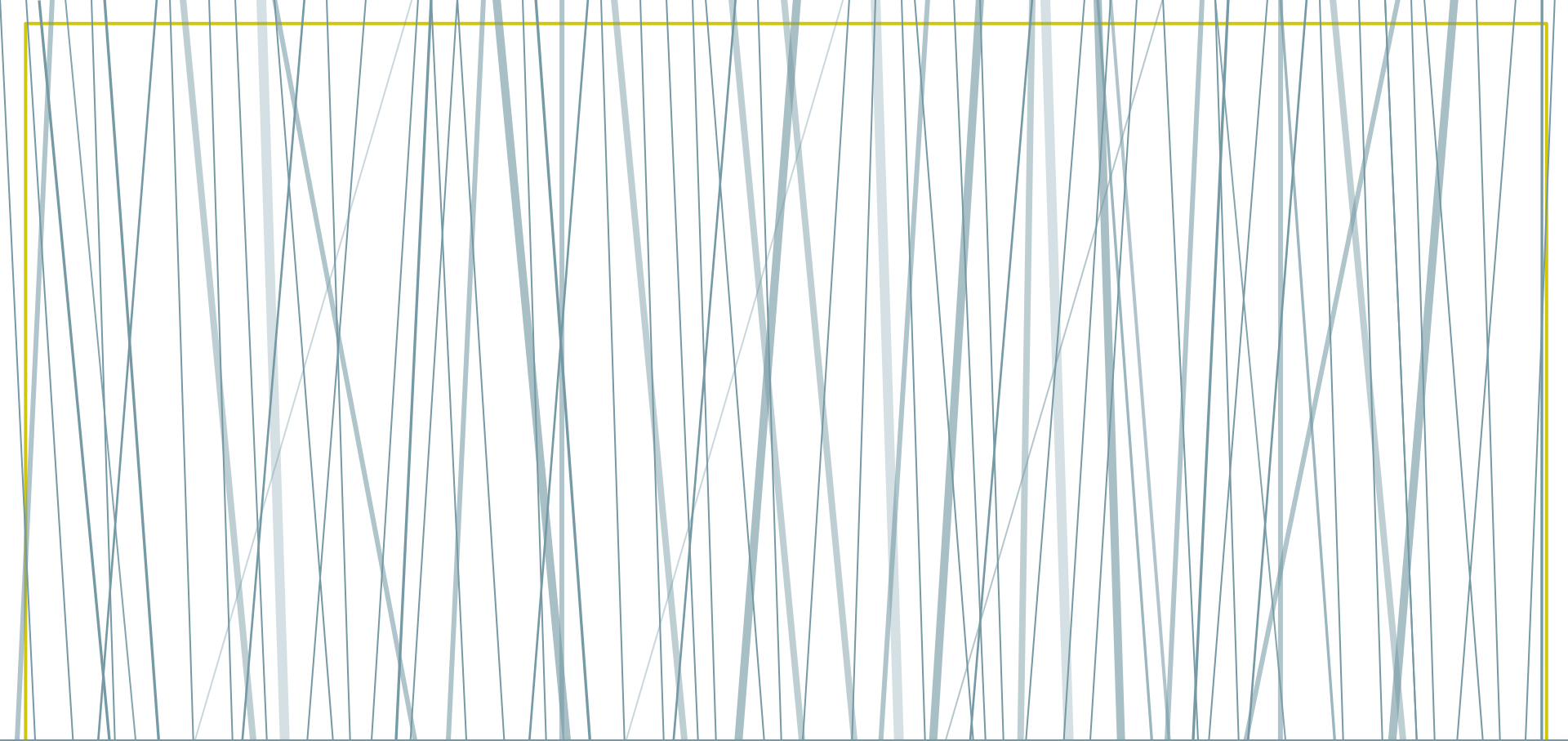


Figure 17.23 Barrier islands of the Wadden Sea in north-western Europe. (Source: after Hofstede, J., 2005, *Danish-German-Dutch Wadden Environments*, in E.A. Koster (editor). *The Physical Geography of Western Europe*. Oxford University Press, Oxford, 185-205. Copyright Oxford University Press. Reprinted by permission.)



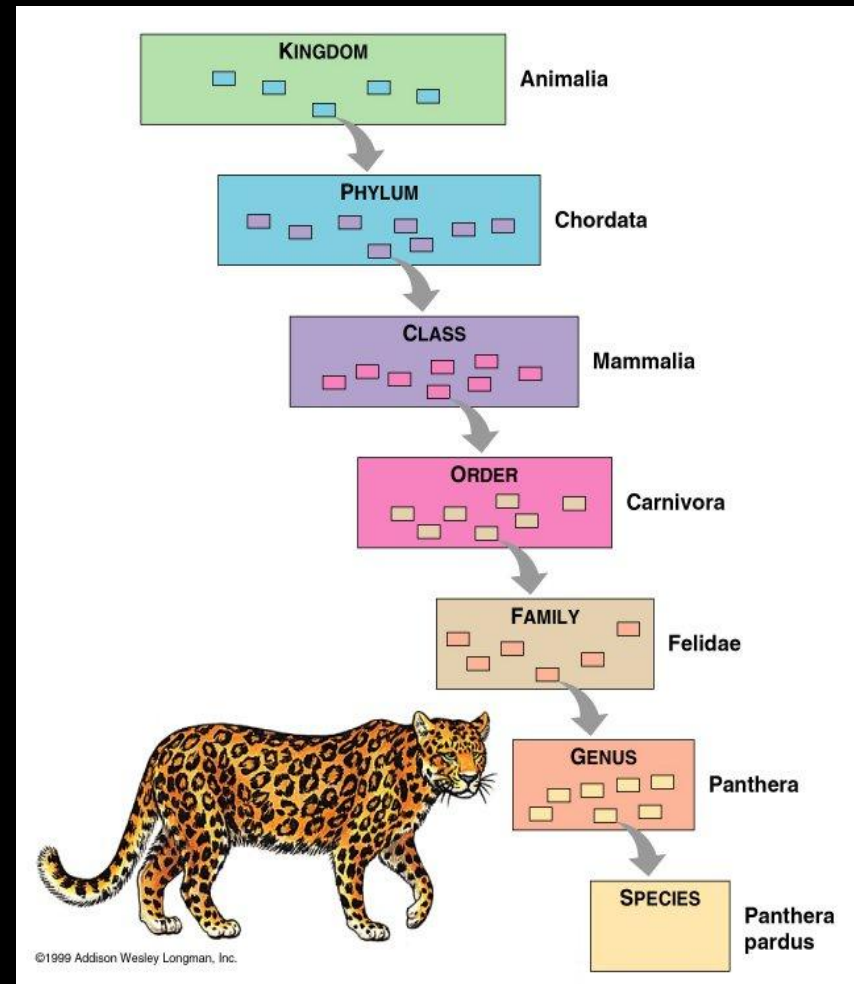
Classification and categorisation

Wave, tide and fluvial dominated coasts



CLASSIFICATION

- Why Classify?
- How can we classify coasts?
- What are the implications?
- Is it important for integrated management?
- Construct a coastal classification based on your knowledge.



Boyd et al (from
Masselink)

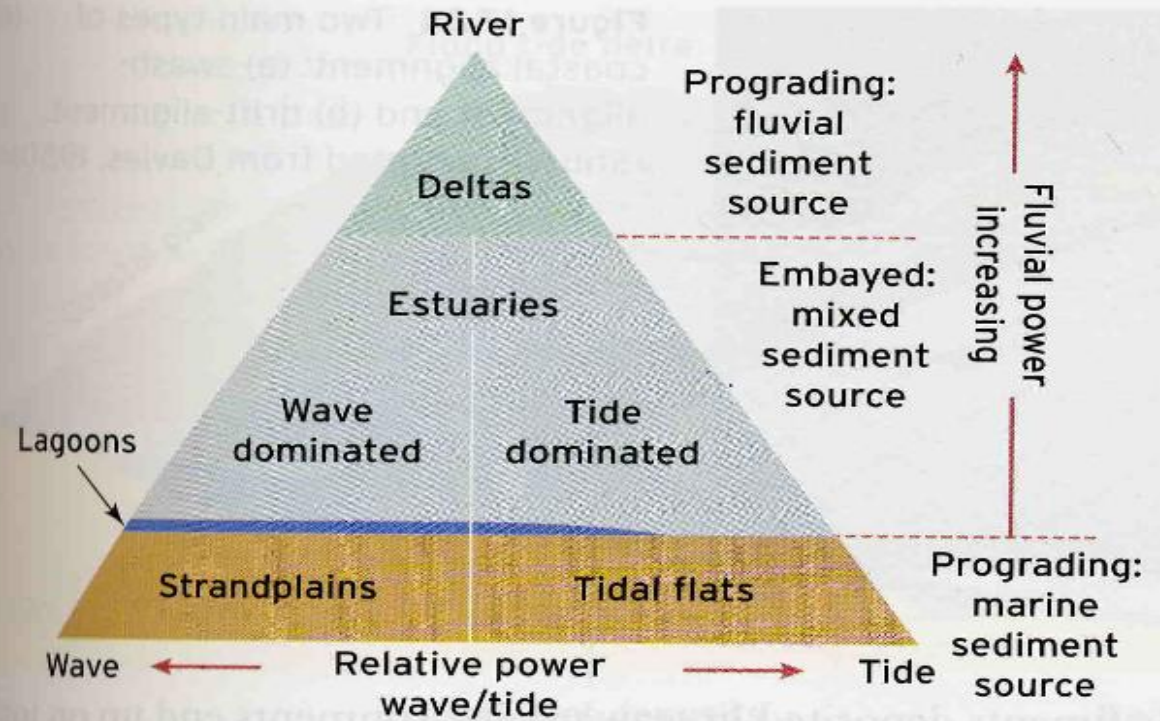


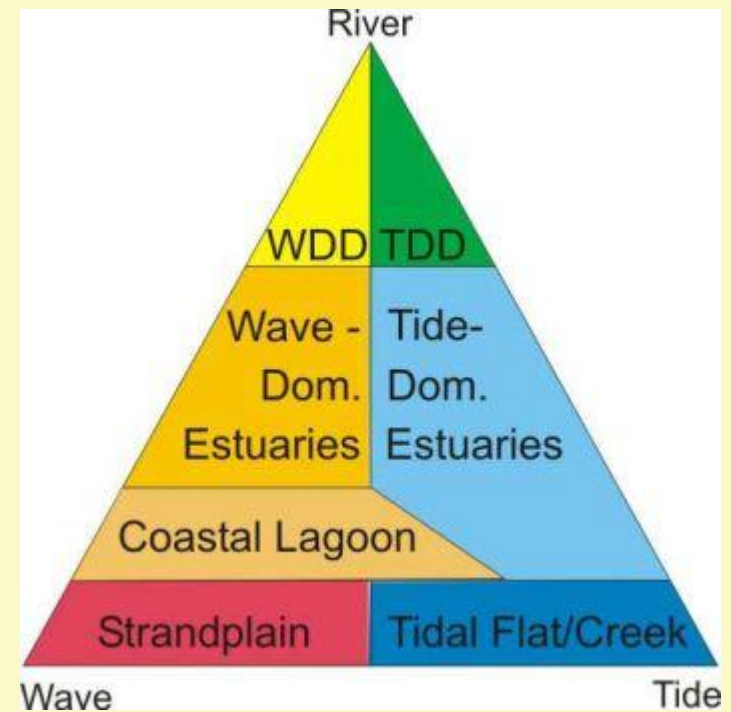
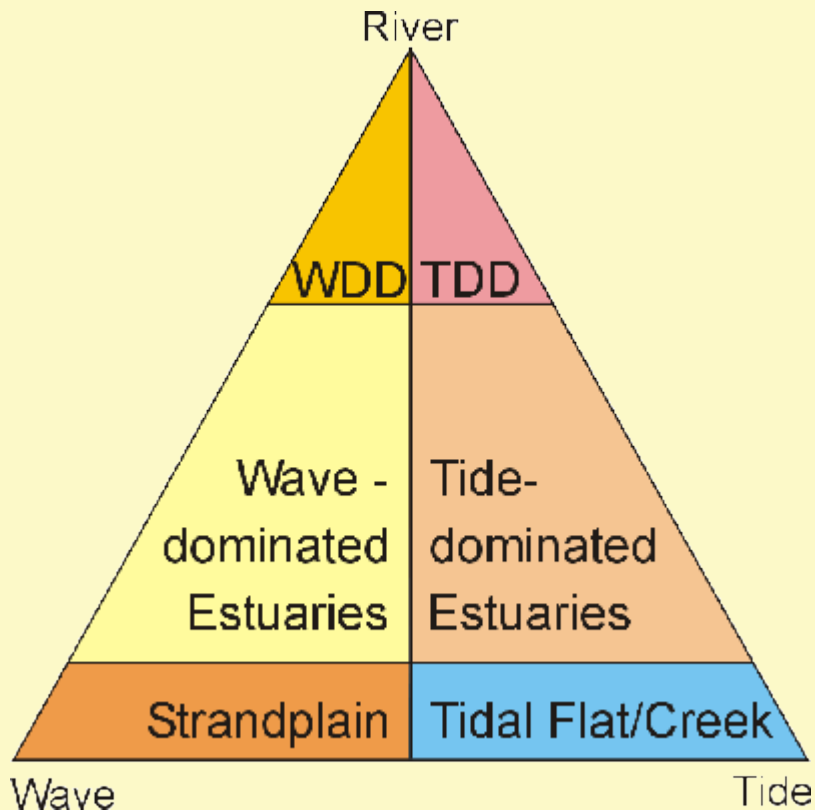
Figure 17.22 Process-based coastal classification based on the relative importance of wave, tide and river processes. (Source: after Boyd *et al.*, 1992)

Reflective question

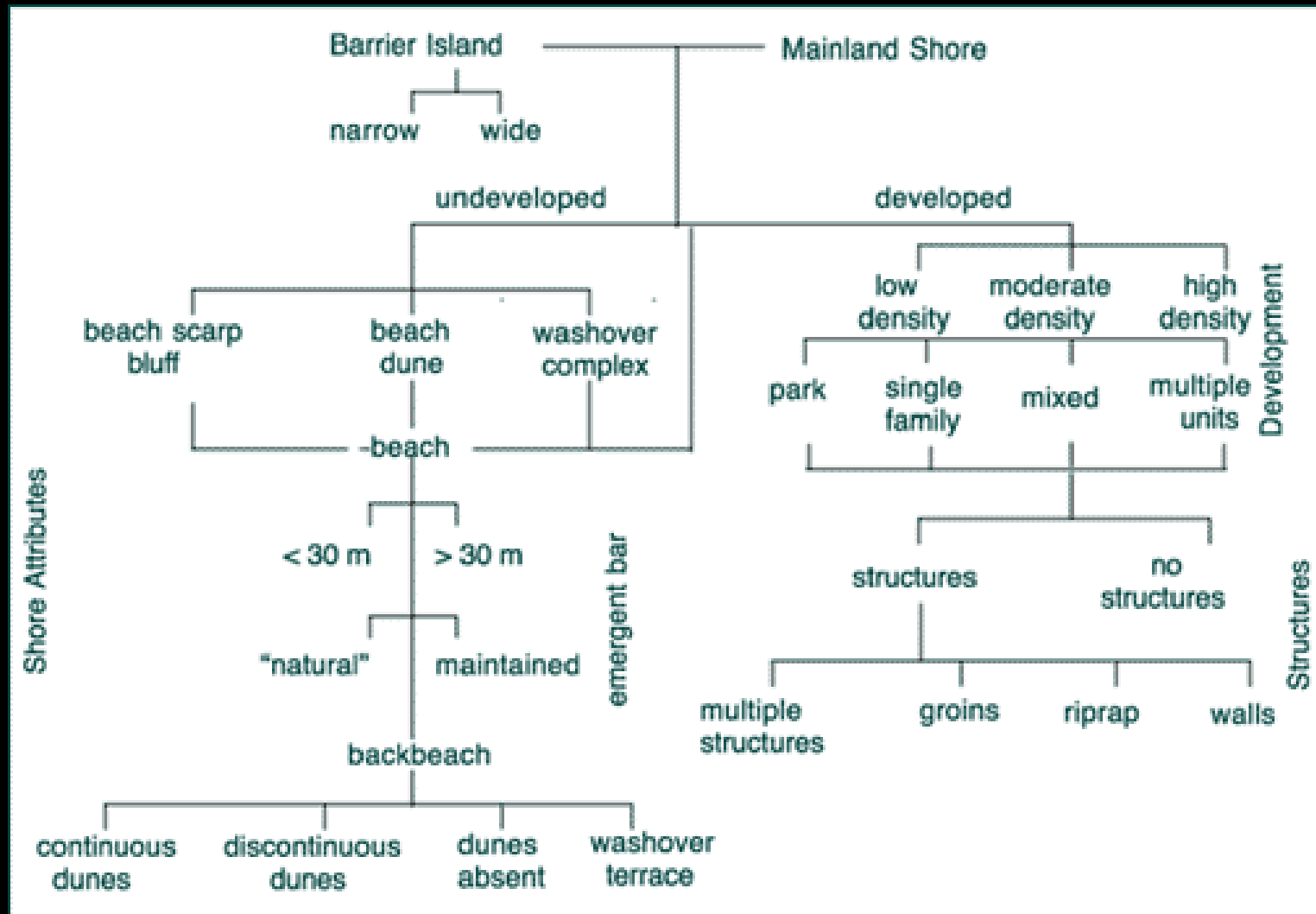
- What is the point of classifying coastlines in distinct types?

Australian Government 2012

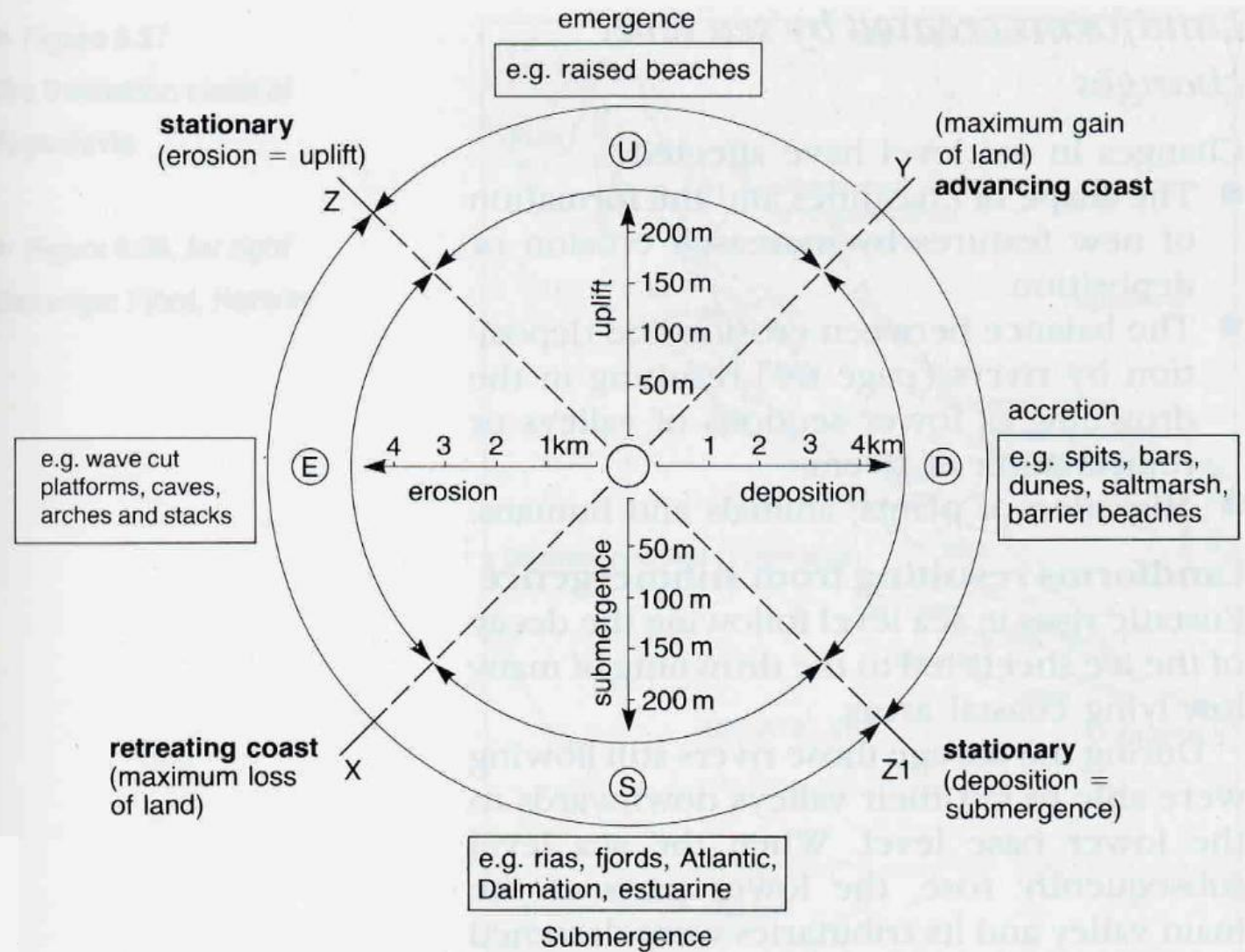
- Classification used for policy development
- What are they based/not based on?



USGS (2012) (<http://coastal.er.usgs.gov/coastal-classification/class.html>)



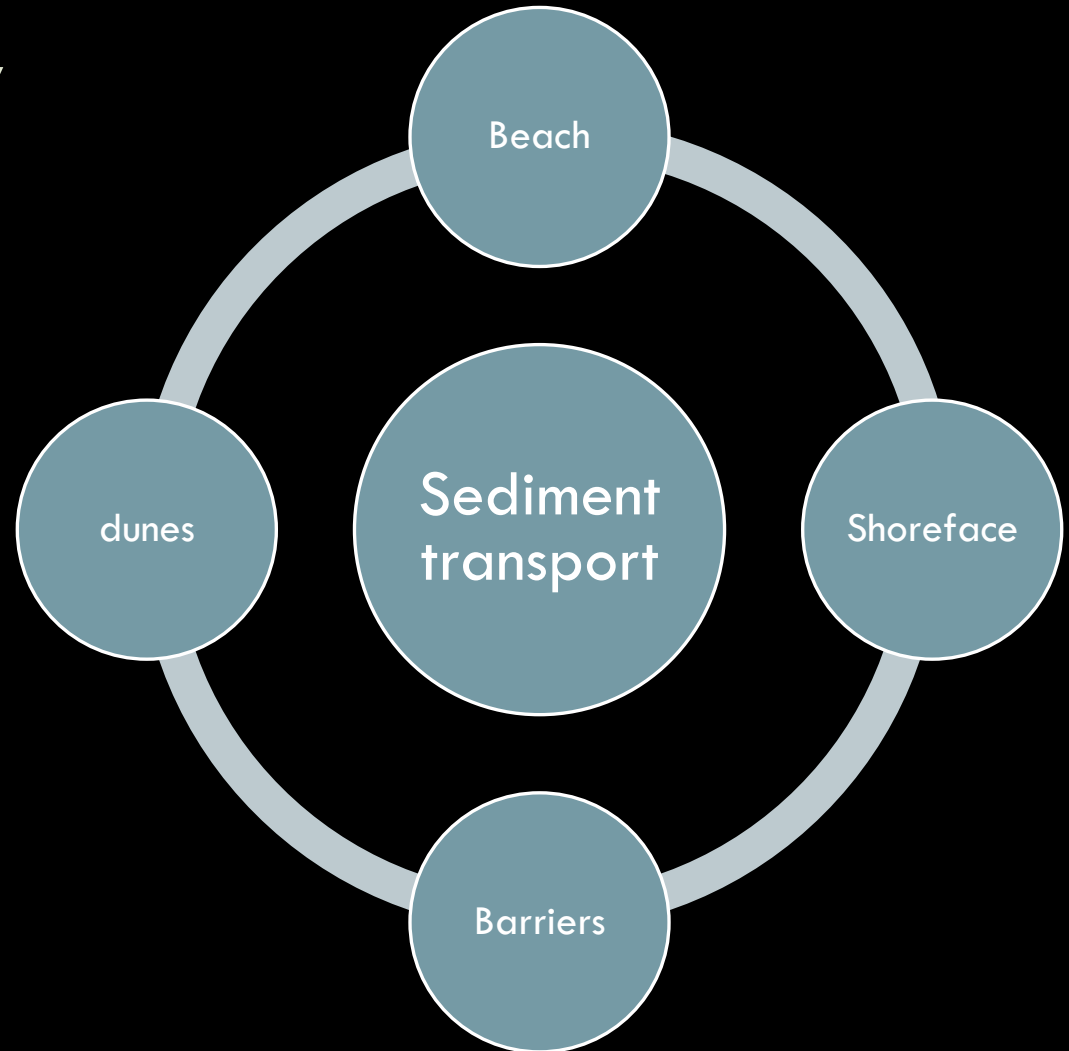
Valentin



Valentin's classification of coasts — this shows the conditions under which the maximum advance or retreat of the coast will occur and how it is possible for a coast to be in equilibrium where there is neither advance or retreat

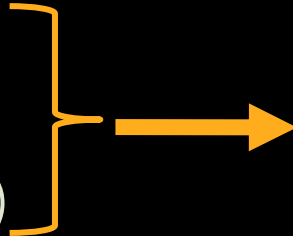
A. WAVE-DOMINATED COASTS

- Sediment is linked by sediment transport pathways



Barriers

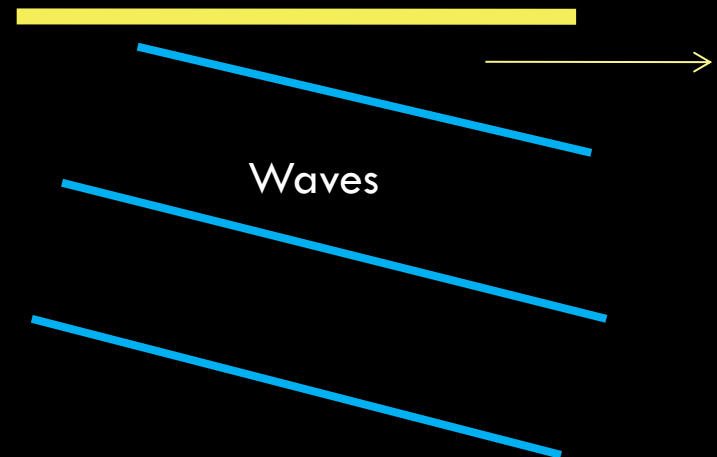
- Barrier islands with shallow coastal lagoons (e.g. Netherlands)
- Swash aligned
 - Closed to LSD
 - Long term stability
 - Seasonal change
- Drift aligned (e.g. spits)
 - LSD Spits
 - Sensitive to change (esp. Sediment supply) (Masselink & Hughes, 2003)
- Transgressive (refer to next slide)
 - Migrate landwards due to rising SL
 - Neg- sediment budget
 - Lagoon VG for conservation
- Regressive
- Migrate seaward due to receding SL / pos+sediment budgets
- Landward sediments are deposited.
- Aolian deposits



Swash aligned beach



Drift aligned



Barriers

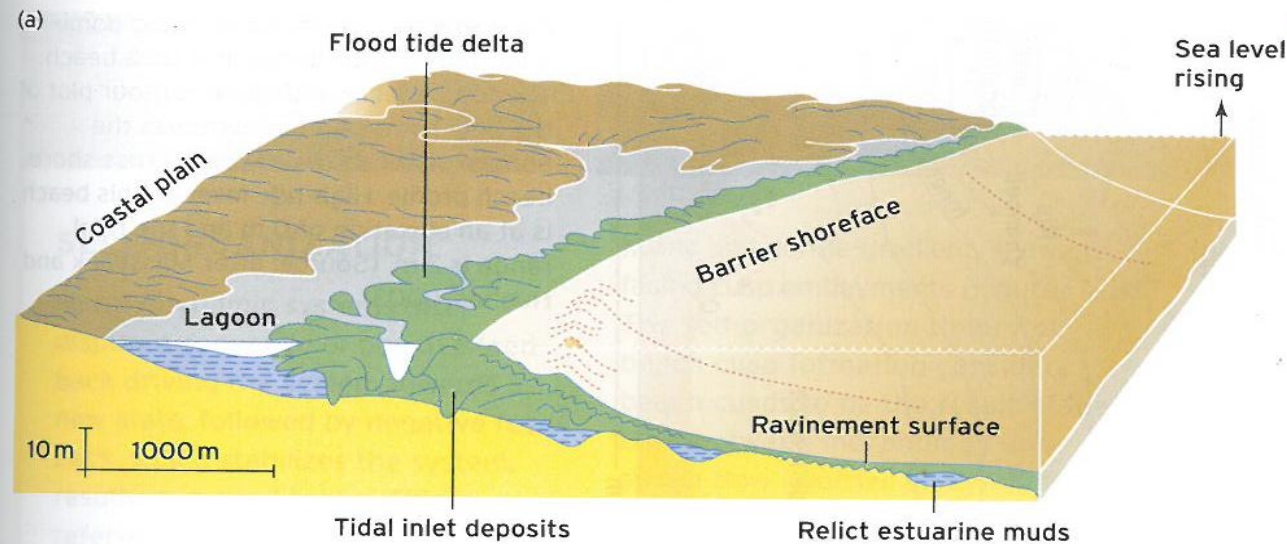
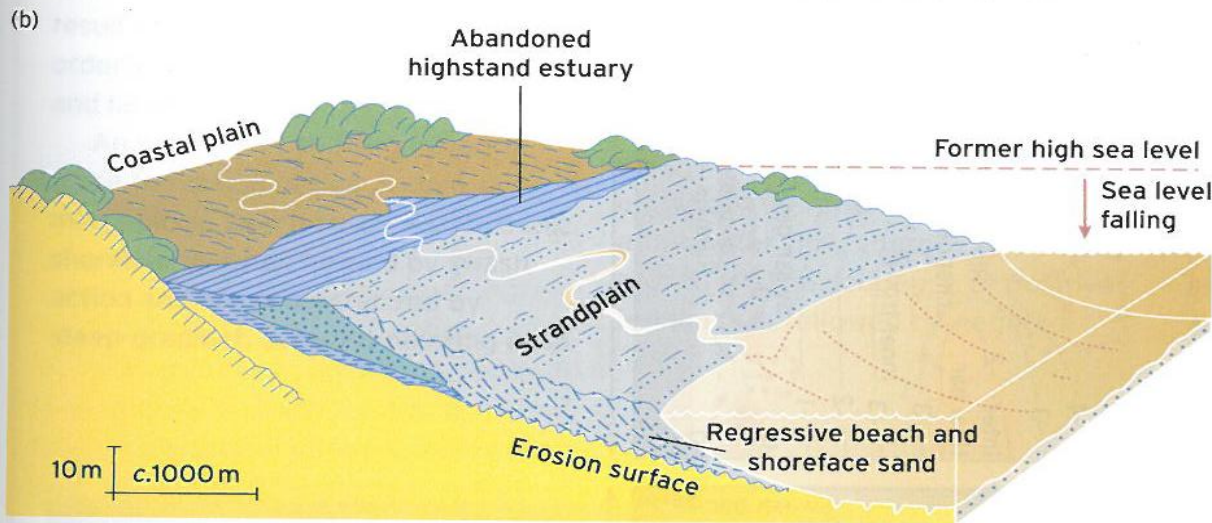


Figure 17.25 (a) Model of transgressive barrier during sea-level rise. Transgressive barriers are almost entirely composed of tidal delta and washover deposits. The barrier migrates into estuarine and lagoonal environments as sea level rises. (b) Model of regressive barrier during sea-level fall. The surface of the regressive barrier forms a wide strandplain, generally without estuaries. (Source: after Roy *et al.*, 1994)



Natural protection

- Beaches
 - Concave (with micro features)
 - Underwater beach called the shoreface
 - Self organisation
 - Berm Protects (steep in gravel beaches)
 - Beaches respond to changing wave conditions e.g. Seasonal profiles

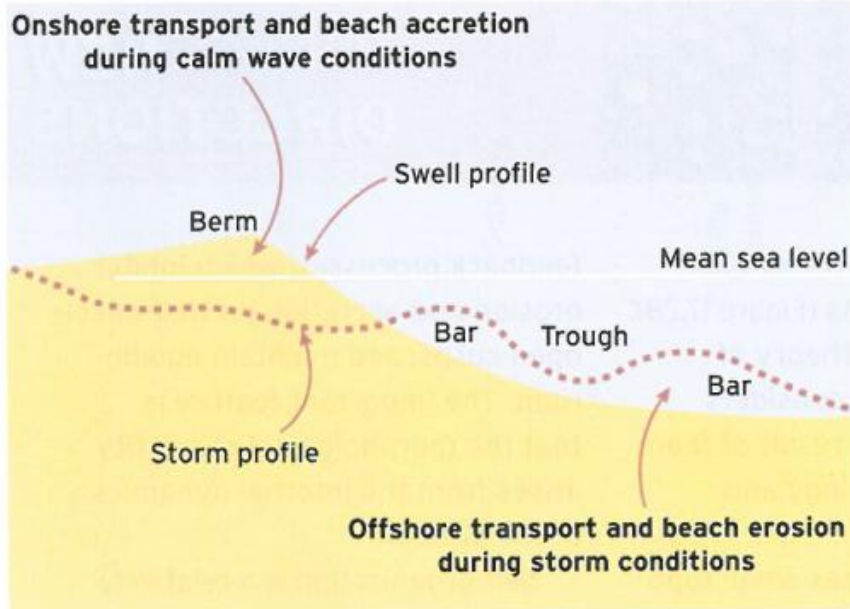


Figure 17.29 Idealized beach profiles with and without bars. Storm conditions induce offshore transport, beach erosion and the formation of a nearshore bar. Calm wave conditions result in onshore sediment transport, beach accretion and the formation of a berm. (Source: Aggard and Masselink, 1999)

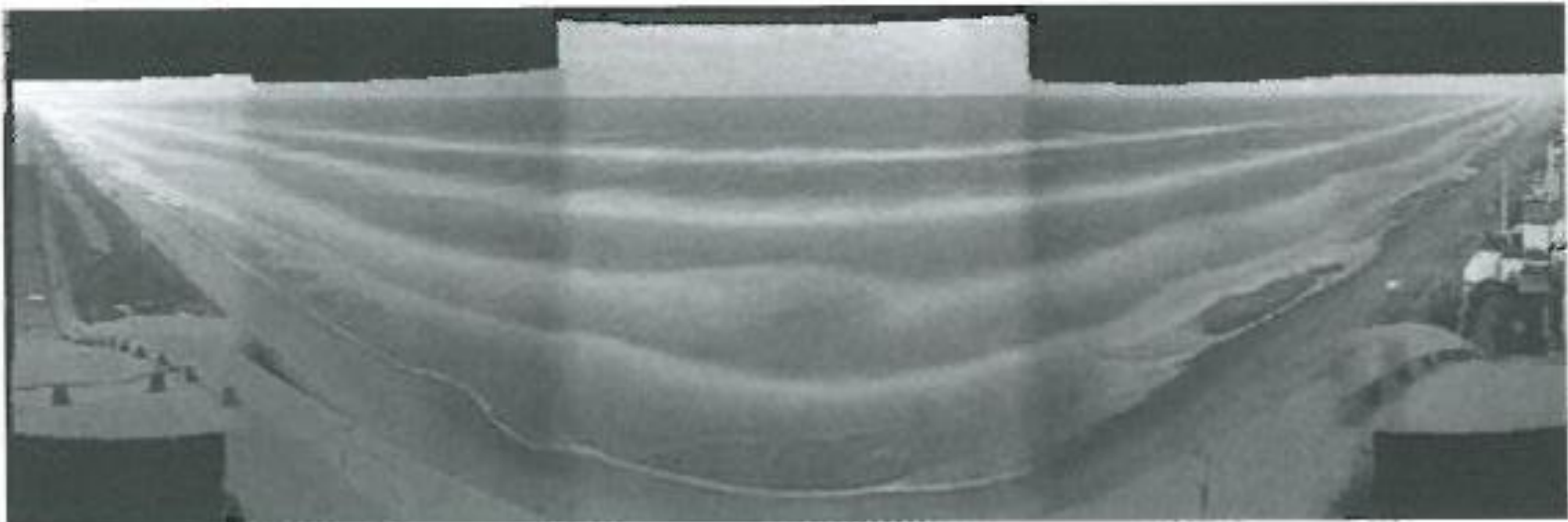
Beach cusps (pos+ & Neg- feedback leads to equilibrium)



Figure 17.28 Beach cusps on a gravel beach. The longshore spacing of the cusps is approximately 3 m.

Research

- In recent decades our understanding significantly improved with the use of video monitoring



Dunes

(a)



- Denmark 2013

B. TIDE-DOMINATED COASTS

- Estuarine

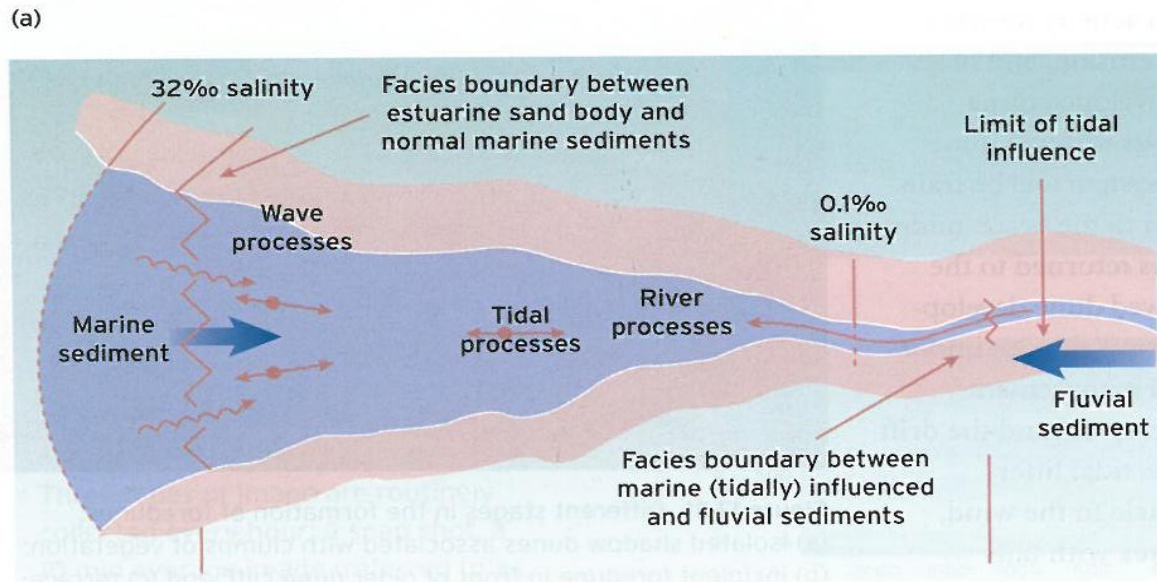
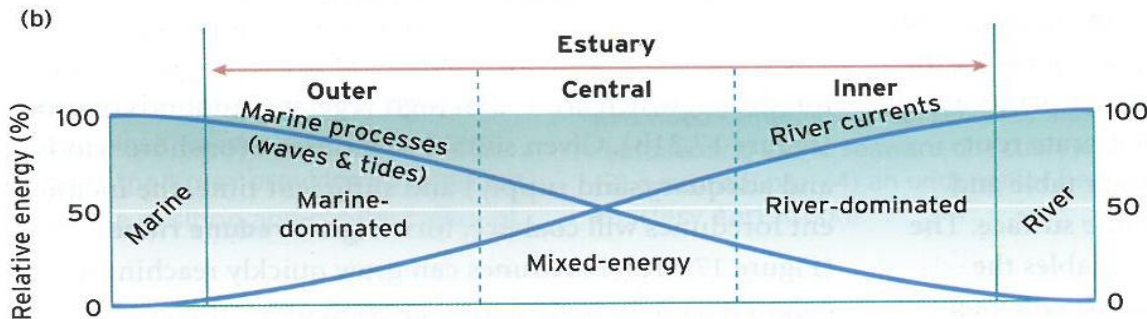


Figure 17.32 (a) Plan view of an estuary showing sediment and hydraulic boundaries. (b) Chart showing the changing mix of wave, tide and river processes along the estuary axis. (Source: after Dalrymple *et al.*, 1992, SEPM (Society for Sedimentary Geology))



Wave and Tide dominated estuaries

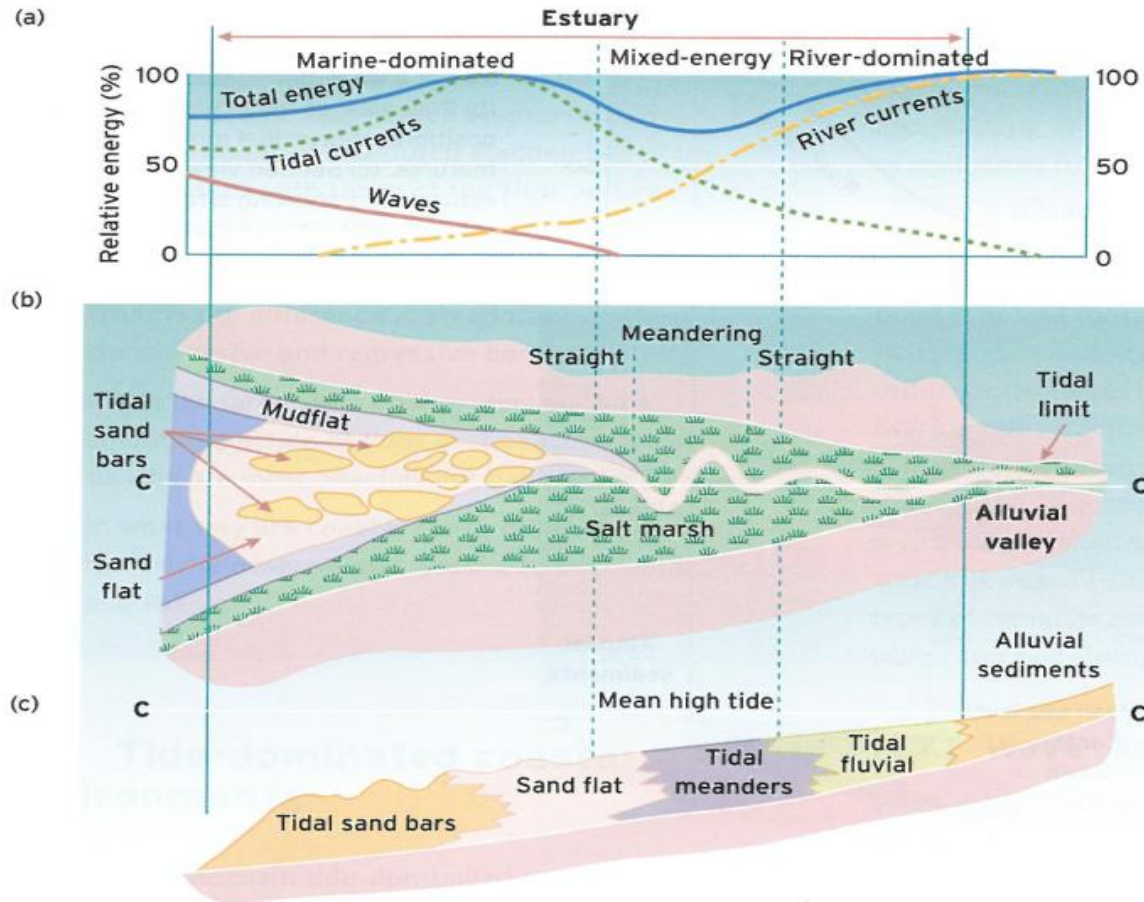


Figure 17.34 (a) Chart showing the change in energy regime along the axis of a tide-dominated estuary. (b) Plan view of the estuary showing positions of principal morphological features. (c) Section view along the estuary axis showing stratigraphy. (Source: after Dalrymple *et al.*, 1992, SEPM (Society for Sedimentary Geology))

Major ecological considerations in relation to estuary type and processes associated with them

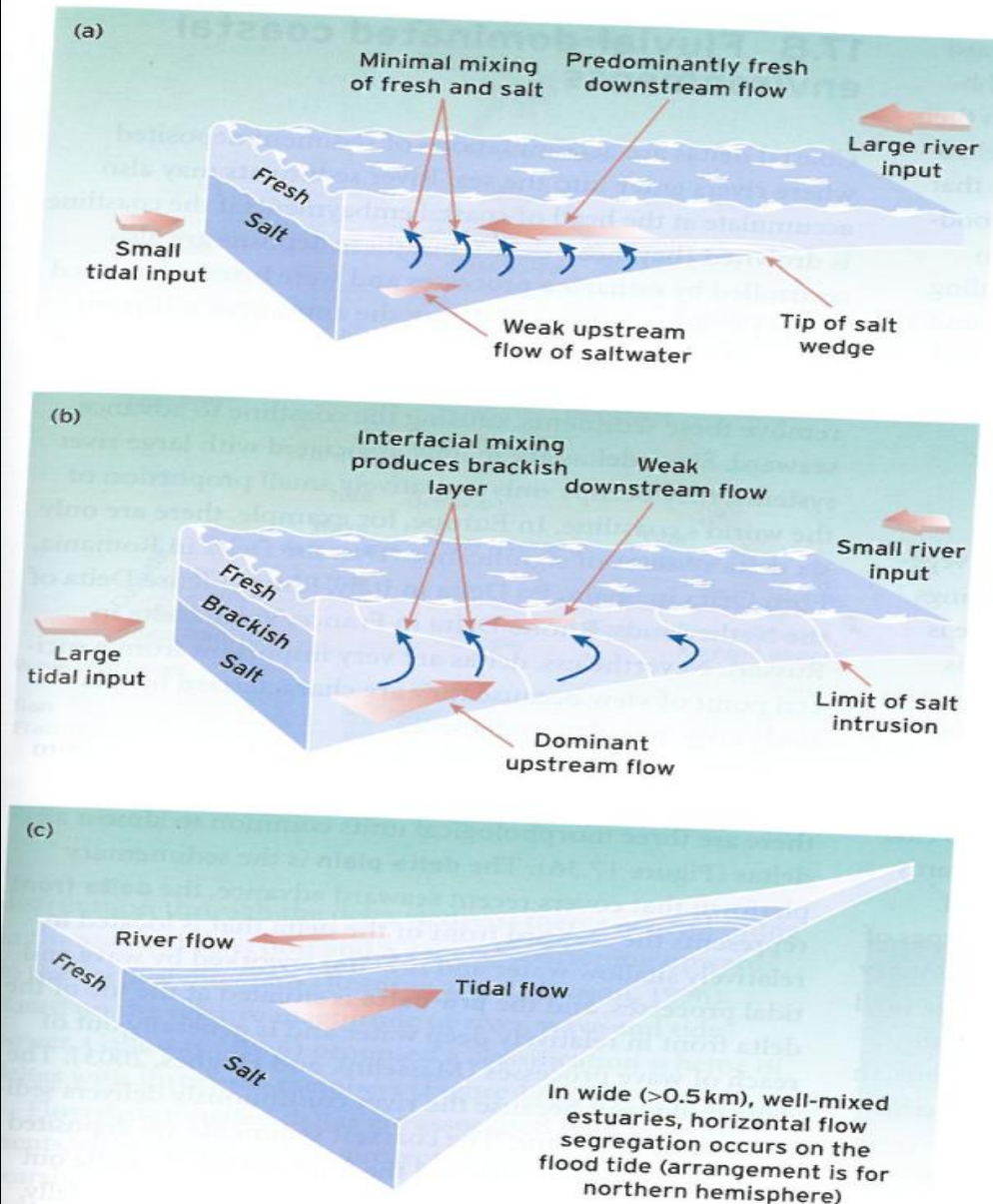
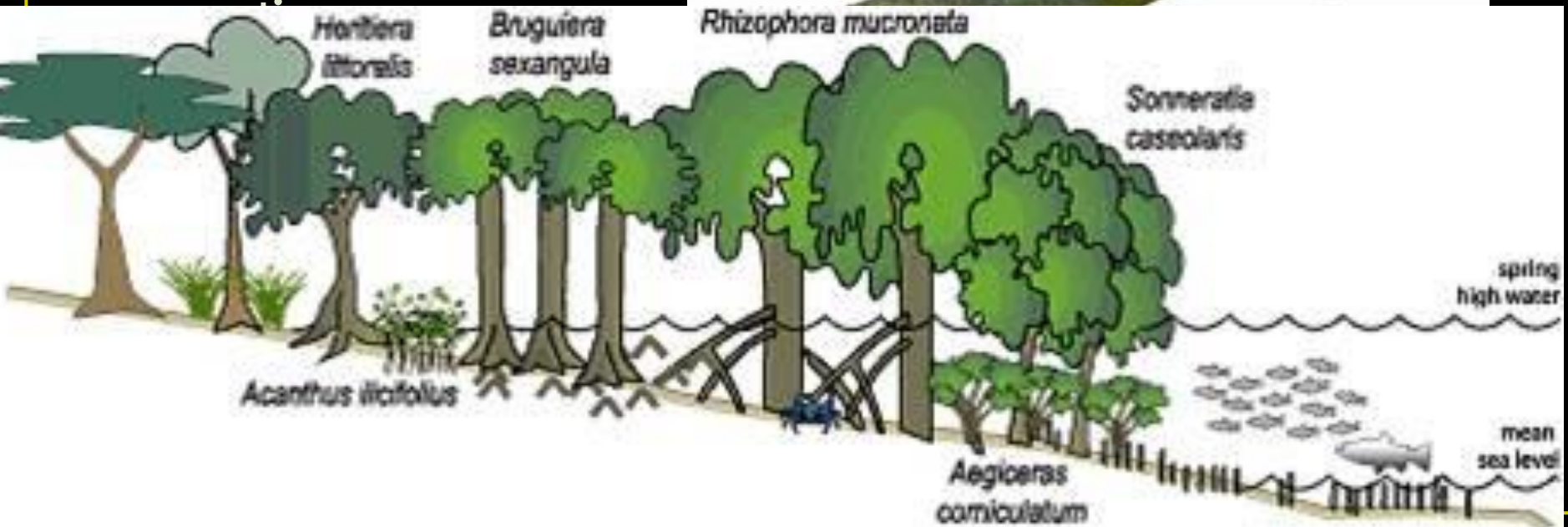


Figure 17.35 Diagram illustrating three main types of estuaries based on density stratification: (a) stratified; (b) partially mixed; and (c) well-mixed estuary. Water masses are indicated by shading on the front face of each block. Salinity contours (arbitrary scale) are indicated by thin lines on the side face of each block in (a) and (b) and on the top face of the block in (c). In (a) and (b) vertical mixing is indicated by thin arrows and non-tidal currents are indicated by thick arrows. (Source: after Pethick, 1984)

Upper intertidal zone

- Salt marsh
 - temperate
- Mangrove
 - Tropical
- Both have distinct ecological



C. FLUVIAL-DOMINATED

- Deltas
 - Sediment from rivers is $>$ than the erosion from coastal processes
 - Large rivers (only 6 in Europe)
 - Very imp. For ecological and demographics

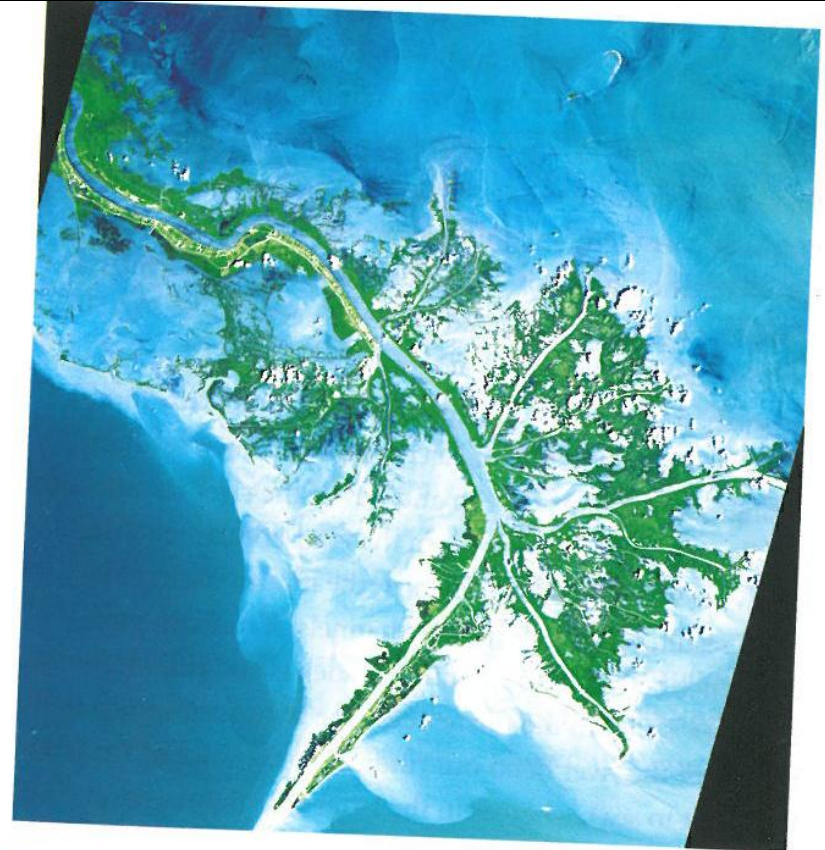


Figure 17.38 The Mississippi Delta is shaped like a 'bird's foot' and is the classic example of a river-dominated delta. The scene shown in this false-colour image covers an area of 54 km by 57 km and represents the currently active delta front of the Mississippi known as the Balize.

Morphology and classification of Deltas

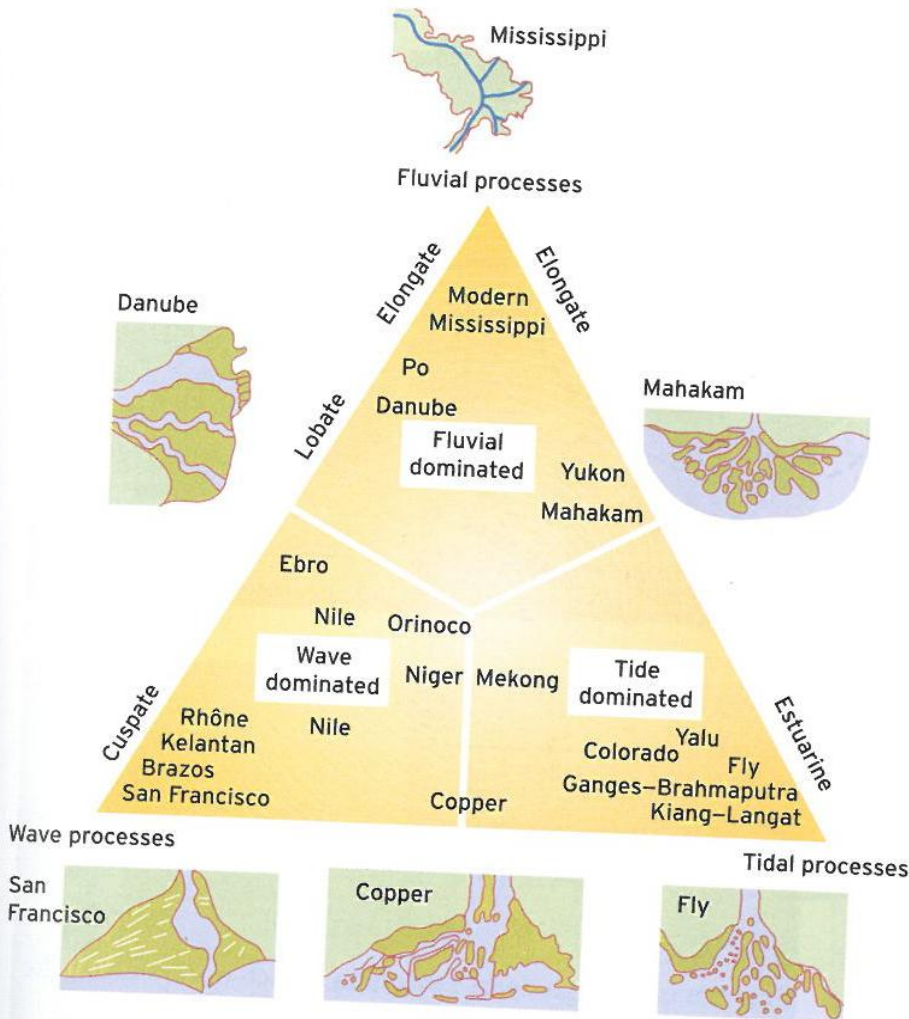


Figure 17.37 Classification of fine-grained deltas proposed by Galloway (1975). The end-member types are fluvial-, tide- and wave-dominated. (Source: From Briggs *et al.*, 1997)

Dynamic environment (Delta switching)

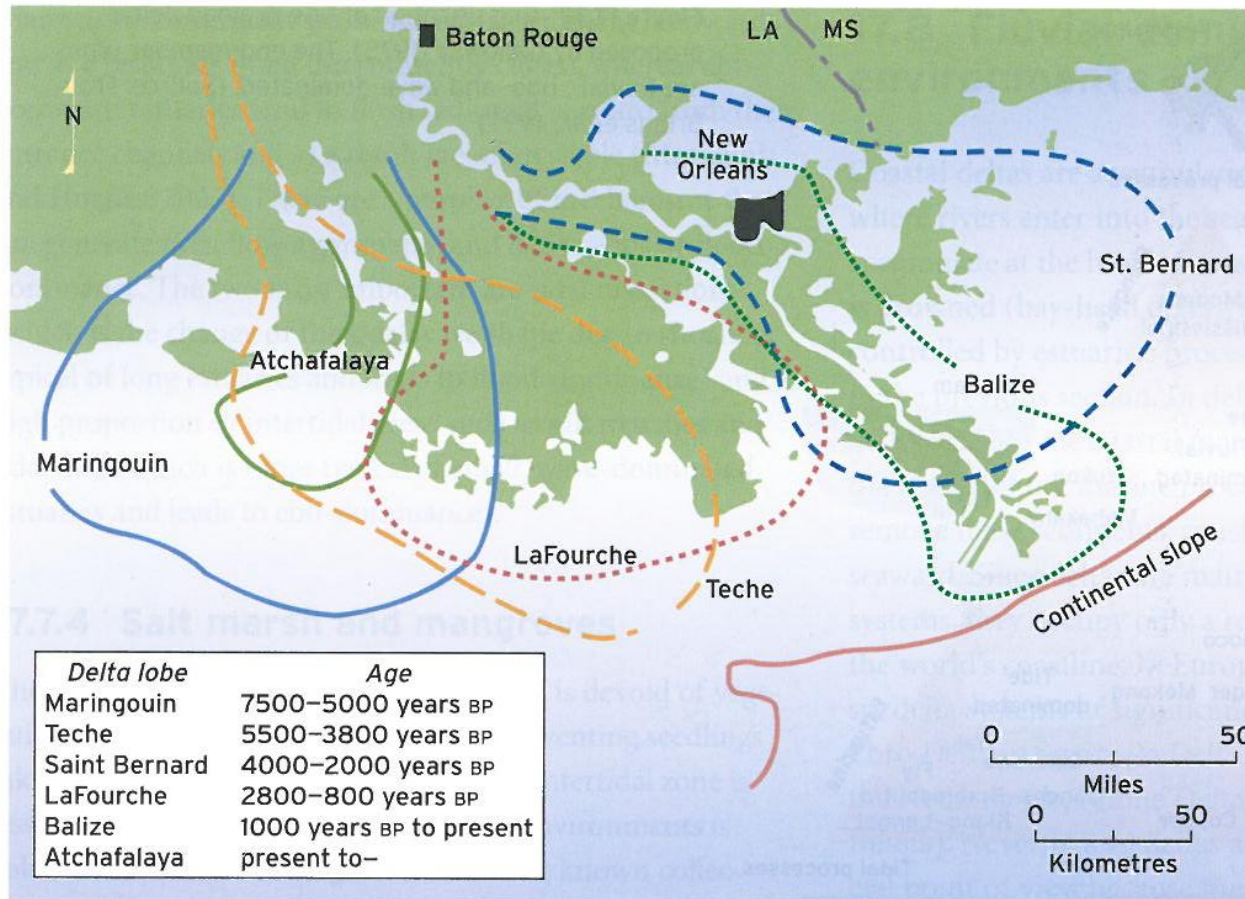


Figure 17.39 Outlines of the five delta lobes that make up the Mississippi Delta. The currently active delta lobe, the Balize, is shown in Figure 17.38. The youngest delta lobe is the Atchafalaya, which is not yet fully occupied by the river. (Source: adapted from Pilkey, 2003)

Distributaries
Human influence

Conclusion

- Coastal processes and habitat management
- Coastal management and conservation
- SL rise and conservation















