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Lecture 3: Hydrodynamics and sediment dynamics

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Colin Woodroffe (2002) "Coasts: Form, Process and Evolution", Outline of Chapter 3:

3.1. Historical Perspective – Wave Theory

Airy (1845) – Linear wave theory

Stokes (1847) – Second-order waves (asymmetry of shoaling waves)

3.1. Historical Perspective (cont.) – Hjulstöm Diagram

Initiation of Sediment Motion:

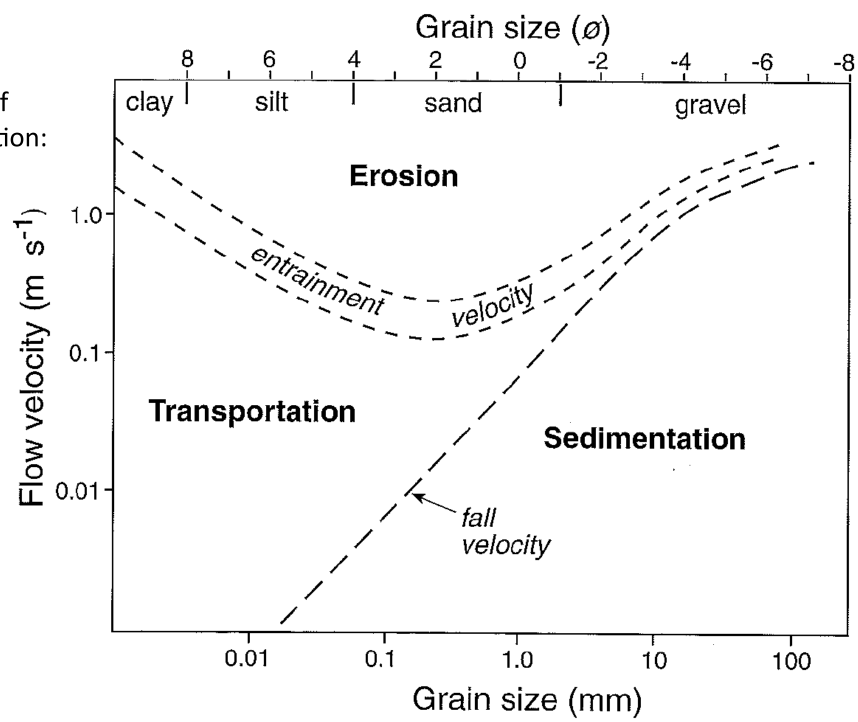
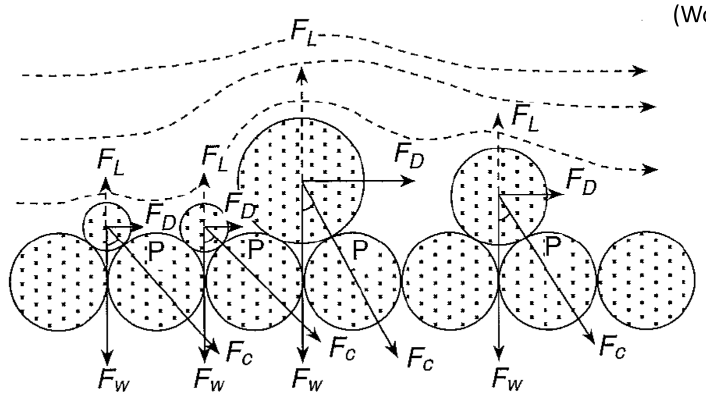


Figure 3.1. Relationship between sediment entrainment and deposition and grain size and fluid velocity (based on Hjulström, 1935).

3.2. Sedimentary Processes, 3.2.1. Sediment Entrainment

L3/3

(Woodroffe Fig. 3.2)



ρ = Fluid density
μ = Fluid viscosity
$\bar{U}$ = Mean velocity
F_D = Fluid drag
F_L = Fluid lift
h = Flow depth
g = Gravitational constant
P = Pivot point
F_W = Immersed weight
F_c = Cohesion/friction

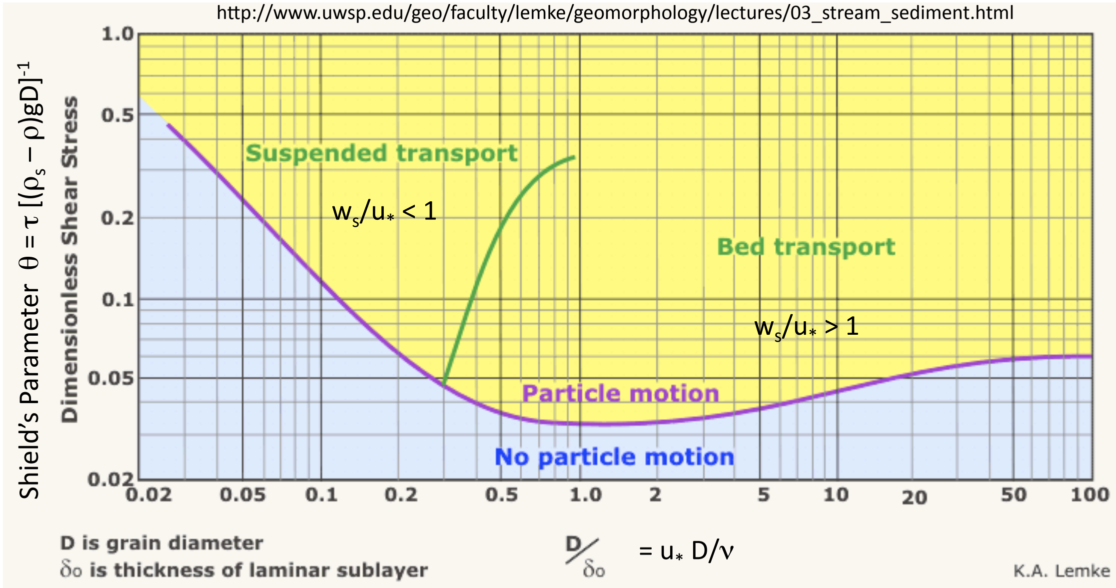
Shield's Parameter $\theta = \tau\,[(\rho_s - \rho)gD]^{-1}$ is nearly the same as ratio (Fluid lift)/(Fluid drag)

Complicating factors: grain motion, irregular grain shapes, bedforms, mixed grain sizes, cohesion

3.2.2. Sediment Transport – Two dominant types – suspended vs. bed load

L3/4

http://www.uwsp.edu/geo/faculty/lemke/geomorphology/lectures/03_stream_sediment.html



What determines suspended vs. bed load?

Ans. Ratio of settling velocity (w_s) to shear velocity (u_*): Rouse parameter = w_s/u_*
Settling velocity moves sediment down, eddies (with vertical velocity u_*) move sediment up

3.2.3. Sediment Deposition – Stokes Law

Stokes settling velocity:

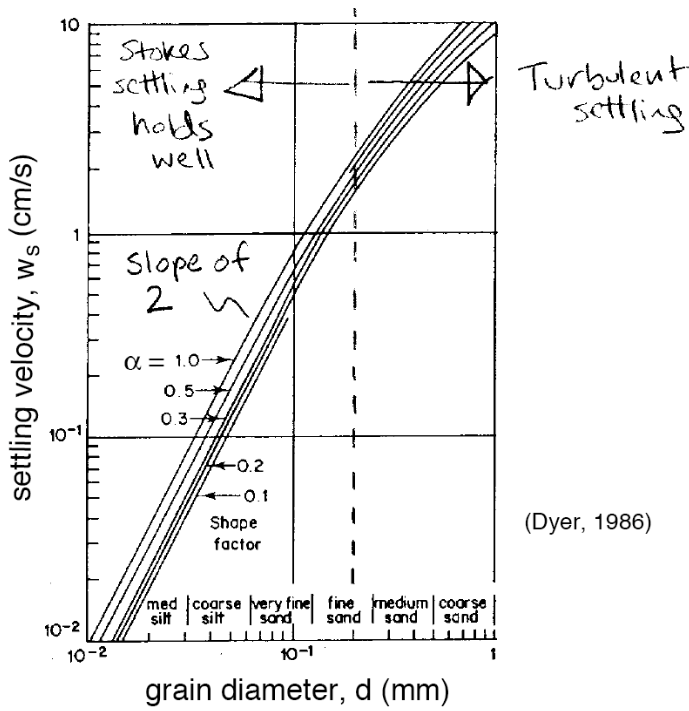
Sediment stops accelerating (steady w_s) when

weight of grain = resistance due to molecular viscosity, ν

$$\alpha g(\rho_s - \rho)\pi d^3/6 = 3\pi\rho\nu d w_s$$

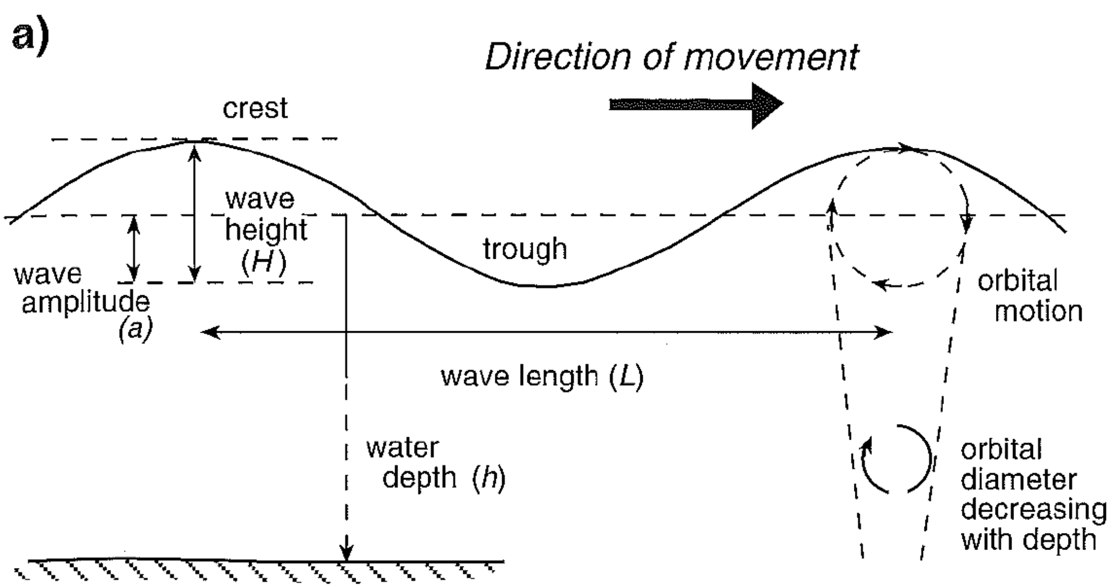
$$w_s = (\rho_s/\rho - 1)\, g d^2 \alpha/(18\nu)$$

Flocculation affects ρ_s, d and α



(Dyer, 1986)

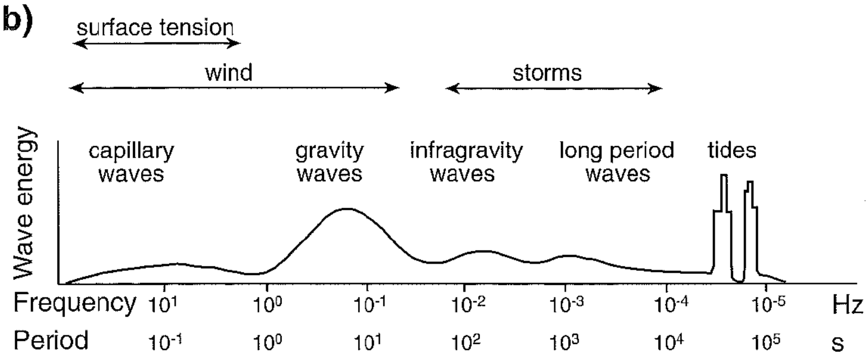
3.3. Wave Processes, 3.3.1. Types of Waves



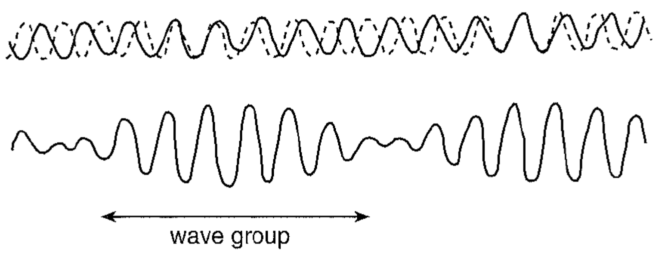
(Woodroffe Fig. 3.3)

Deep water $h/L > \sim 1/4$
Shallow water $h/L < \sim 1/20$
Intermediate

b)



c)

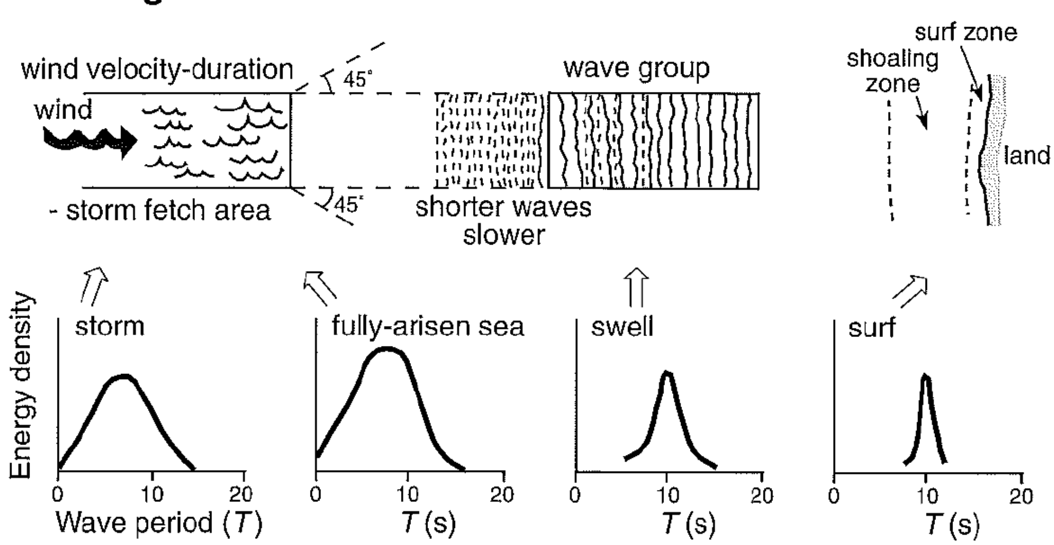


(Woodroffe Fig. 3.3)

Types of waves: wind waves (swell, local sea), tide, tsunami, internal waves, Kelvin waves, edge waves, shear waves, seiches, soliton, bore (breaker), standing vs. progressive

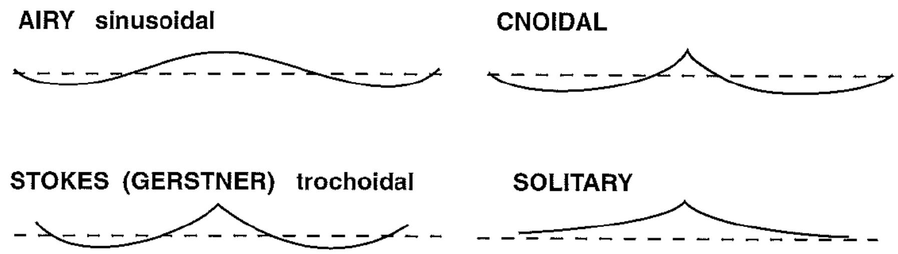
3.3.2. Wave Generation and Movement

Wave generation



(Woodroffe Fig. 3.4)

3.3.3. Wave Transformations



(Woodroffe Fig. 3.6)

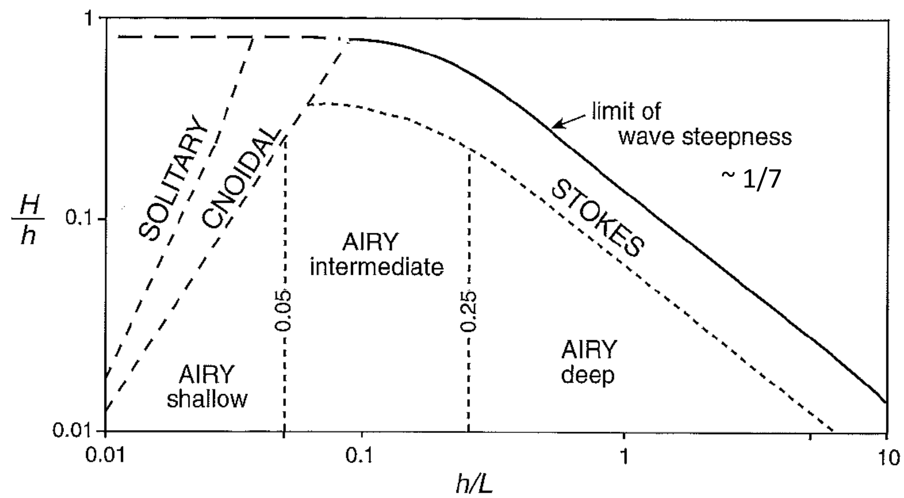
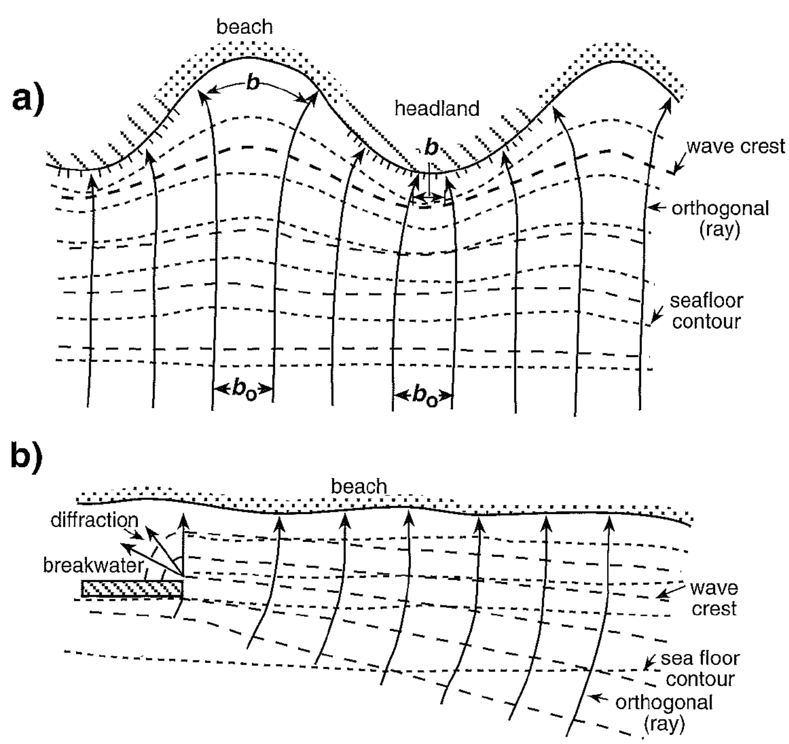


Figure 3.7. Wave refraction. (a) Waves approaching normal to shore. Convergence of rays indicated where $b<b_o$ and divergence $b>b_o$. (b) Waves approaching oblique to shore. Diffraction occurs behind breakwater.



$$C_g = C = (gh)^{0.5}$$

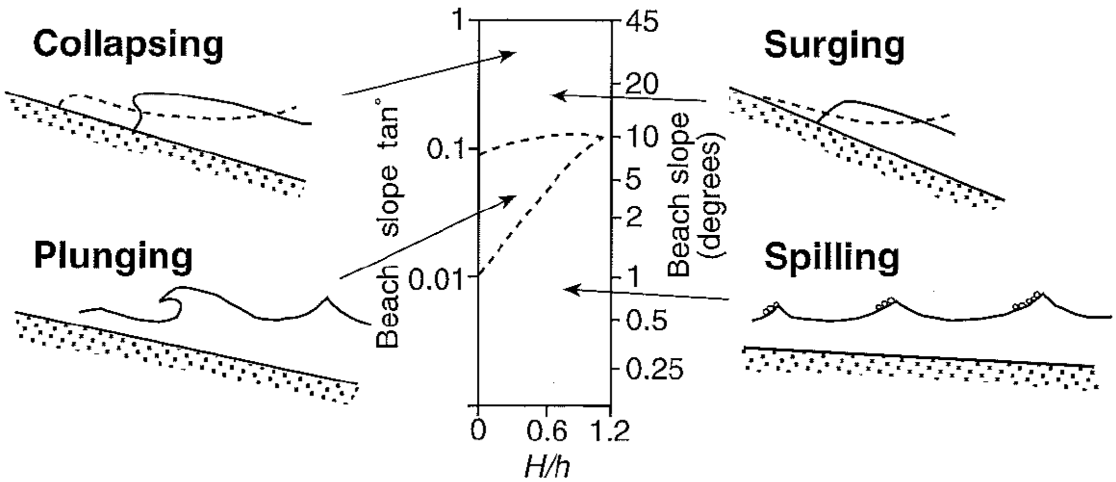
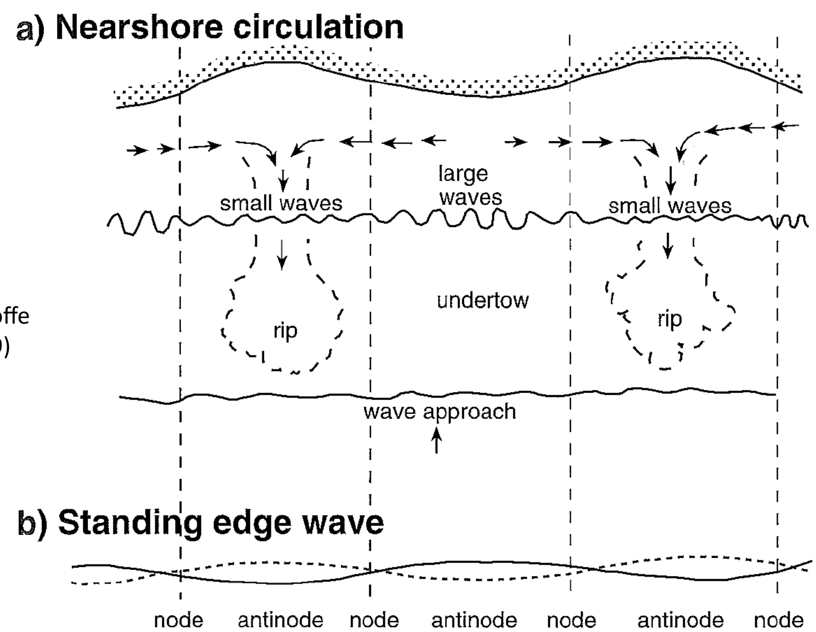


Figure 3.8. Breaking wave forms and the conditions of beach slope and relative wave height (H/h) under which they occur (based on Galvin, 1968).

What does $C = (gh)^{1/2}$ tell us about why waves become asymmetric in shallow water?
-- Waves asymmetrically steepen because $C = (gh)^{1/2}$ causes crest to move faster than trough.
-- Once steepness exceeds ~1/7, waves become unstable (c.f. spilling case).
-- Run-up extends to ~0.7 H_o ; run-up is mainly at infra-gravity frequency.

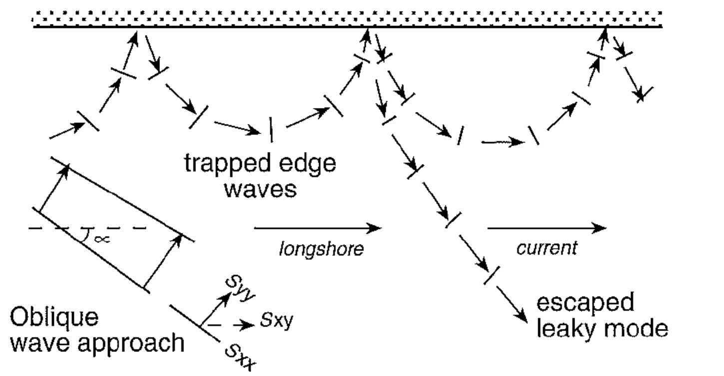


(Woodroffe Fig. 3.9)

How do wave groups create rip currents?
-- Groups at infragravity frequencies cause spatial variations in radiation stress (wave-induced momentum flux) which excite periodic set-up (a form of standing edge waves).
-- Resulting periodic set-up drives periodic along-shore currents and rip-current cells.

c) Longshore edge wave and sediment transport

(Woodroffe Fig. 3.9)



Snell's law

$$\frac{\sin\alpha_b}{C_b} = \frac{\sin\alpha_0}{C_0} = k$$

Longshore velocity = $f(C_b \sin\alpha_b \cos\alpha_b)$

C = velocity   ∝ = wave angle

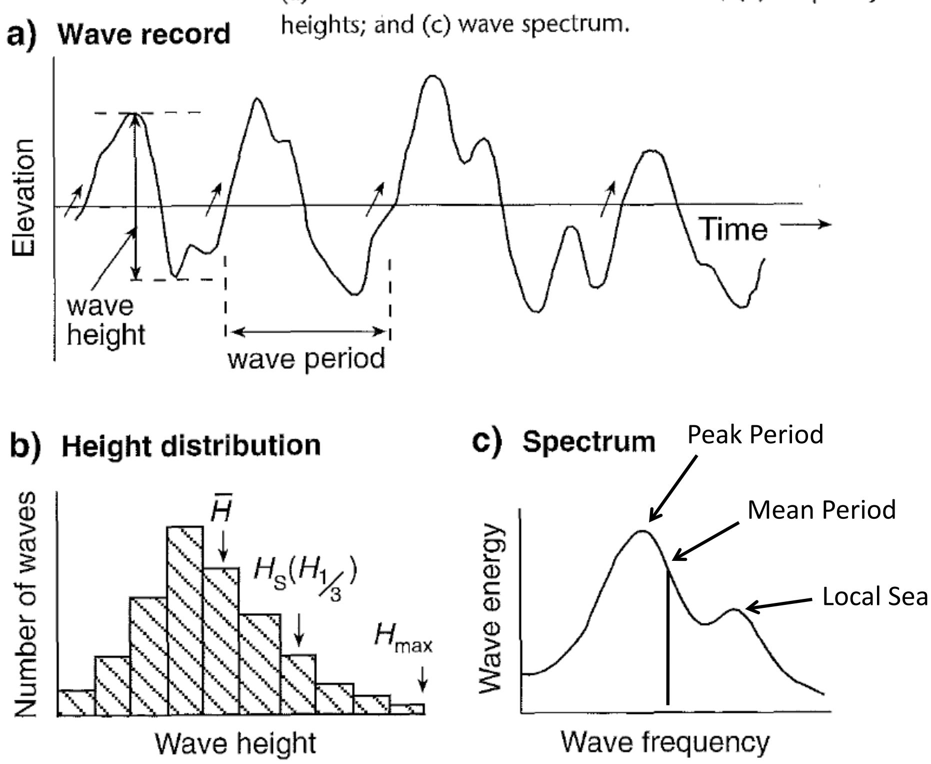
(c) Longshore current where waves approach the shore obliquely, and the reflection of a trapped edge wave (based on Komar, 1998).

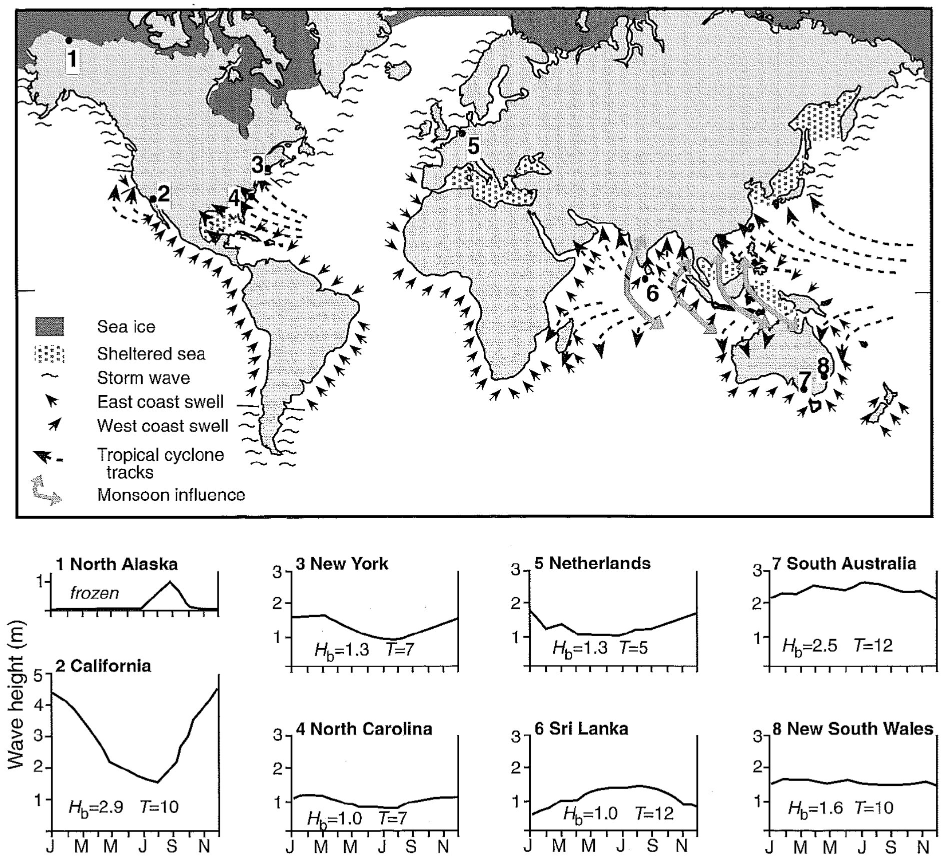
How do waves approaching at an angle drive longshore current?

-- Radiation stress (S) from waves approaching at an angle delivers along-shore momentum to surf zone; result is longshore current and progressive (not standing) trapped edge waves.

3.3.6. Wave Measurement

Figure 3.10. Analogue wave record and the zero-upcrossing technique by which height distribution or spectra are defined (based on Sunamura, 1992). (a) Time-series of water surface elevation; (b) frequency distribution of wave heights; and (c) wave spectrum.





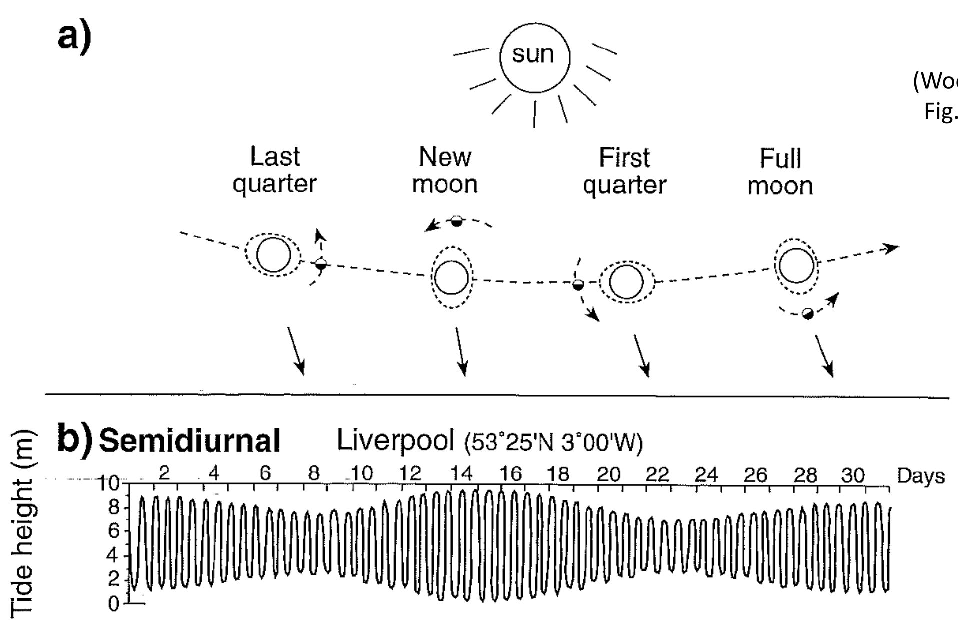
"Roaring 40s"

Trade Winds

Doldrums

(Woodroffe Fig. 3.11)

3.4. Tides and Tidal Influence, 3.4.1. Tidal Oscillations



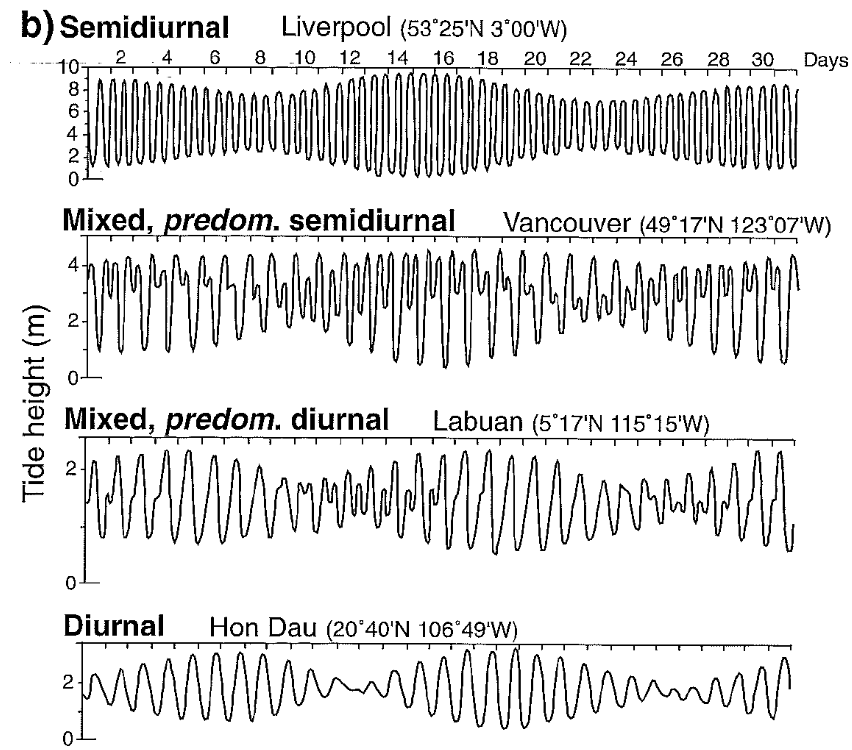
(Woodroffe Fig. 3.12)

-- Why two bulges?

-- Why is M_2 period > ½ day?

-- Why 2-week spring-neap cycle?

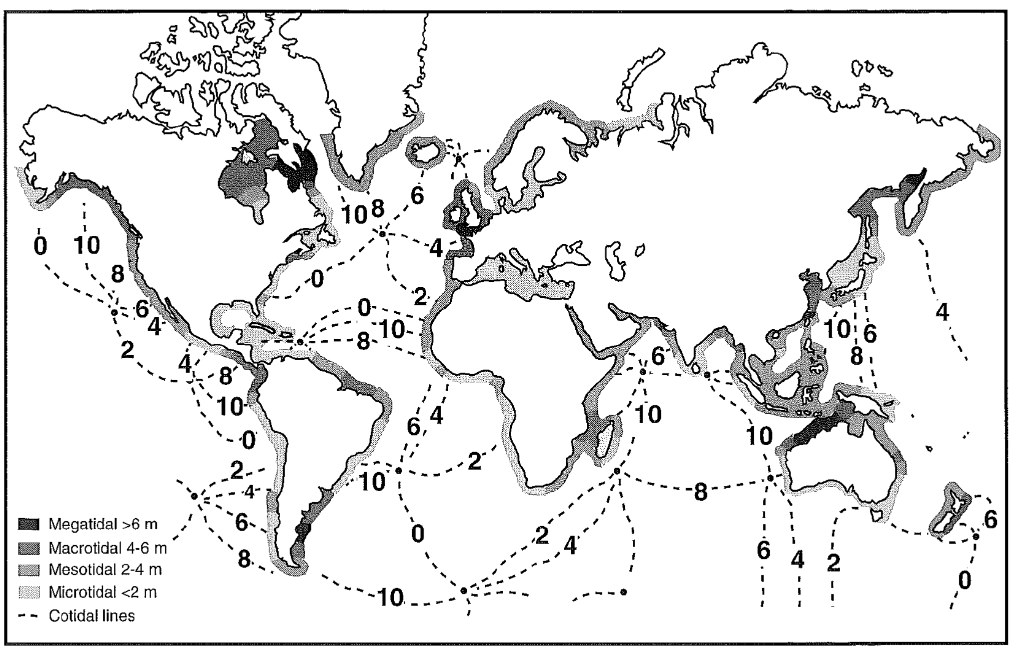
L3/17



What produces diurnal tide?

(Woodroffe Fig. 3.12)

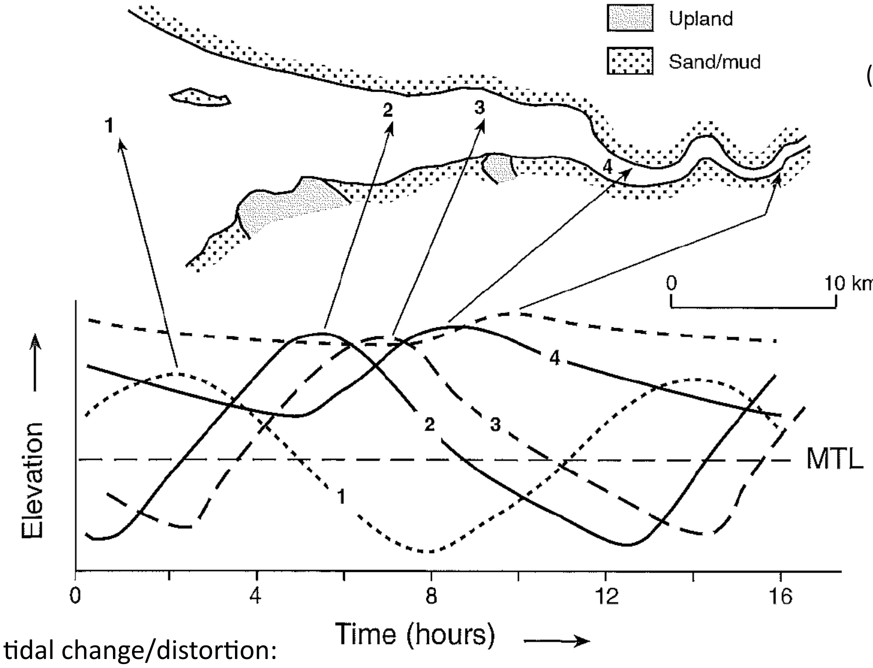
L3/18



(Woodroffe Fig. 3.13)

-- How fast can tide freely propagate?
-- Can tide keep up with astronomical forcing?
-- What is "equilibrium" open ocean tidal range from "bulge"?
-- What determines direction of tidal propagation along coasts?
-- Why is tidal range larger along some coasts?

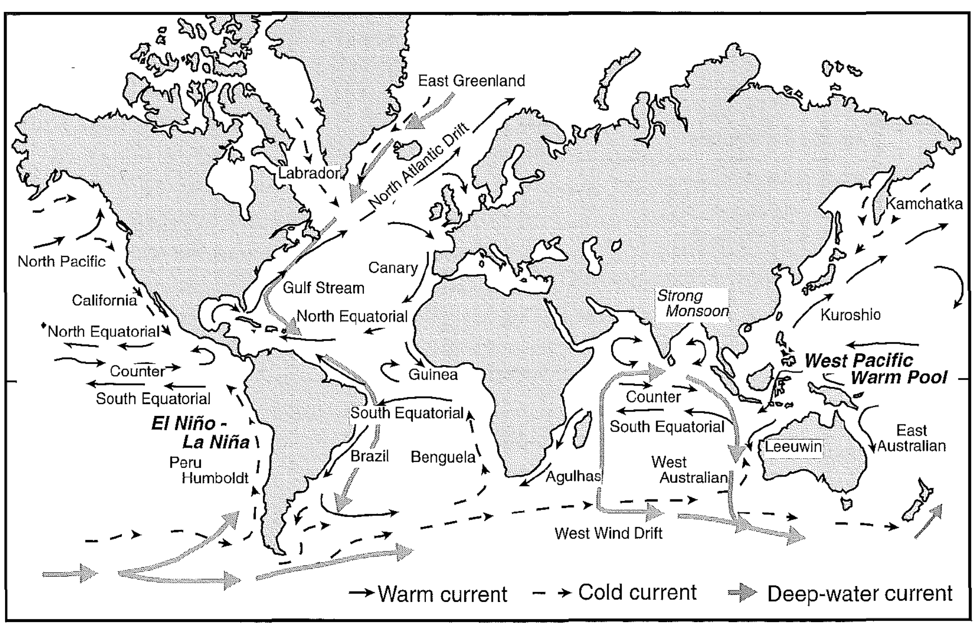
3.4.2. Tidal Processes in Embayments, Estuaries and Creeks L3/19



(Woodroffe Fig. 3.14)

Causes of tidal change/distortion:
-- Why does range grow and then decrease?
-- Why does tide become asymmetric?
-- Why does low tide become higher?
-- In long term, what controls tidal distortion?

3.5. Other Oceanographic Processes, 3.5.1. Ocean Currents L3/20



(Woodroffe Fig. 3.15)

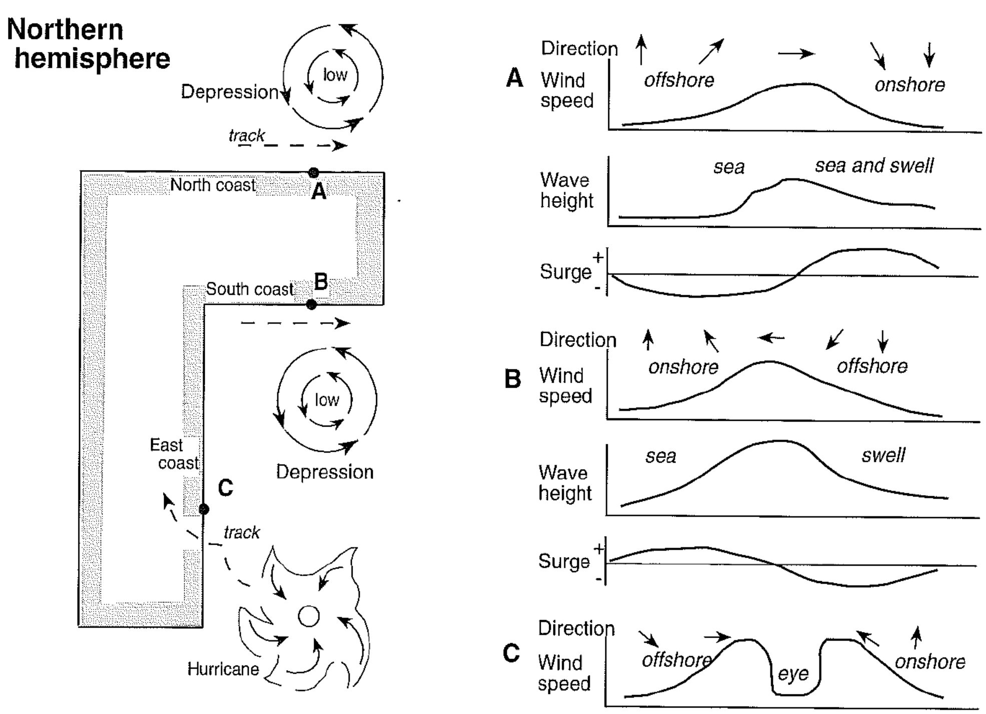
-- Current causes/constraints: Wind, density (T, S), surface slope, Coriolis, land, bathymetry.
-- Circulation cells: Sub-tropical & sub-polar gyres, influence water temp, upwelling, rainfall.
-- Where does deep water form: Ans. North Atlantic, Antarctica → Ocean Conveyor.
-- Long-term changes associated with: Sea-level, temperature, state of deep water formation.
-- Localized scour & transport, but main morphodynamic effects indirect via control on climate.

3.5.2. Sea Ice
-- Effect on waves and tides: Even thin ice damps wave action, no tidal currents if frozen solid.
-- Effect on sediment: Frozen sediment is much less mobile.
-- Sediment transport: Deposits on top of ice, grounded ice lifting sediment, ice gouging.
-- Direct effects of sea ice on coastal equilibrium profile generally localized or minor.

3.5.3. El Nino-Southern Oscillation
-- El Nino: Reduced trade-winds, decline in East Pacific upwelling, higher sea level in E. Pacific.
-- Remote effects: e.g., Drought in Australia & Indonesia, rain and cyclones in central Pacific.
-- Morphodynamics: Beach & erosion changes in response to storms, sea-levels;
cycles of river and sediment discharge.

3.5.4. Storms and Extreme Events
-- Are "extreme" events or "normal" long-term processes (e.g., many small storms, gradual sea-level rise) more important to morphology?
-- High latitude storms = "extra-tropical" cyclones (e.g., North-Easters)
-- Tropical storms = hurricanes (Atlantic), typhoons (Asia), tropical cyclones (E. Pacific)
-- Tsunamis -- sudden inundation up to 30 m (100 ft!)
-- Large floods – "hundred year", "500-year", etc., but effects are mainly inland and offshore.
-- Some major morphological (unidirectional) changes are only likely during extreme events – some types of cliff erosion, movement of large rocks, avulsion of major river or delta channels

L3/22



(Woodroffe Fig. 3.16)

-- Sequence of winds, waves & surge depend on: location relative to eye and storm track

-- Sea breezes (~ 2.5 m/s, land heats & cools faster, air rises over hotter region).
-- Sand waves and/or dunes form from 0.1 – 0.3 mm sand on beaches at ~ 5 m/s.

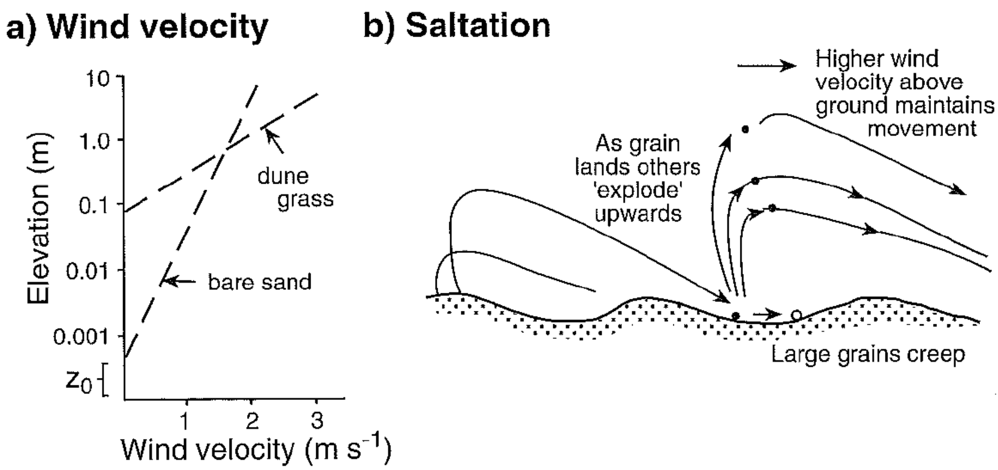


Figure 3.17. Processes operating on dunes. (a) Wind velocity with elevation above a dune vegetated with dune grass and a bare dune. The value Z_0 is defined by roughness, being related to vegetation height or grain size respectively (based on Carter, 1988). (b) The process of saltation (based on Pethick, 1984).

3.6.2. Frost Action
-- Permafrost and seasonal ground freezing: heaves sediment, ice mounds.
-- Ice lenses: vertical depressions.
-- Frost shattering: cracks in rocks fill with water and ice expands. Forms talus slopes, erodes rock cliffs. Relict talus slopes from earlier glacial cold periods.
-- Thawing of shoreline permafrost with climate change: rapid shoreline erosion.
-- Kettle holes: melting of ice blocks followed by flooding.

3.6.3. Fluvial Processes
-- Deltas, sediment supply, fresh water, etc. See Chapter 7.

3.6.4. Weathering and Hillslope Processes
-- Creep, slopewash, rockfall, spalling, toppling, sliding, slumping, flowing. See Chapter 4.

3.7. Biological Processes
-- Coral reefs (see Chapter 5).
-- Sediment supply: carbonate sands from coral rubble, shell hash, forams.
-- Bioadhesion of sediment particles: algal mats, organic flocs.
-- Stabilizing grasses: dune grass, marsh grass, SAV.
-- Bioturbation (e.g., bioturbated muddy subtidal sediment).
-- Grazing and boring of rock (e.g., gastrods).
-- Human impact (see Chapter 10).