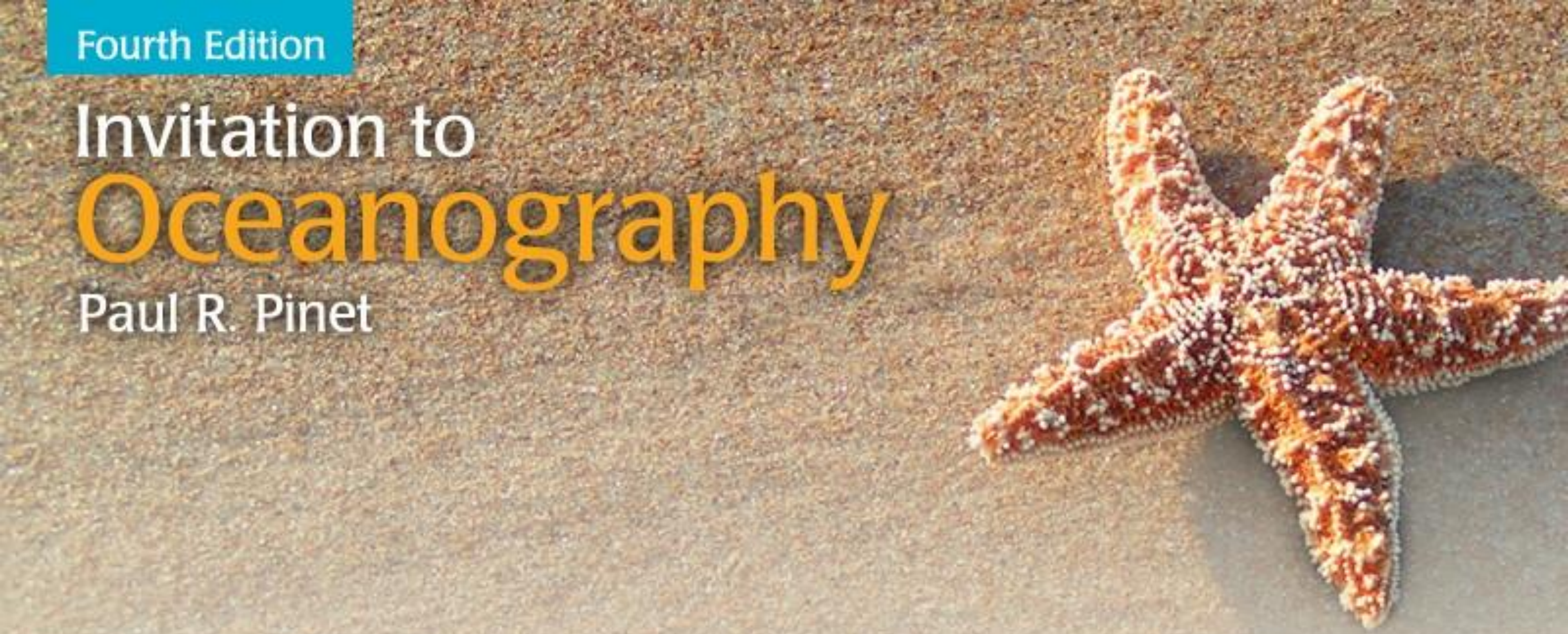


Chapter 7

Waves in the Ocean

Waves are the undulatory motion of a water surface

- Parts of a wave are:
  - wave crest
  - wave trough
  - wave height (H)
  - wave amplitude
  - wave length (L)
  - wave period (T)

Wave classification

- Wave period provides a basis for classifying waves

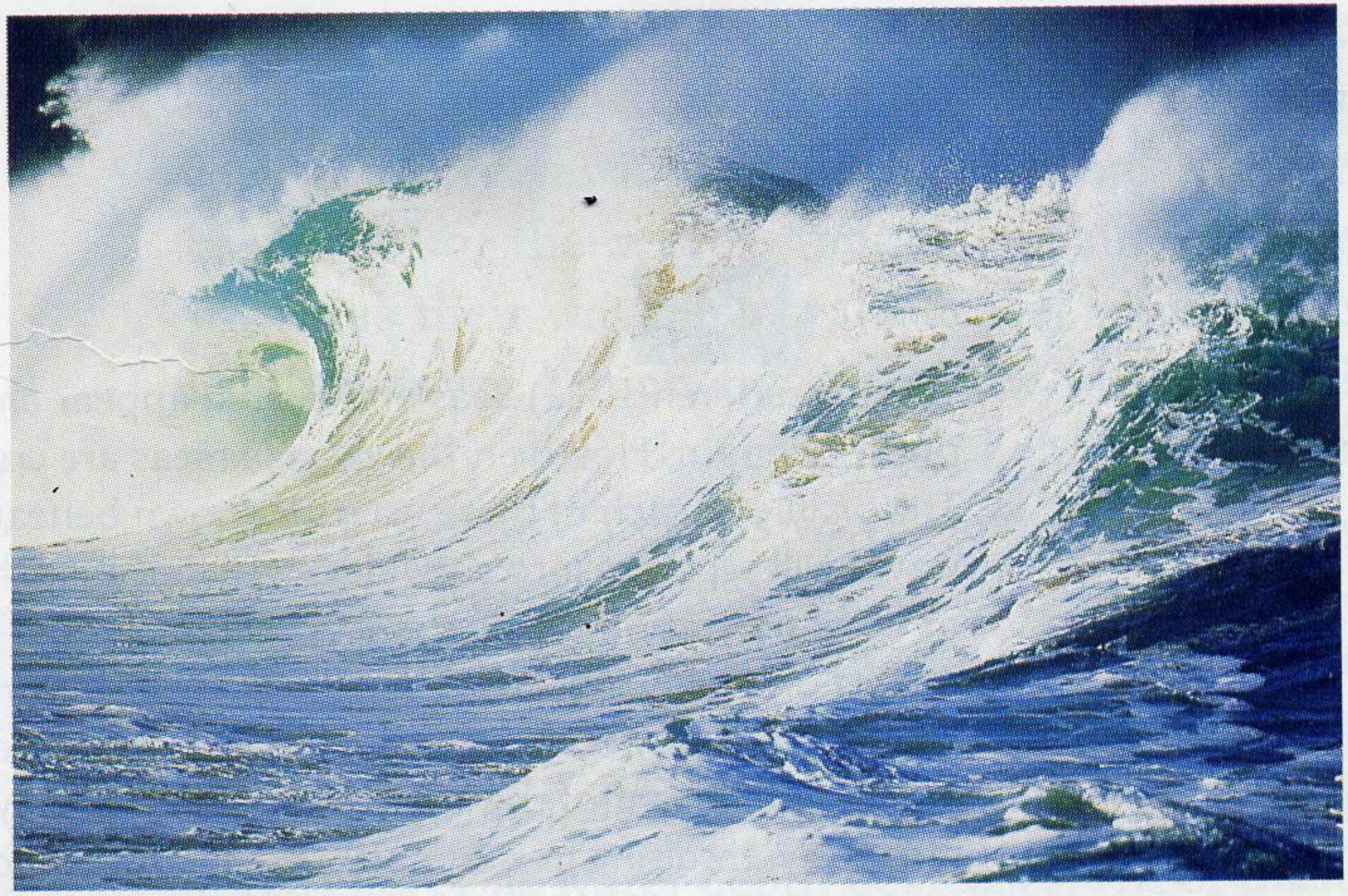
TABLE 7-1

Wave classification

Wave	Period	Wavelength	Wave Type	Cause
Capillary wave	<0.1 sec	<2 cm	Deep to shallow	Local winds
Chop	1–10 sec	1–10 m	Deep to shallow	Local winds
Swell	10–30 sec	Up to hundreds of m	Deep or shallow	Distant storm
Seiche	10 min–10 hr	Up to hundreds of km	Shallow or intermediate	Wind, tsunami, tidal resonance
Tsunami	10–60 min	Up to hundreds of km	Shallow or intermediate	Submarine disturbance
Tide	12.4–24.8 hr	Thousands of km	Shallow	Gravitational attraction of sun and moon
Internal wave	min to hr	Up to hundreds of m	Deep to shallow	Disturbance at pycnocline

(a) CHAOTIC WAVES

(b) OCEAN SWELLS



(c) OCEAN BREAKERS

Waves and their Properties

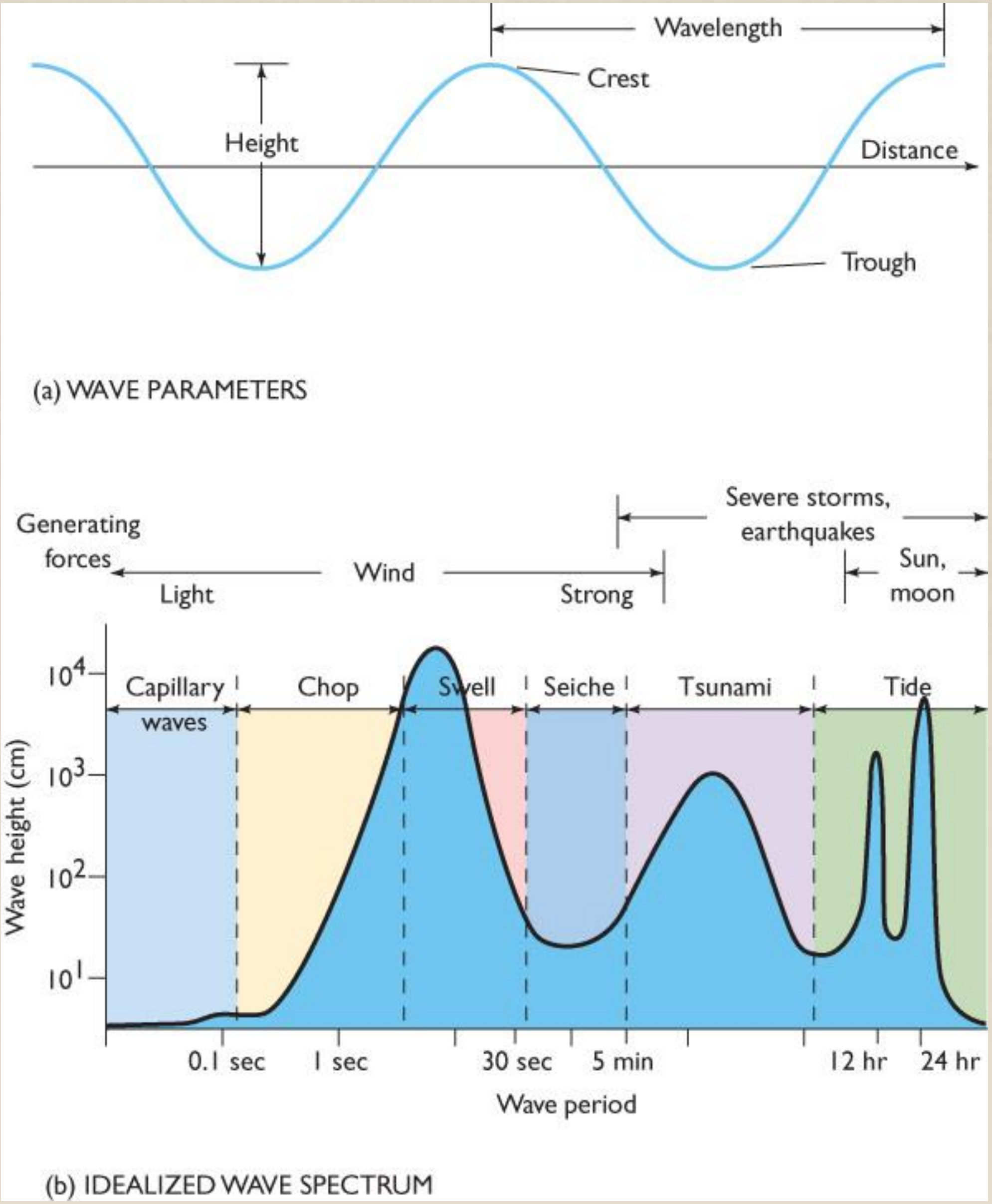


Figure 7-1a Wave Parameters

Figure 7-1b Idealized Wave Spectrum

7-1 Properties of Ocean Waves

Most of the waves present on the ocean's surface are wind-generated waves

- Size and type of wind-generated waves are controlled by:
  - wind velocity
  - wind duration
  - fetch
  - original state of the sea surface

- As wind velocity increases:
    - Wavelength
    - period
    - height
  - increase, but only if wind duration and fetch are sufficient.

- A **fully developed** sea means the wind-generated waves are as large as they can be under current wind velocity and fetch.

- Significant wave height is the average of the highest 1/3 of the waves present.

  – It is a good indicator of potential for:
    - wave damage to ships
    - erosion of shorelines

Progressive waves are waves that move across a surface

- As waves pass, wave form and wave energy move rapidly forward, but **not** the water.

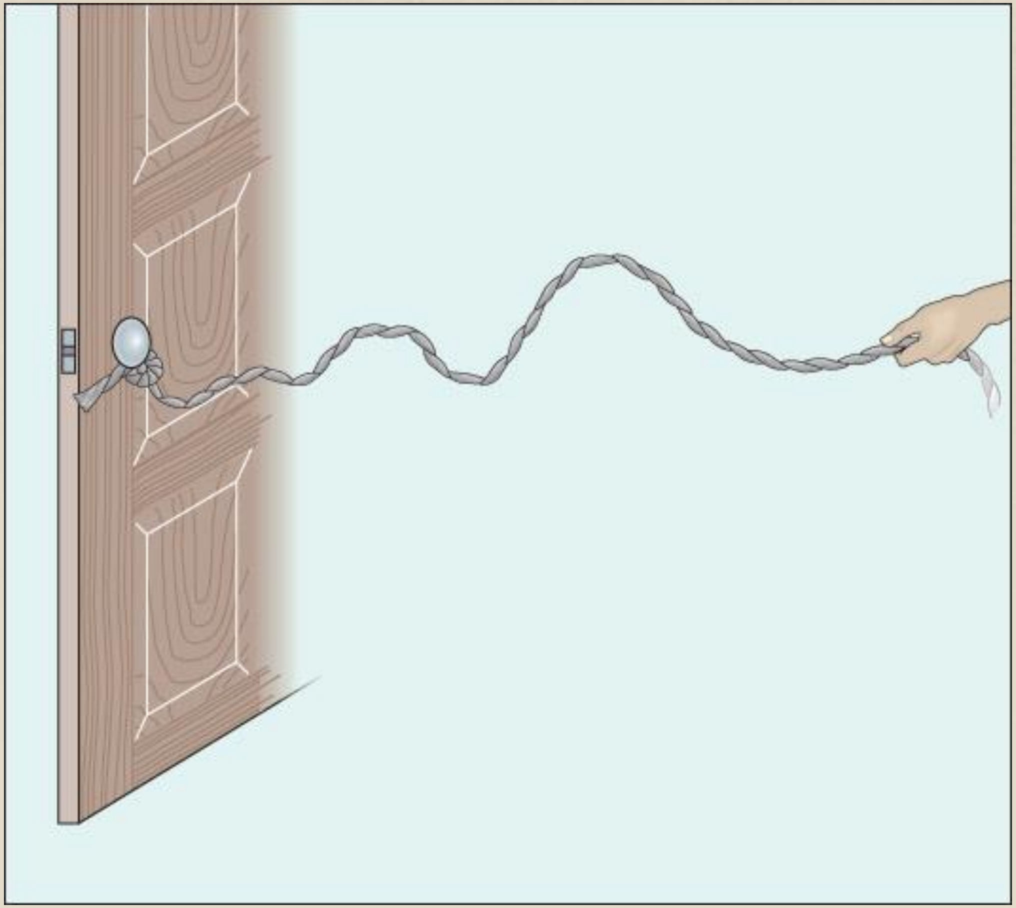


Figure 7-2 Wave Motion

- Water molecules move in an **orbital** motion as the wave passes.

- Diameter of orbit:
  - increases with increasing wave size
  - decreases with depth below the water surface

The Motion of Water Particles Beneath Waves

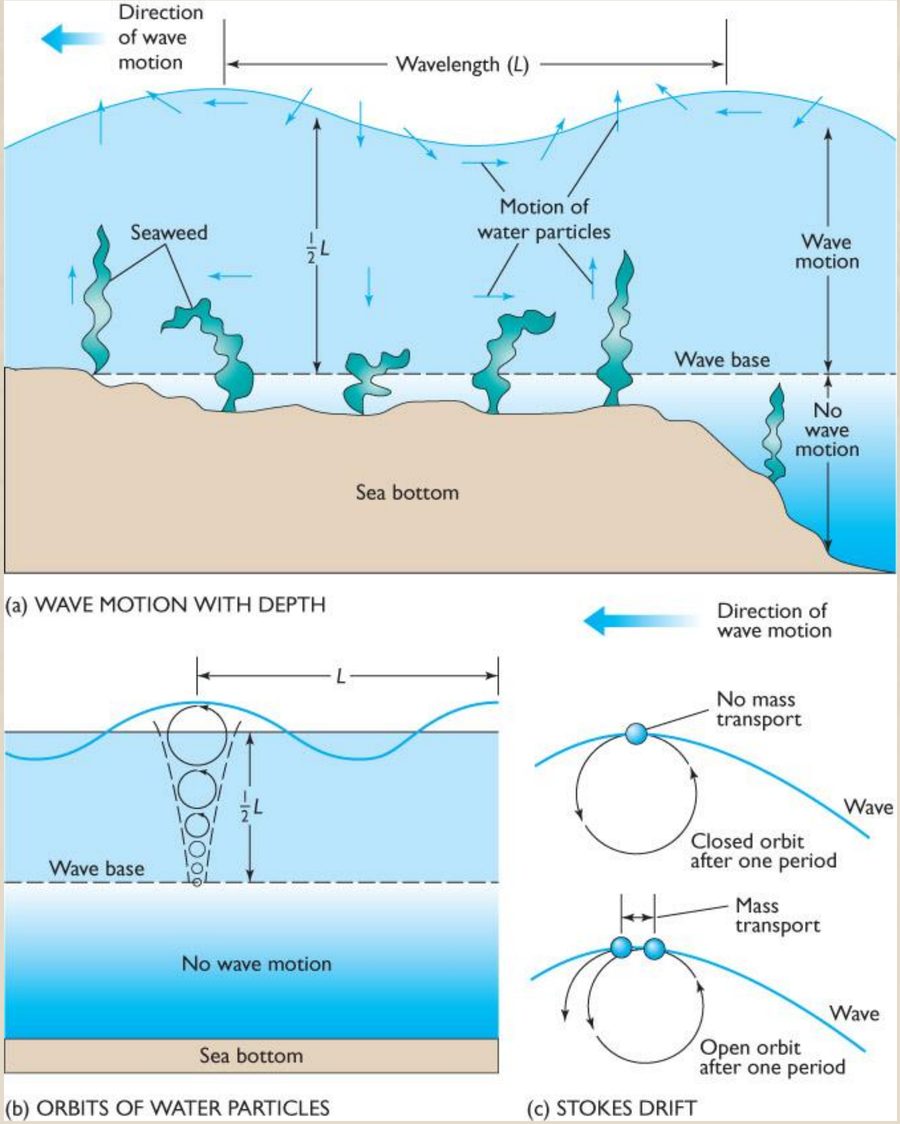


Figure 7-3a Wave Motion with Depth

Figure 7-3b Orbits of Water Particles

Figure 7-3c Stokes Drift

7-2 Wave Motions

- Wave base is the depth to which a surface wave can move water.

- If the water is **deeper** than wave base:
  - orbits are circular
  - there is no interaction between the bottom and the wave

- If the water is **shallower** than wave base:
  - orbits are elliptical
  - Orbits become increasingly flattened towards the bottom

The Distortion of Water-Particle Orbits in Shallow Water

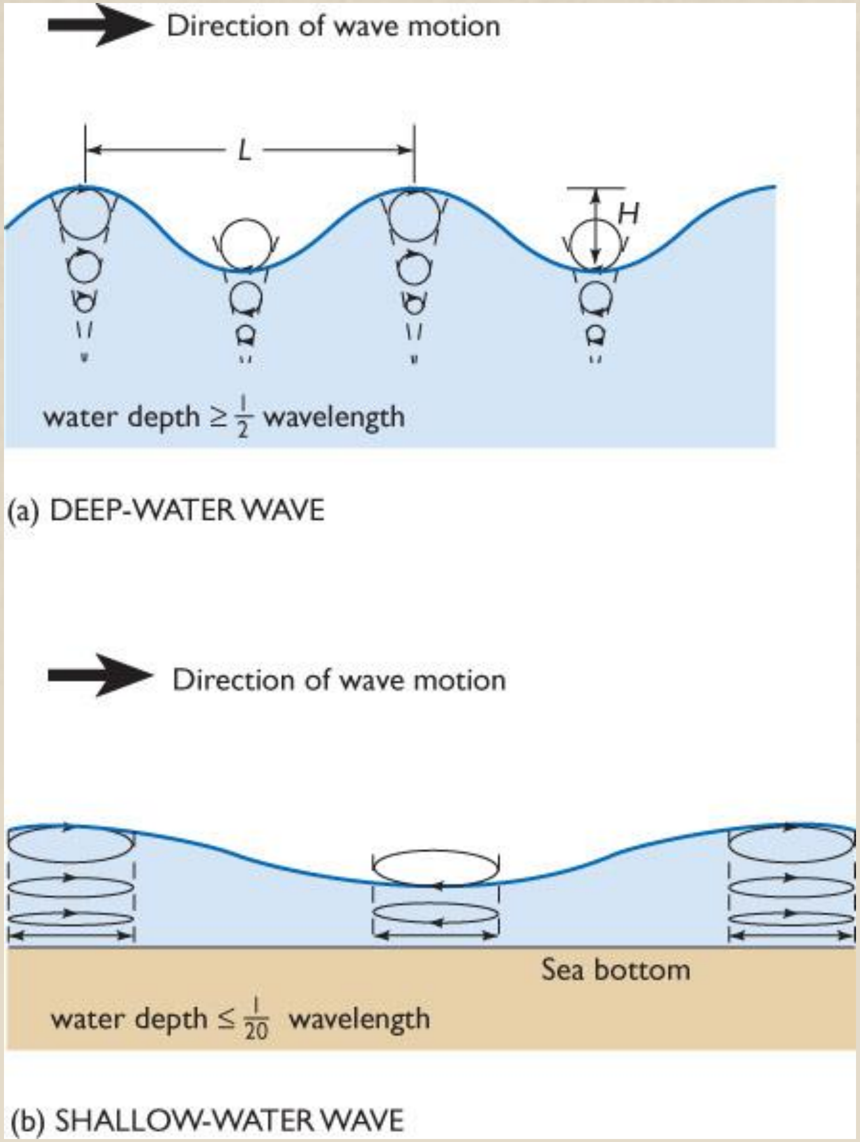


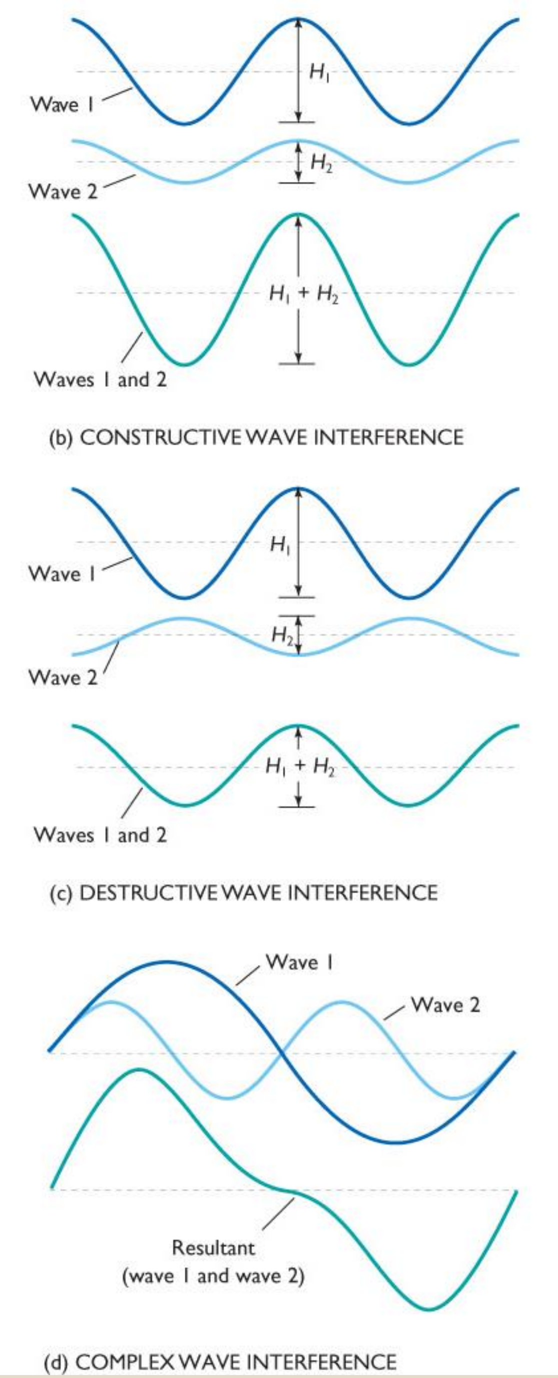
Figure 7-4

- There are three types of waves defined by water depth:
  - Deep-water wave
  - Intermediate-water wave
  - Shallow-water wave

- **Celerity** is the velocity of the **wave form,** not of the water.

- The celerity of a group of waves all traveling at the same speed in the same direction is **less than** the speed of individual waves within the group.

- **Fetch** is the area of contact between the wind and the water.
  – It is where wind-generated waves begin.
- **Seas** is the term applied to the sea state of the fetch when there is a chaotic jumble of new waves.
- Waves continue to grow until the sea is fully developed or becomes limited by fetch restriction or wind duration.



- Wave **interference** is the momentary interaction between waves as they pass through each other.
  - Wave interference can be
    - **constructive**,
    - **destructive**,
    - or **complex**.

Figure 7-6b-d Wave interference

7-3 The Life History of Ocean Waves

- Because celerity increases as wavelength increases, long waves travel faster than short waves.

- This causes dispersion outside of the fetch and regular ocean swell.

- The shallower the water, the greater the interaction between the wave and the bottom.
  - This alters the wave properties, eventually causing the wave to collapse.

- When depth decreases:
  - Wave speed decreases
  - Wavelength decreases
  - Wave height increases

- In shallow water:
  - Troughs become flattened and the wave profile becomes extremely asymmetrical.
  - Period remains unchanged.
    - Period is a fundamental property of a wave.
  - **Refraction** is the bending of a wave crest into an area where it travels more slowly.

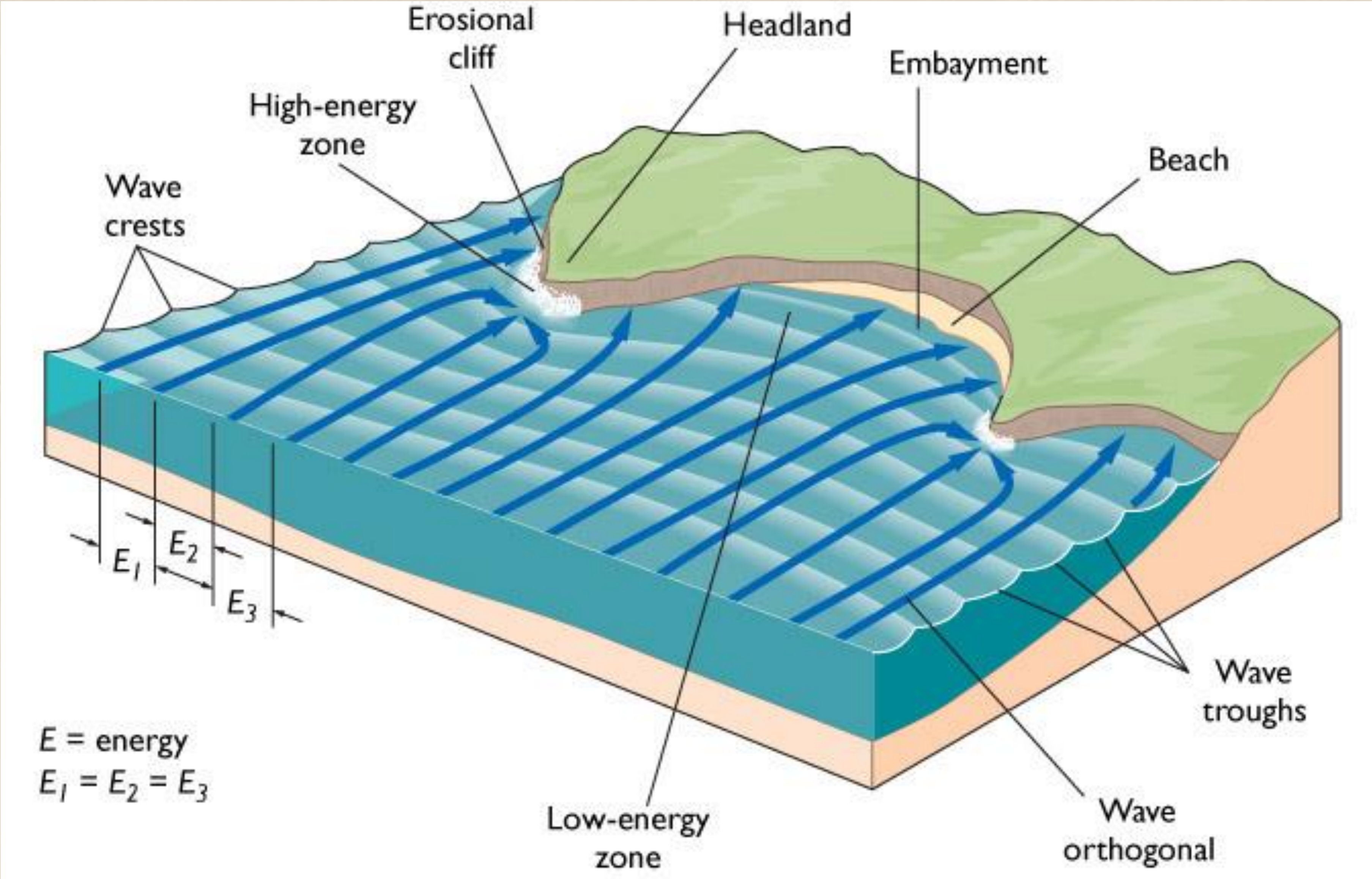


Figure 7-8a Wave Refraction

7-3 The Life History of Ocean Waves

Wave Transformation

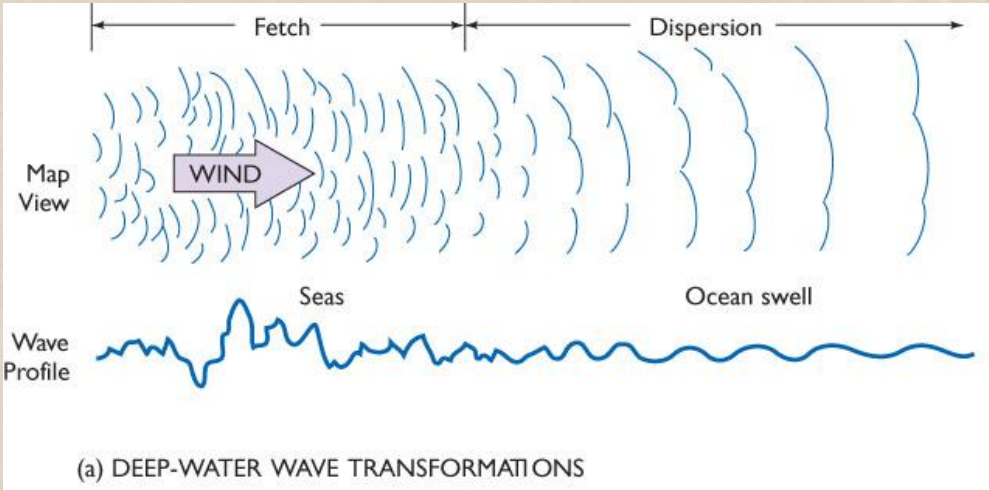


Figure 7-7a Deep-Water Wave Transformations

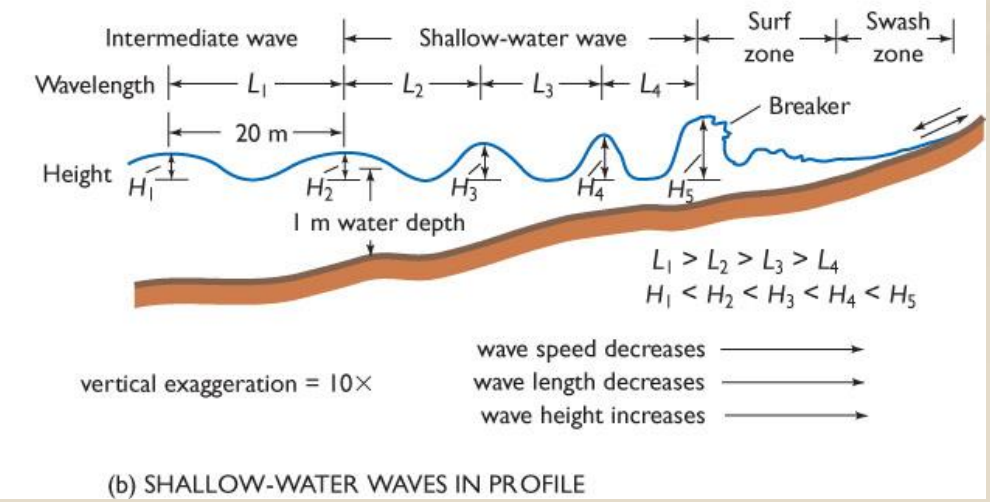


Figure 7-7b Shallow-Water Waves in Profile

Wave steepness is a ratio of **wave height** divided by **wavelength** (H/L)

- In shallow water:
  - wave height increases
  - wave length decreases
- When $H/L \geq 1/7$, the wave becomes unstable and **breaks**.

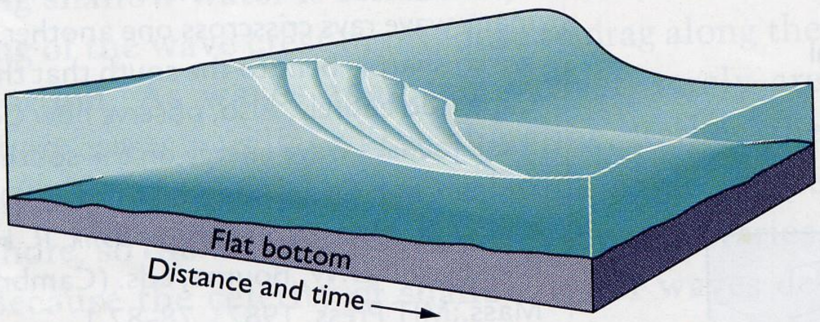
There are Three Types of Breakers

Figure 7-9a Spilling Breaker

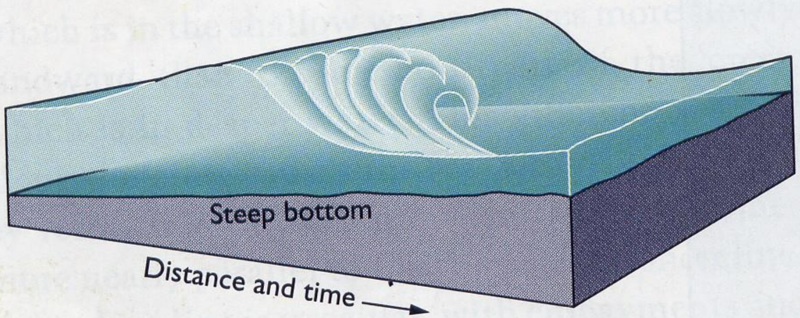
Figure 7-9b Plunging Breaker

Figure 7-9c Surging Breaker

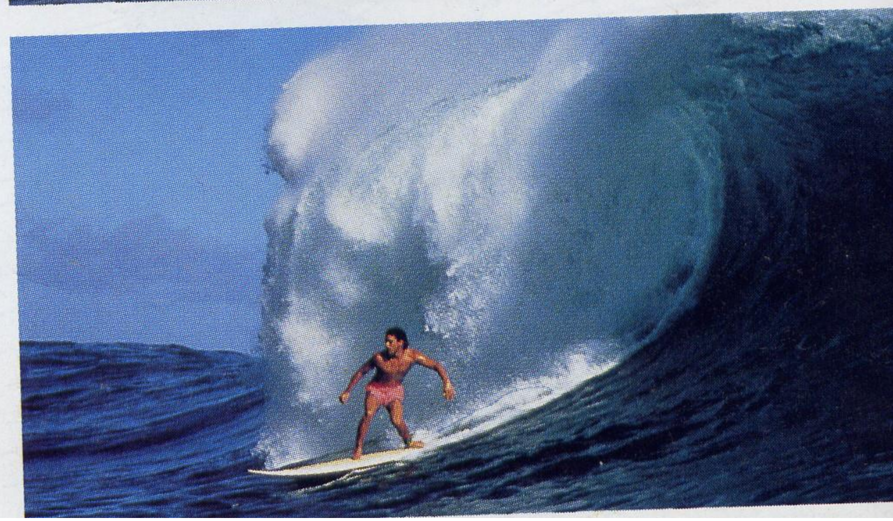
7-3 The Life History of Ocean Waves

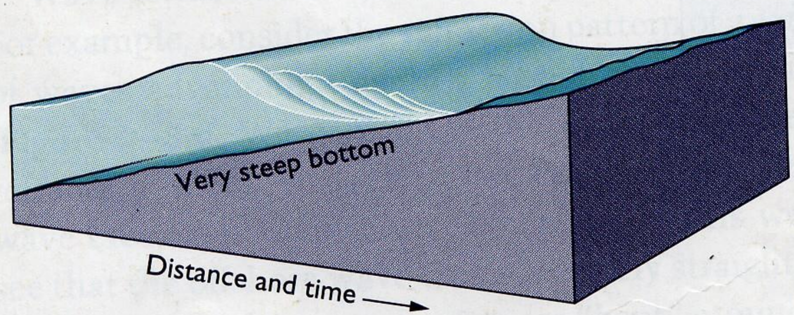


(a) SPILLING BREAKER



(b) PLUNGING BREAKER





(c) SURGING BREAKER

- **Storm surge** is the rise in sea level resulting from:
  - low atmospheric pressure
  - accumulation of water driven shoreward by storm winds

- Water is deeper at the shore area, allowing waves to progress farther inland.

- Storm surge is especially severe during a spring high tide.

Hurricane Damage

Figure 7-10a Storm Damage

Figure 7-10b Storm Surge Effect

(a) STORM DAMAGE

(b) STORM SURGE EFFECT

Standing waves or **seiches** consist of a water surface "seesawing" back and forth

- A **node** is an imaginary line across the surface that experiences no change in elevation as the standing wave **oscillates**.
  - It is the line about which the surface oscillates.
- **Antinodes** are where there is maximum displacement of the surface as it oscillates.
  - They are usually located at the edge of the basin.

Natural Period of Standing Waves

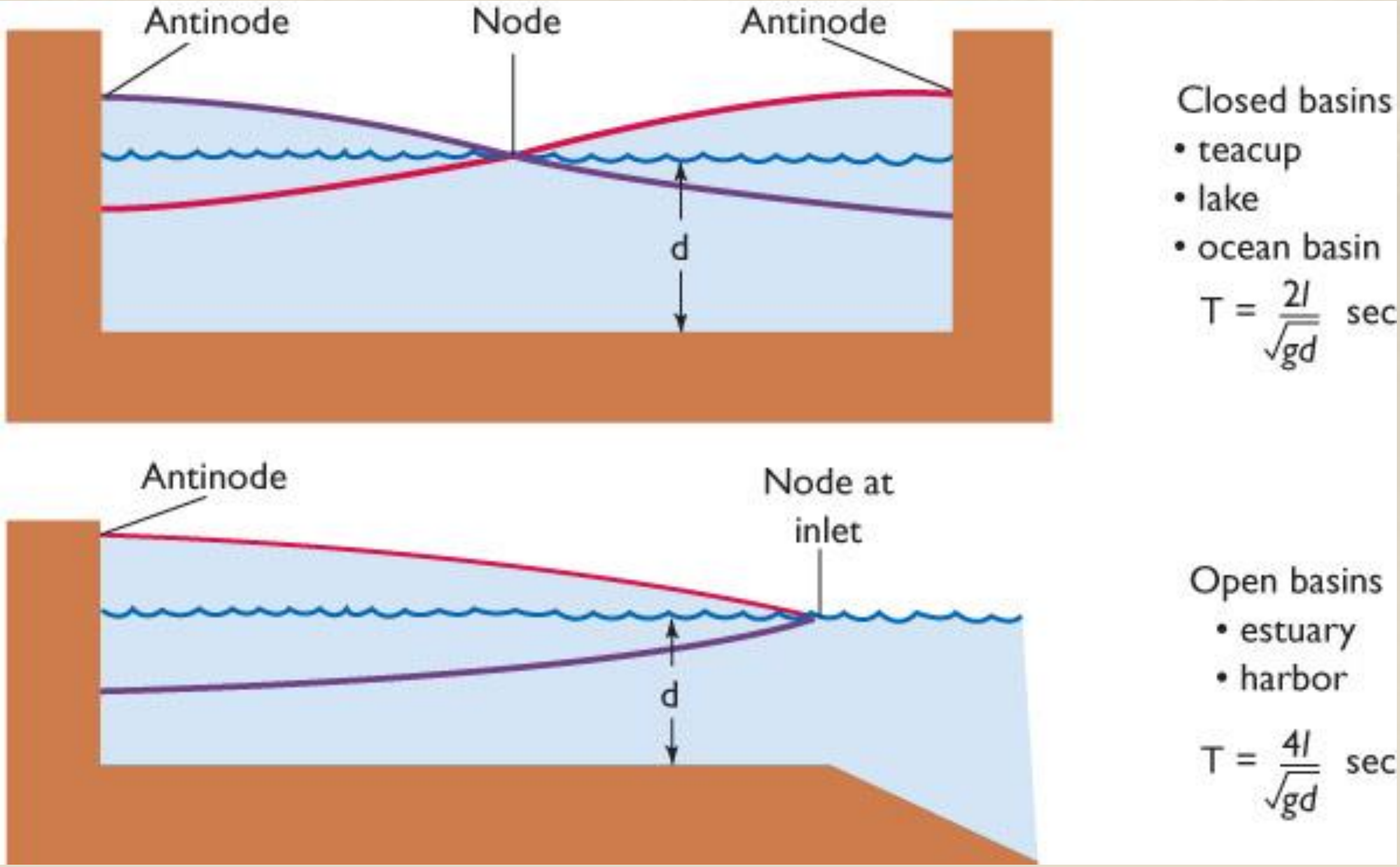


Figure 7-11 Natural Period of Standing Waves

- Geometry of the basin controls the period of the standing wave.
  - A basin can be closed or open.

- Standing waves can be generated by storm surges.

- **Resonance** amplifies the displacement at the nodes.
  - It occurs when the period of the basin is similar to the period of the force producing the standing wave.

Internal waves form within the water column along the pycnocline

- There is small density difference between the water masses above and below the pycnocline.
  - Therefore, properties of internal waves are different from surface waves.
    - They travel more slowly
    - They can be much larger

- Internal waves display all the properties of surface progressive waves including:
  - Reflection
  - Refraction
  - Interference
  - breaking, etc.

- Any disturbance to the pycnocline can generate internal waves, including:
  - flow of water related to the tides
  - flow of water masses past each other
  - storms
  - submarine landslides

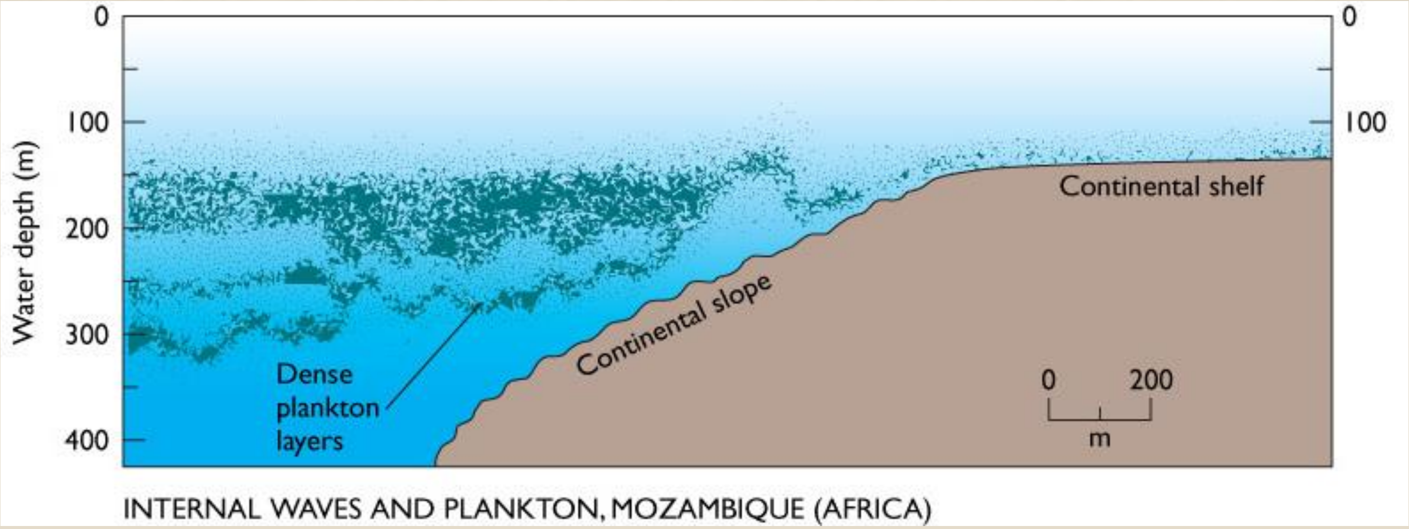


Figure 7-12 Internal Waves

Tsunamis

- **Tsunamis** were previously called tidal waves, but are unrelated to tides.

- Tsunamis consist of a series of long-period waves characterized by:
  - very long wavelength (up to 100 km)
  - high speed (up to 760 km/hr) in the deep ocean

- Because of their large wavelength, tsunamis are shallow-water to intermediate-water waves as they travel across the ocean basin.

- They only become a danger when reaching coastal areas where wave height can reach 10 m.

Tsunamis originate from earthquakes, volcanic explosions, or submarine landslides.

On December 26, 2004, an earthquake with a magnitude of over 9.0 on the Richter scale triggered a **megatsunami** that affected coastlines throughout the Indian Ocean.

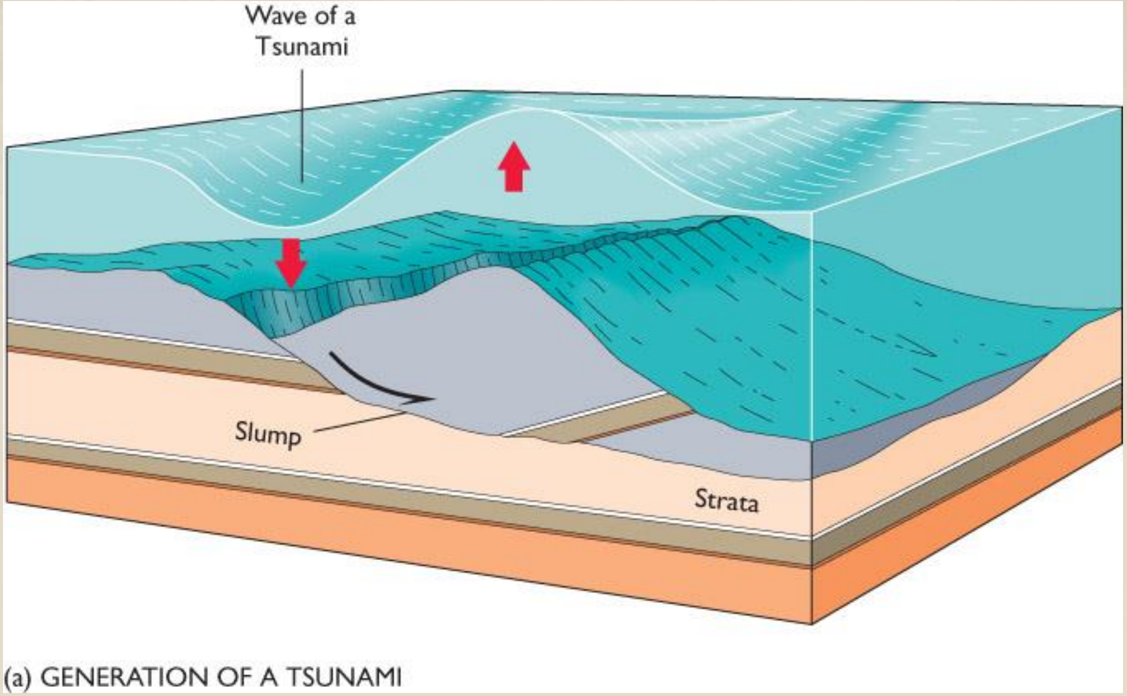
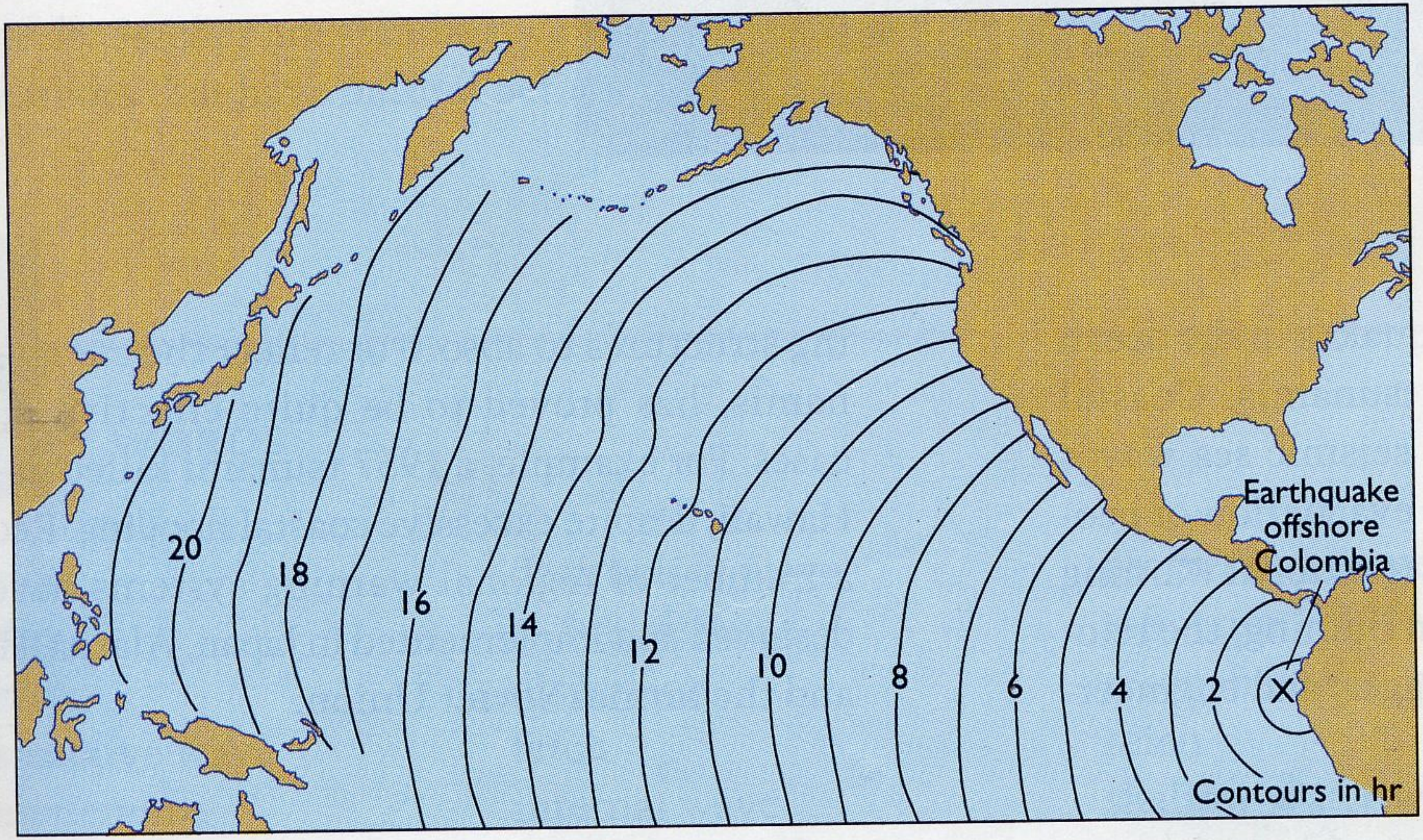


Figure 7-13a Generation of a Tsunami



(b) REFRACTION PATTERN OF 1979 TSUNAMI