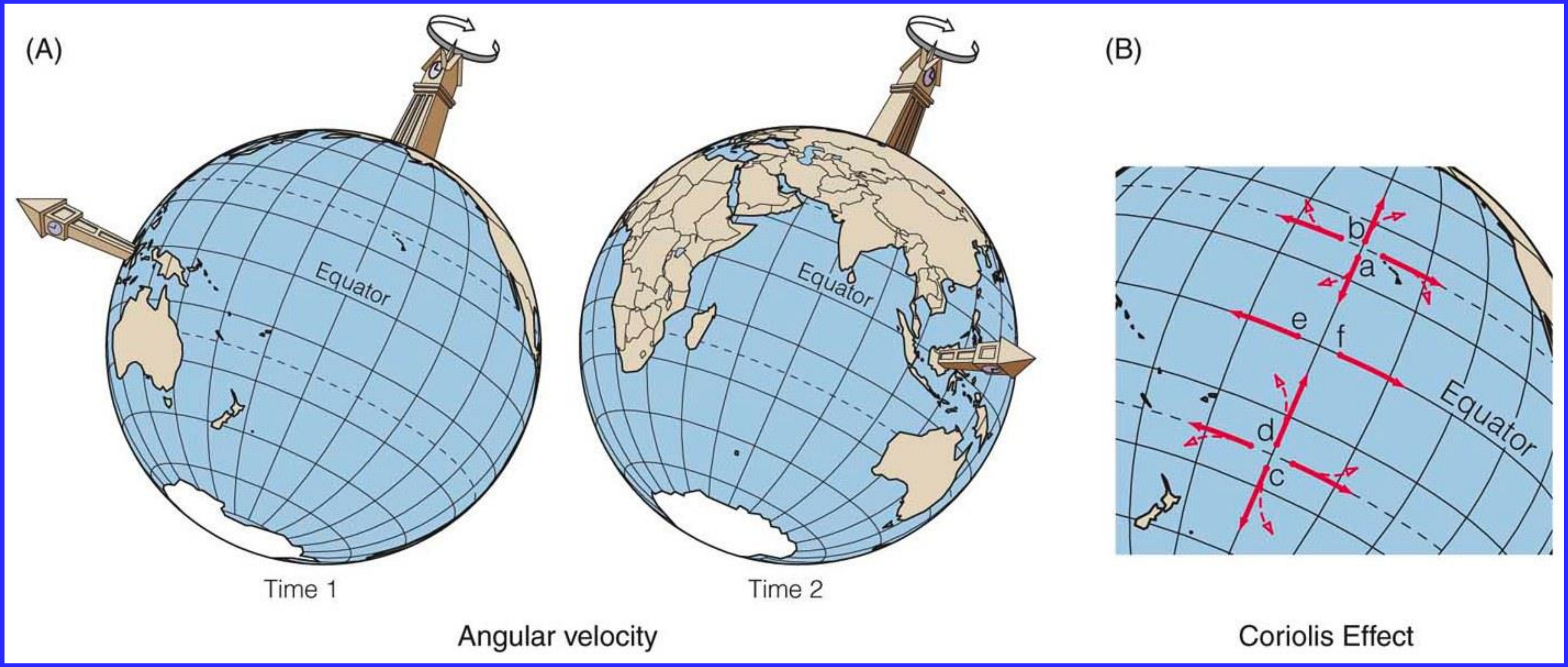
The World Ocean – III
Circulation, Waves, and Tides

Ocean Circulation

- Surface ocean currents are broad, slow drifts of surface water caused by friction between the ocean and air flowing over it
  - 50-100 m deep
  - Solar radiation provides heat energy, non uniform heating generates winds, which drive the movement of surface ocean water
- Ocean current direction is also influenced by the Coriolis force

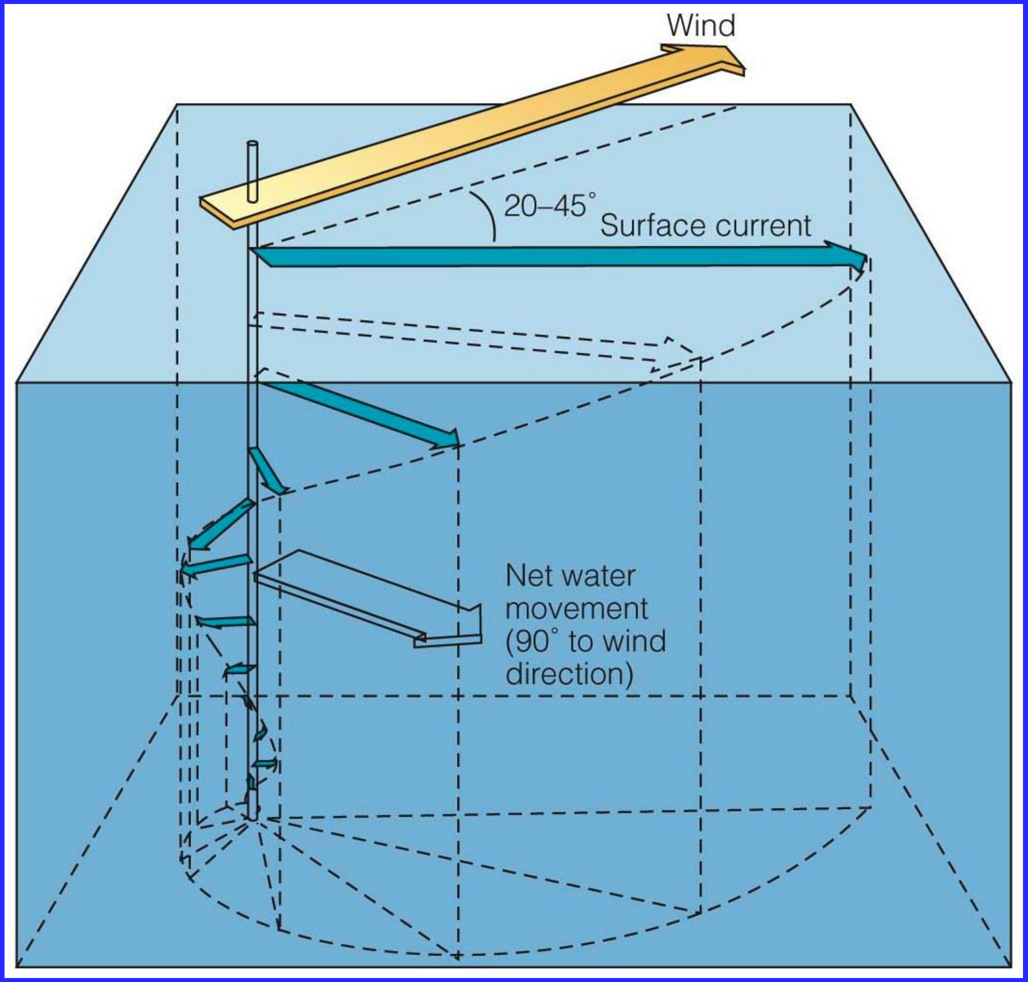
Ocean Circulation



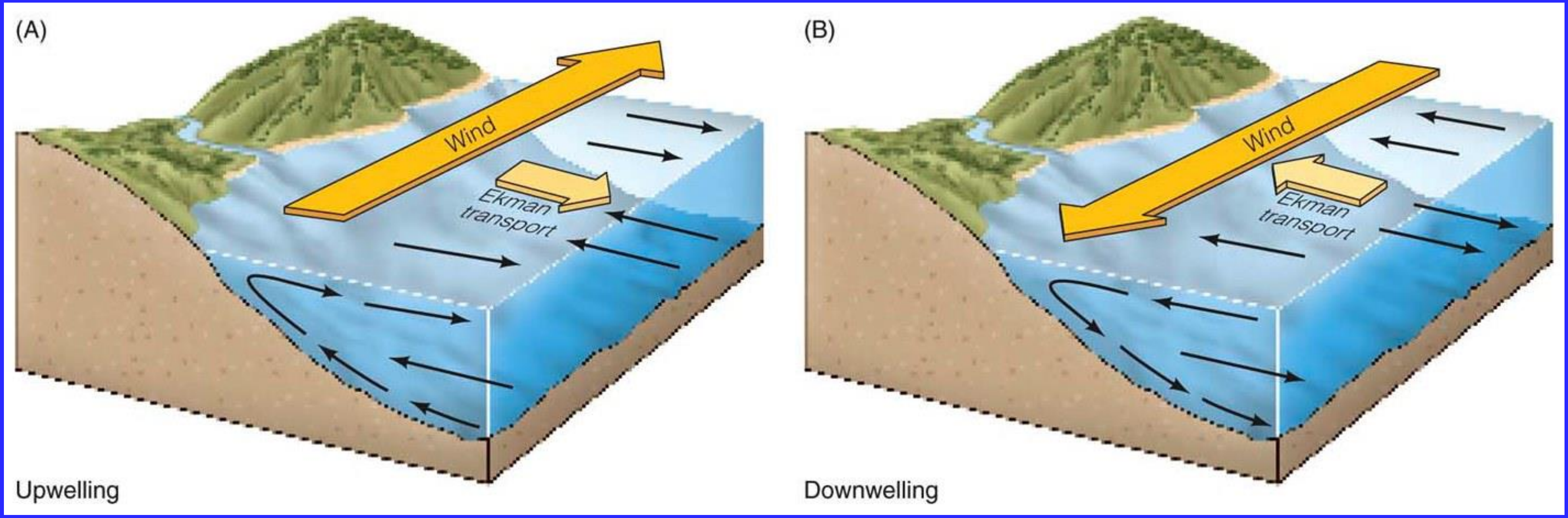
Ocean Circulation

- Ekman transport
  - The balance of the wind on surface water and Coriolis force at depth
  - Generates a spiraling current pattern
  - Results in a net direction of water movement about 90° to the wind direction
  - Near coasts this leads to vertical movement of ocean water
    - Upwelling if net transport is away from land
    - Downwelling if net transport is toward land

Ocean Circulation



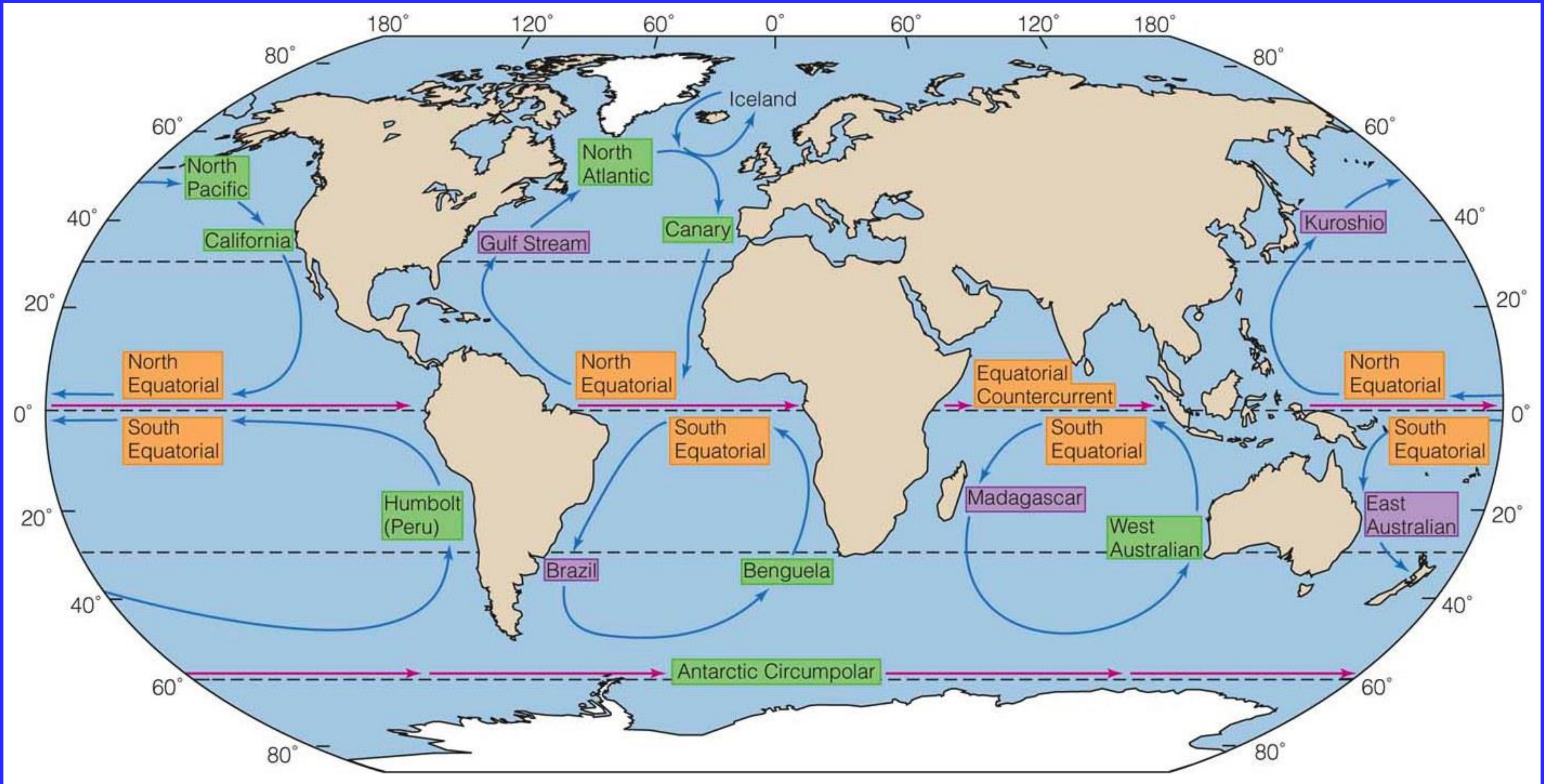
Ocean Circulation



Ocean Circulation

- With geography, ocean current drivers set up the major surface current systems in the world ocean
- Each major ocean current is part of a large subcircular current system called a gyre
  - 2 in the Pacific
  - 2 in the Atlantic
  - 2 in the Indian

Ocean Circulation



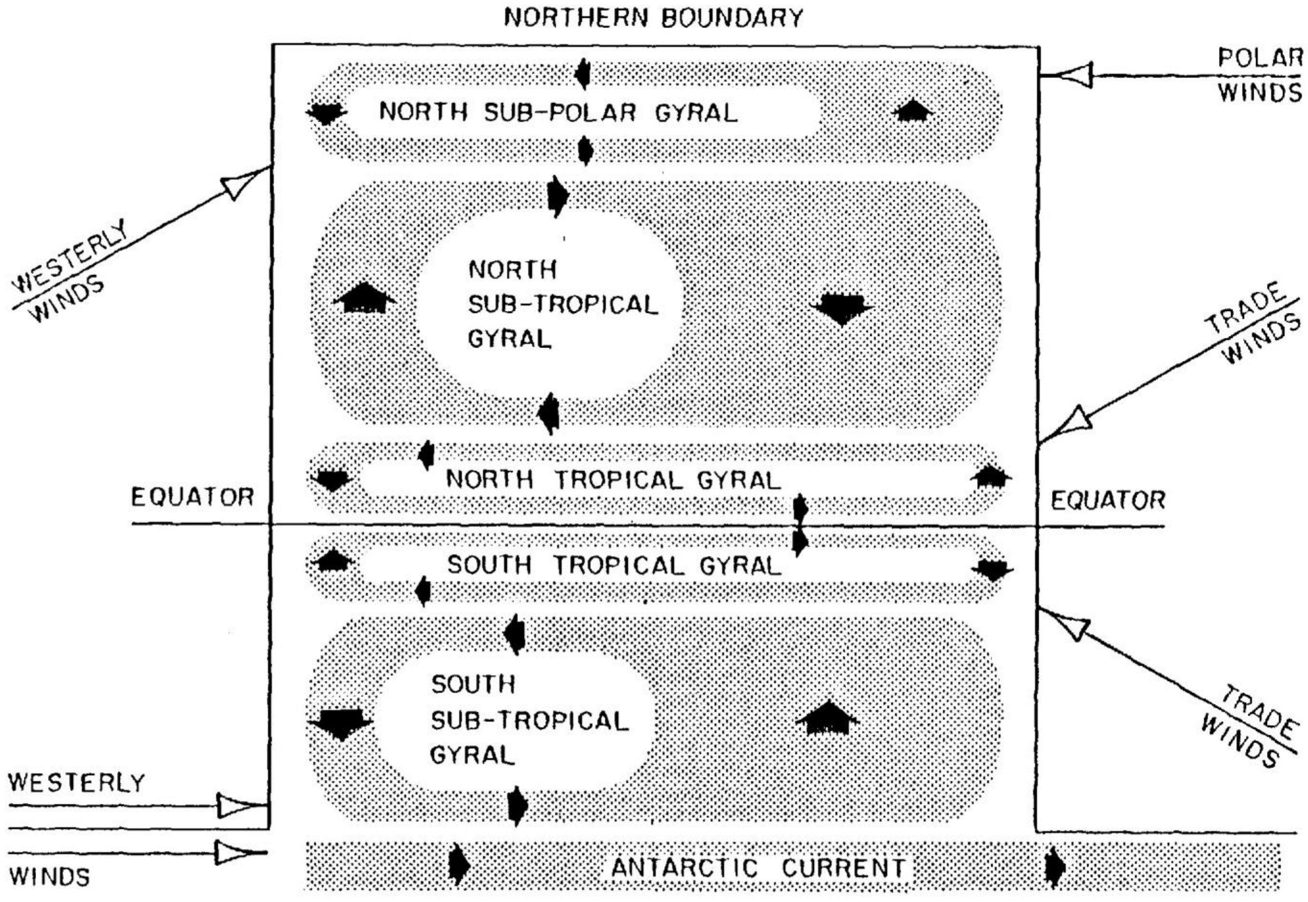


FIGURE XI-3. *A highly idealized representation of the prevailing winds and their effect on the surface currents of an imaginary rectangular ocean.*

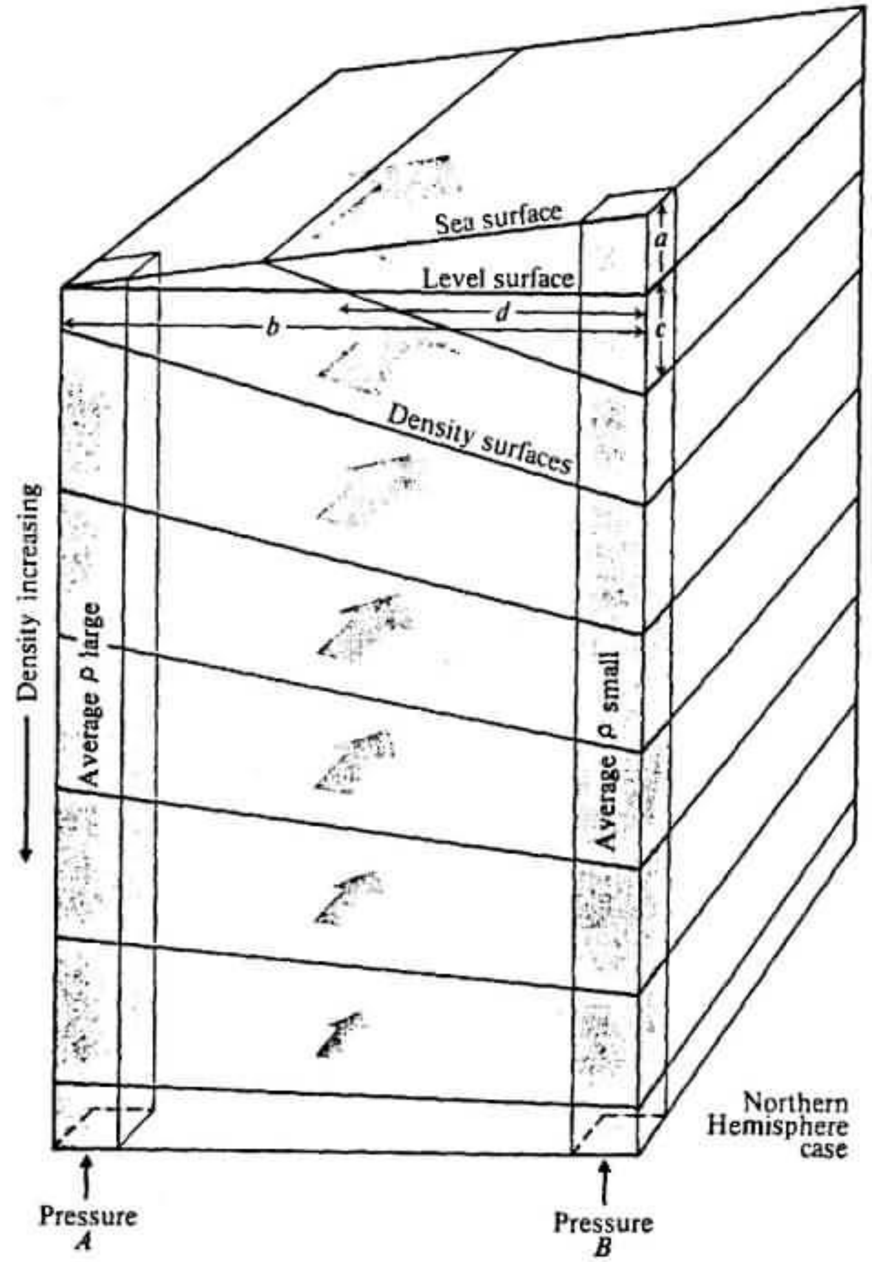


Fig. 12.1 In geostrophic flow, moving water is acted upon by the Coriolis force and deflected until an equal and opposing pressure gradient force is formed. When this balance is struck, the water moves at a right angle to the pressure gradient. The slope of the sea surface required to form this pressure gradient is *a/b*. The density surfaces take on a reverse slope *c/d* which is much greater than the sea-surface slope and which is readily measured. The adjustment in the mass field allows the hydrostatic pressure at some depth to be constant; Pressure *A* equals Pressure *B* even though the columns of water are of unequal lengths.

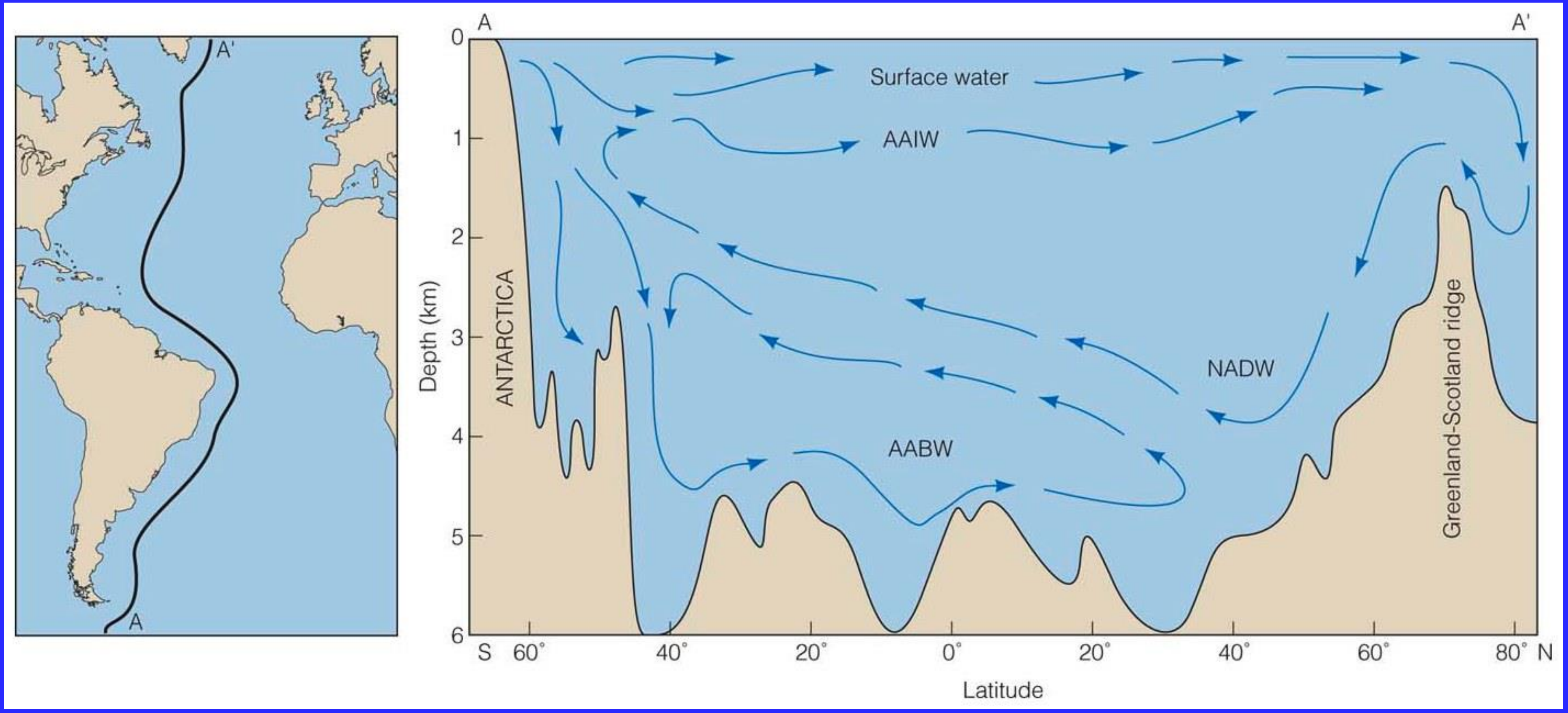
Ocean Circulation

- On either side of the equator, ocean regions are dominated by westward-flowing North and South Equatorial currents
- Along the equator is the eastward-flowing Equatorical Countercurrent
- Near 60° latitude, the Antarctic Circumpolar Current circles the globe

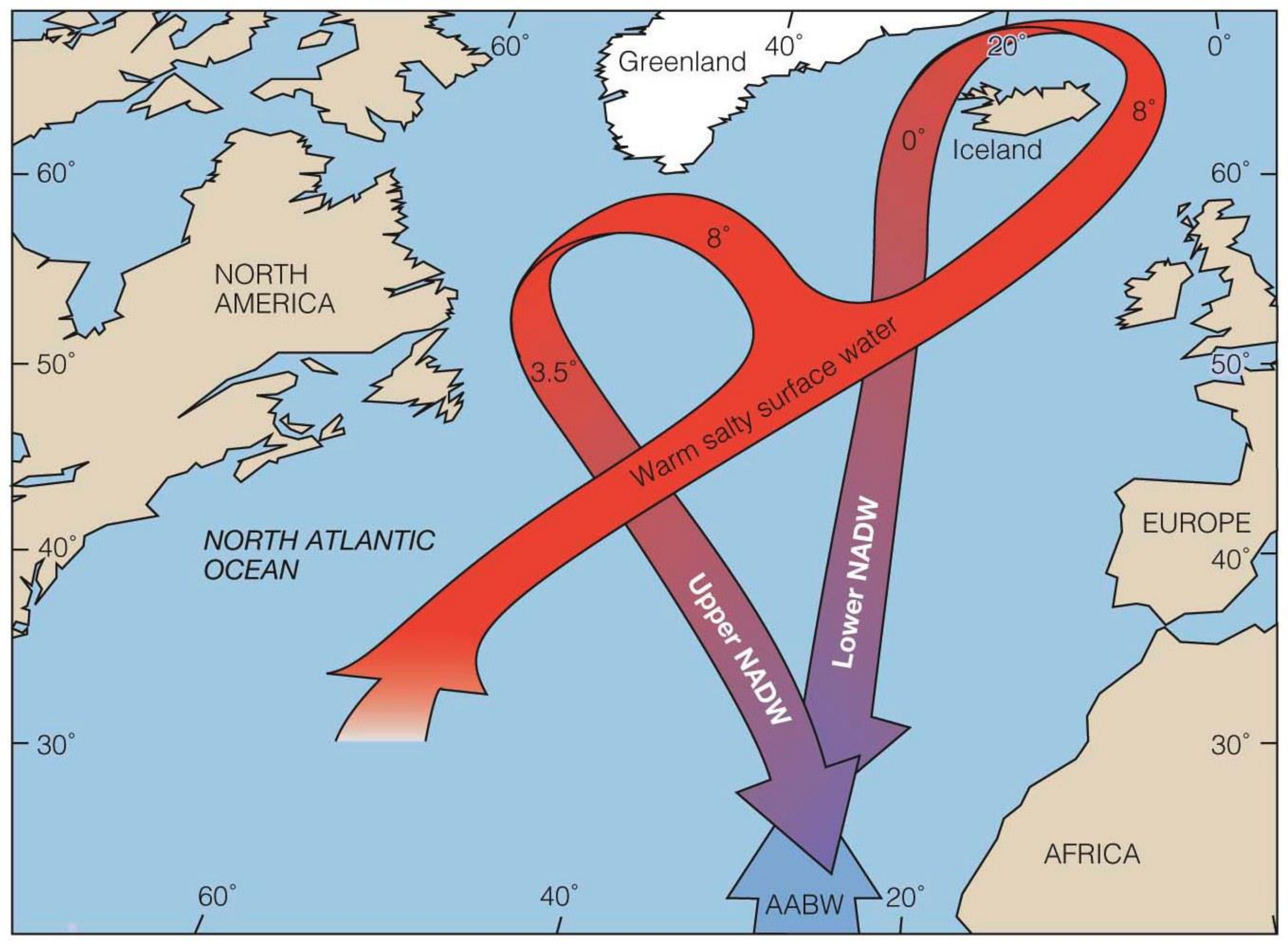
Ocean Circulation

- North Atlantic Deep Water (NADW) originates at the surface of the north Atlantic, flows downward, and spreads southward to the south Atlantic
- Flowing beneath this is the colder, denser Antarctic Bottom Water (AABW)
- The sinking of dense, cold, saline surface water propels a global thermohaline circulation system

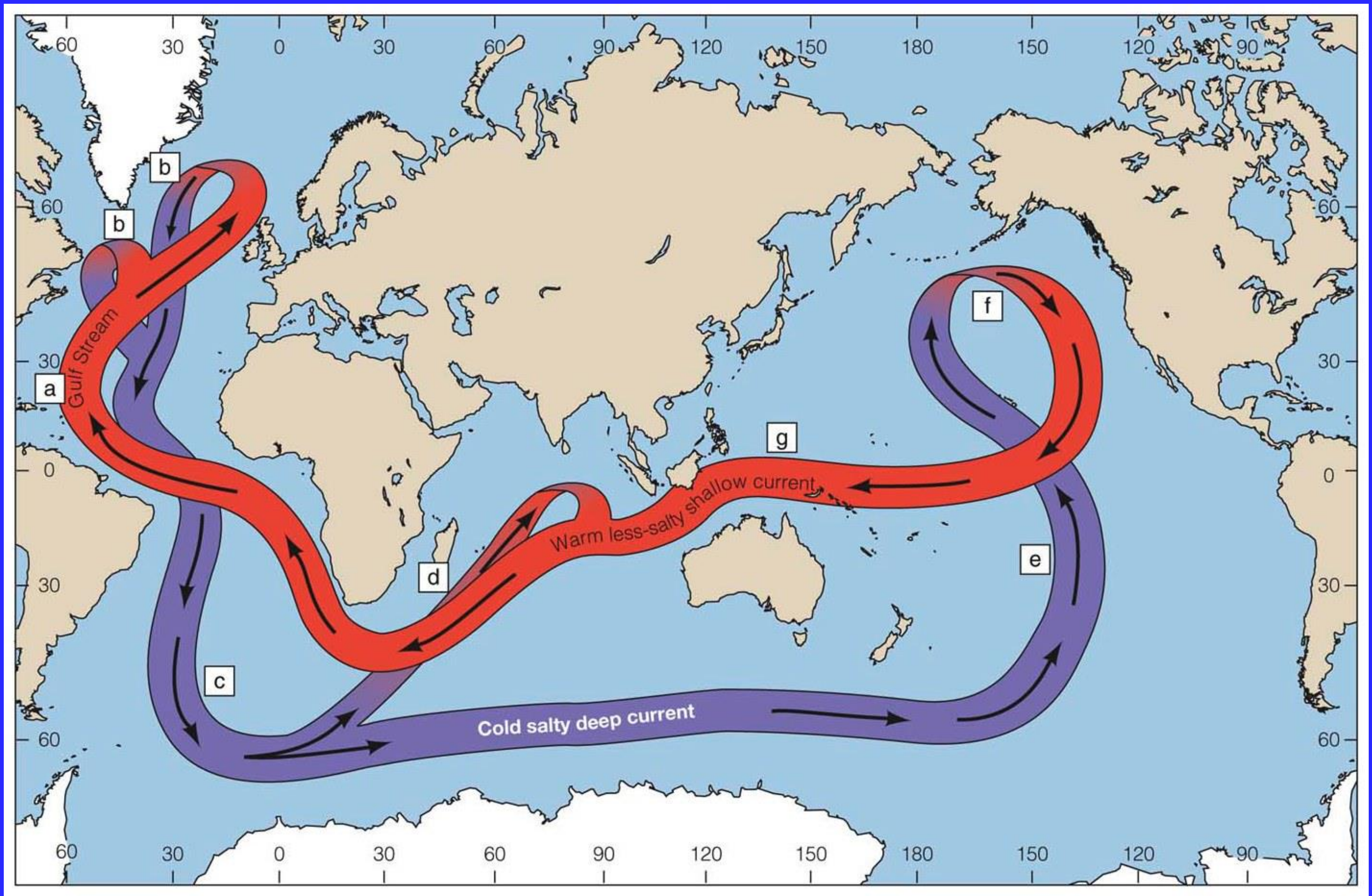
Ocean Circulation



Ocean Circulation



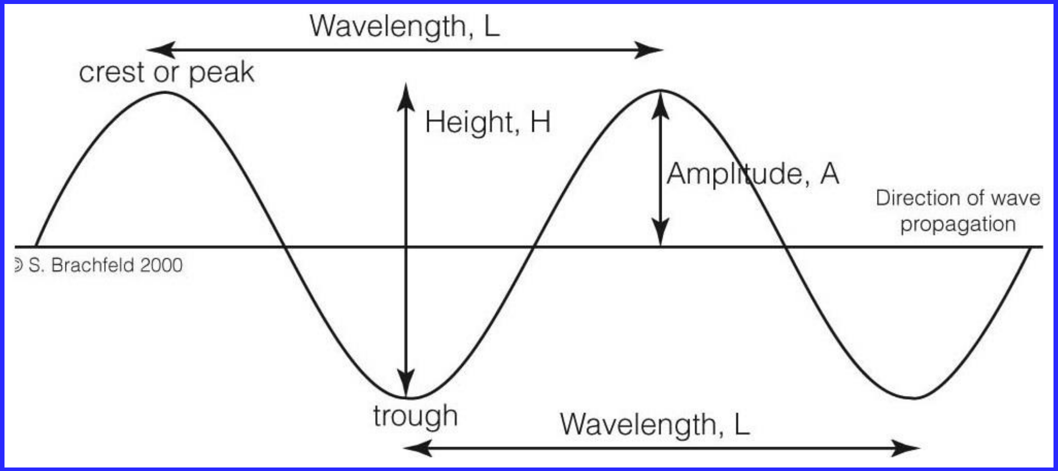
Ocean Circulation

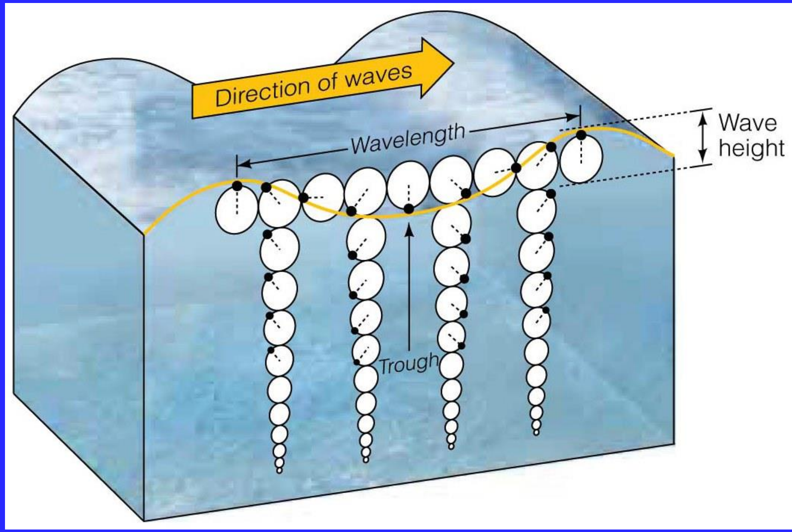


Ocean Waves

- Surface waves receive their energy from wind
  - The size of a wave is determined by wind speed, duration, and fetch (distance)
  - Important wave dimensions are the height (from crest to trough) and wavelength (from crest to crest or crest to trough)
  - As waves move, each parcel of water revolves in a loop, returning nearly to its former position once the wave has passed
  - At a depth of half the wavelength, water motion is negligible, this is the wave base

Ocean Waves

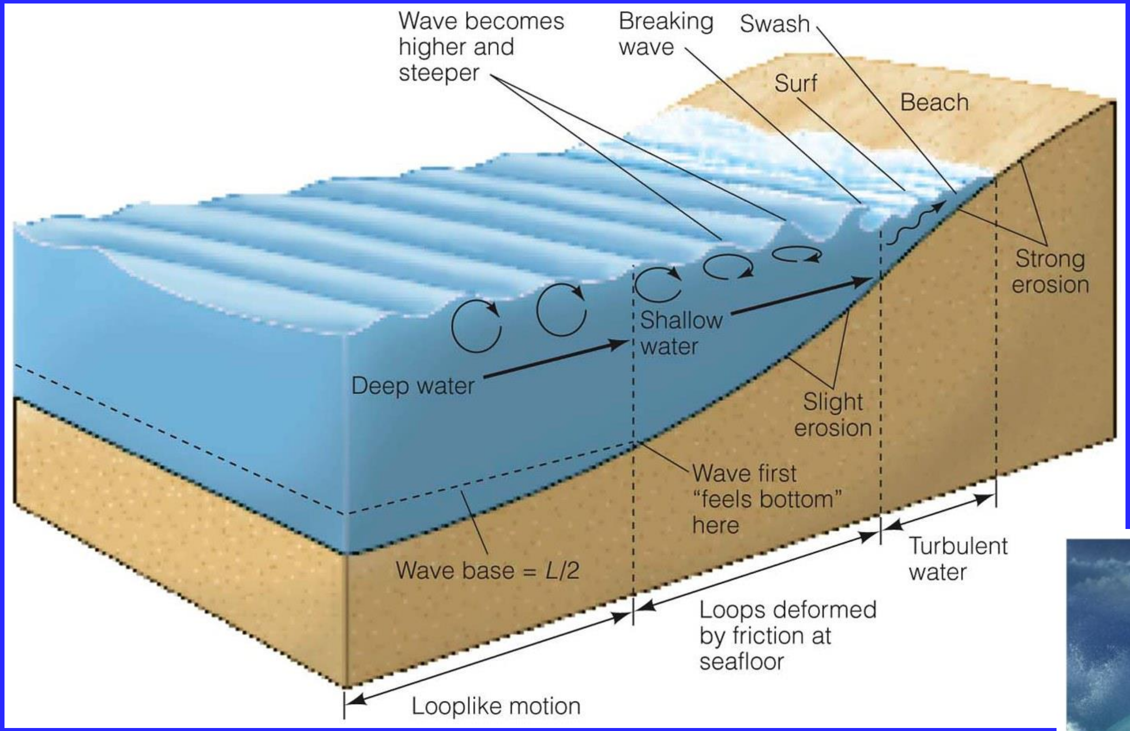

Wavelength, L
crest or peak
Height, H
Amplitude, A
Direction of wave propagation
© S. Brachfeld 2000
trough
Wavelength, L


Direction of waves
Wavelength
Wave height
Trough

Ocean Waves

- Toward land, as water depth becomes less than L/2, the circular motion of the deepest water parcels is restricted by the shallow seafloor, flattening the loop
- As depth decreases, the wave's shape is distorted; height increases, wavelength shortens, and the wave front grows steeper, eventually collapsing (breaking)
  - This is turbulent surf

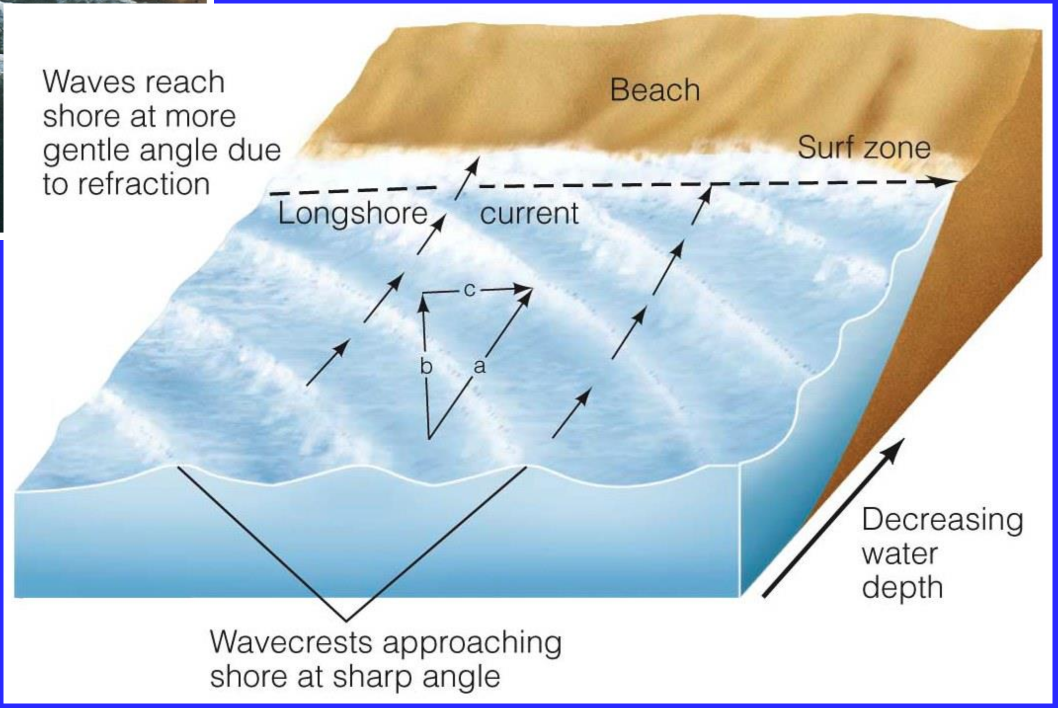
Ocean Waves


Wave becomes higher and steeper
Breaking wave
Swash
Surf
Beach
Strong erosion
Shallow water
Deep water
Slight erosion
Wave first "feels bottom" here
Wave base = L/2
Turbulent water
Loops deformed by friction at seafloor
Looplike motion

Ocean Waves

- Approaching shore, waves become refracted to parallel the bottom contours
- The path of an incoming wave can be resolved in two directional components
  - Parallel to the shore: longshore current
  - Perpendicular to the shore: surf

Ocean Waves


Waves reach
shore at more
gentle angle due
to refraction
Beach
Surf zone
Longshore
current
c
b
a
Decreasing
water
depth
Wavecrests approaching
shore at sharp angle

- Tsunami
  - Technically a seismic sea wave
  - Generated by sudden movements on the seafloor
    - Earthquake
    - Submarine or coastal landslide
    - Large volcanic eruption
  - Sudden seafloor displacement causes displacement in overlying water, when this water falls back down it splits into two oppositely moving components

- Tsunami
  - Travel at speeds up to 950 km/h
  - Have wavelengths measured in kilometers
  - Wave height is only 1-2 meters
    - Typically not seen or felt in the open ocean
  - Periodicity can be from 20 min to 1 hr
  - As the crest moves on shore, water can pile up rapidly to heights of 30 meters and travel great distances inland, as the trough moves on shore, it causes drawdown

The Asian Tsunami

December 26, 2004

Tsunami Damage

Receding waters,
Kalutora Beach,
Sri Lanka

Banda Aceh
Shore, Indonesia

Gleebruk Village, Indonesia


Gleebruk Village, Indonesia

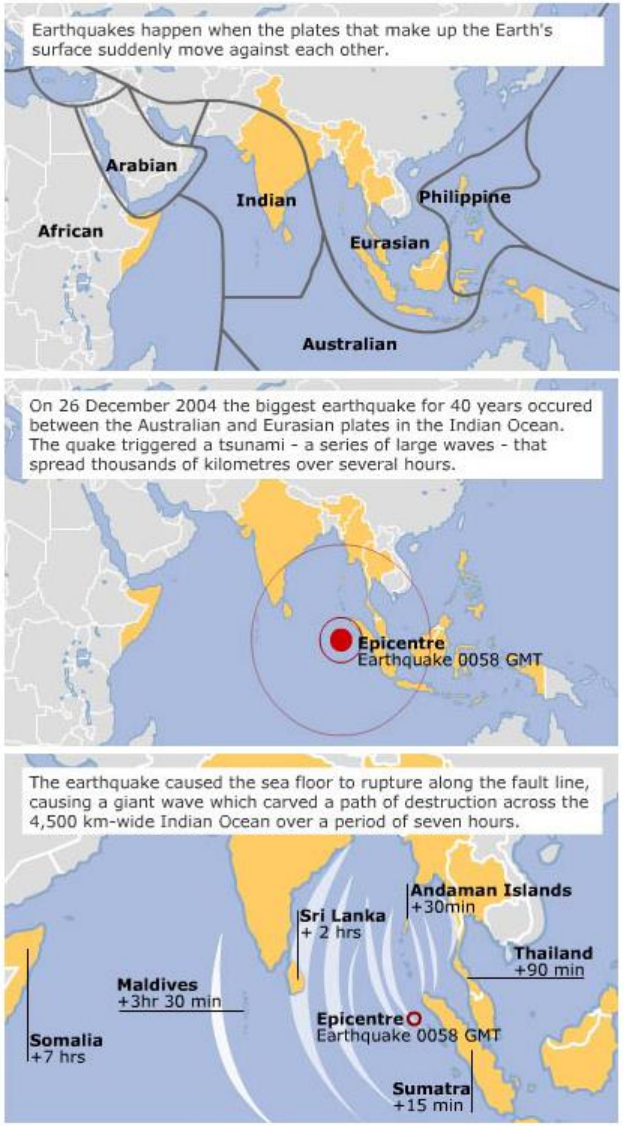
Meulaboh, Indonesia

Meulaboh, Indonesia

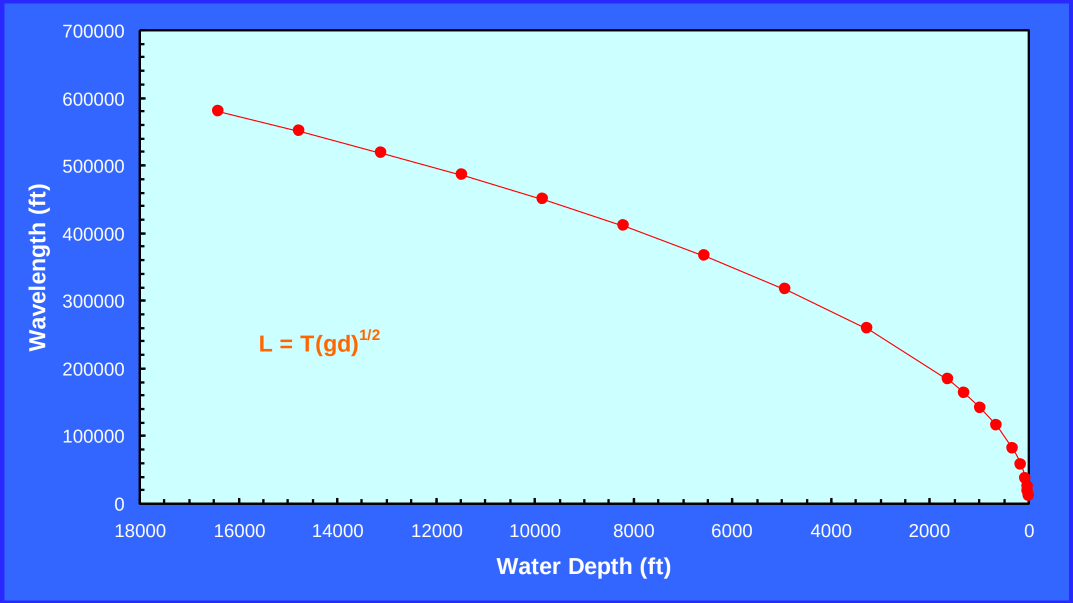
Meulaboh, Indonesia

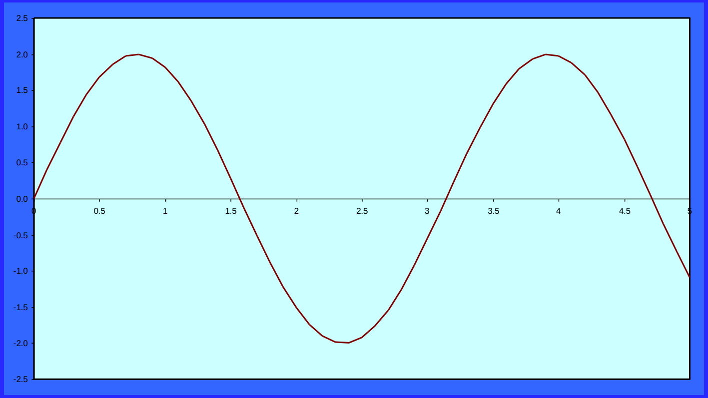
What caused the Asian tsunami

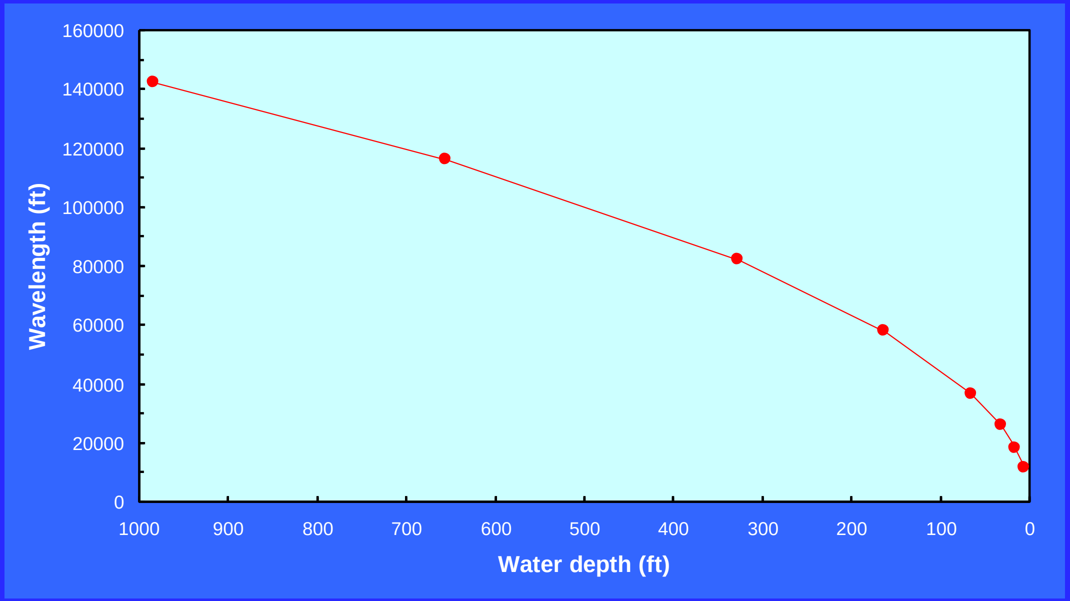
BBC NEWS The tsunami disaster



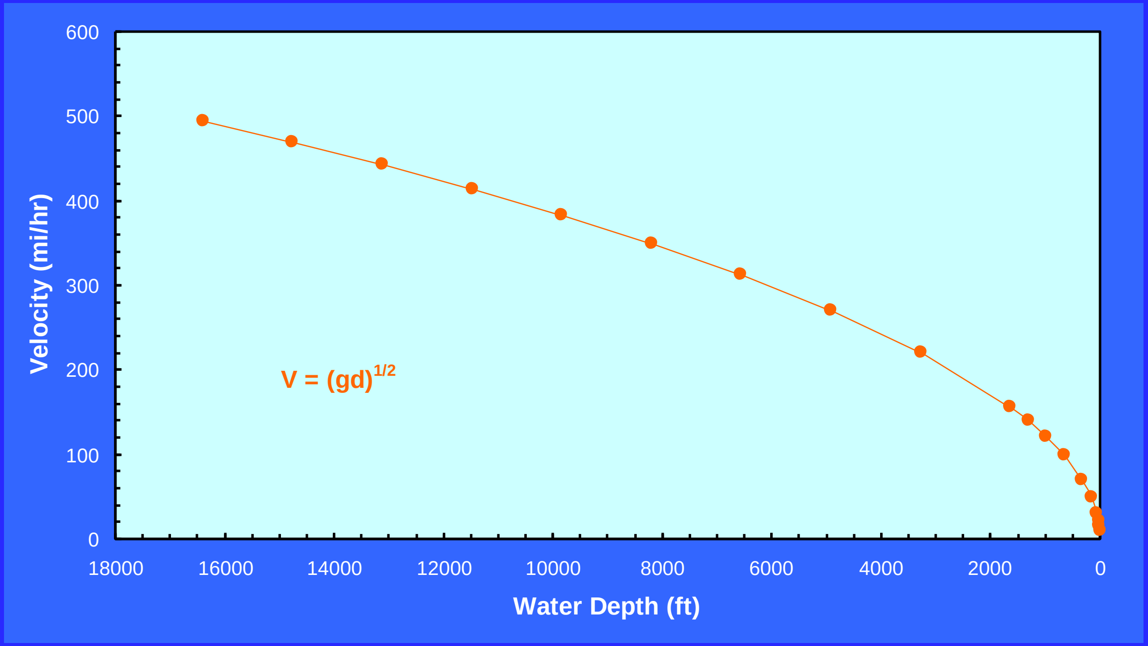
Relationship between water depth and wavelength

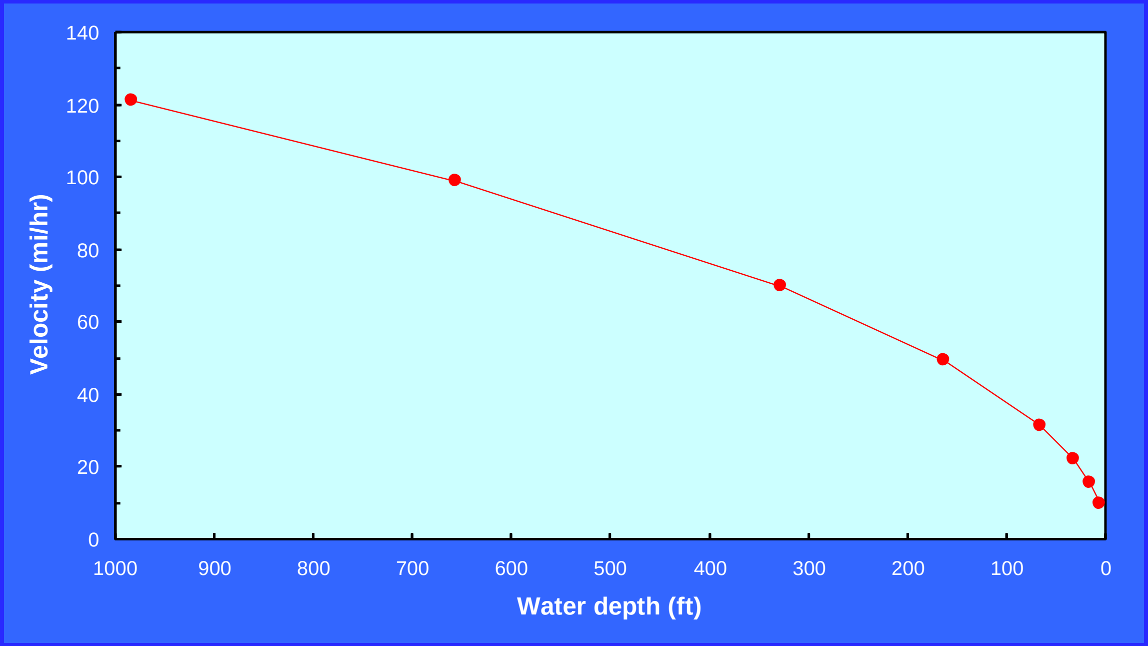






Relationship between water depth and wave velocity





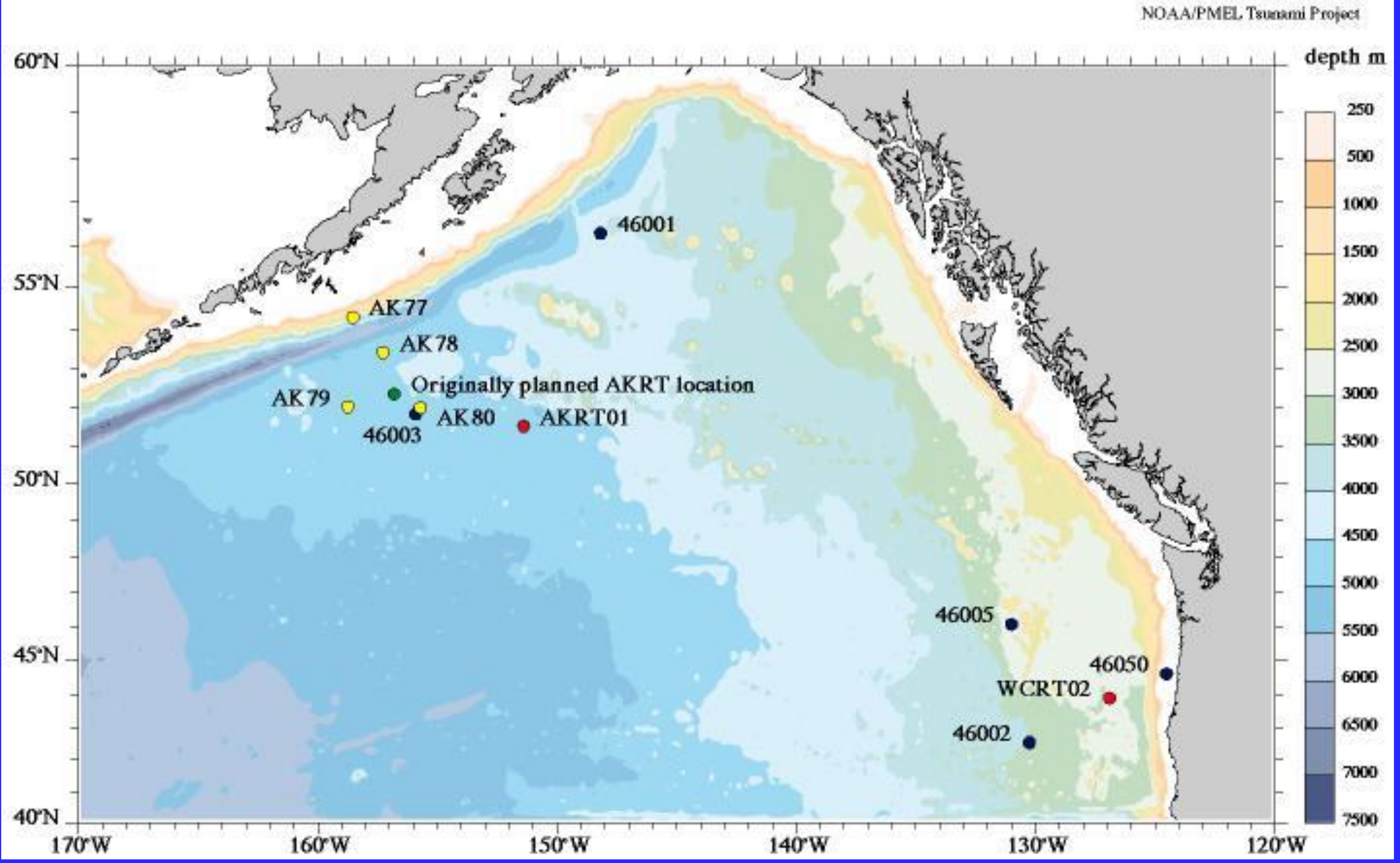
Tsunamis are caused by

- Earthquakes that lead to seafloor displacements (December 26, 2004)
- Volcanic eruptions (Krakatoa, 1883)
- Underwater landslides (LaPalma, Canary Islands)

Tsunami Response

- Detect potential tsunami-causing event
- Detect wave using both surface buoys and seafloor measurements of pressure variations
- Issue tsunami alert
- Evacuate at-risk areas. This is not always possible
- Tsunami mitigation – structures that may reduce damage, for example barrier islands and coastal forests

Research Array, Real-Time BPRs and NDBC Buoy Stations



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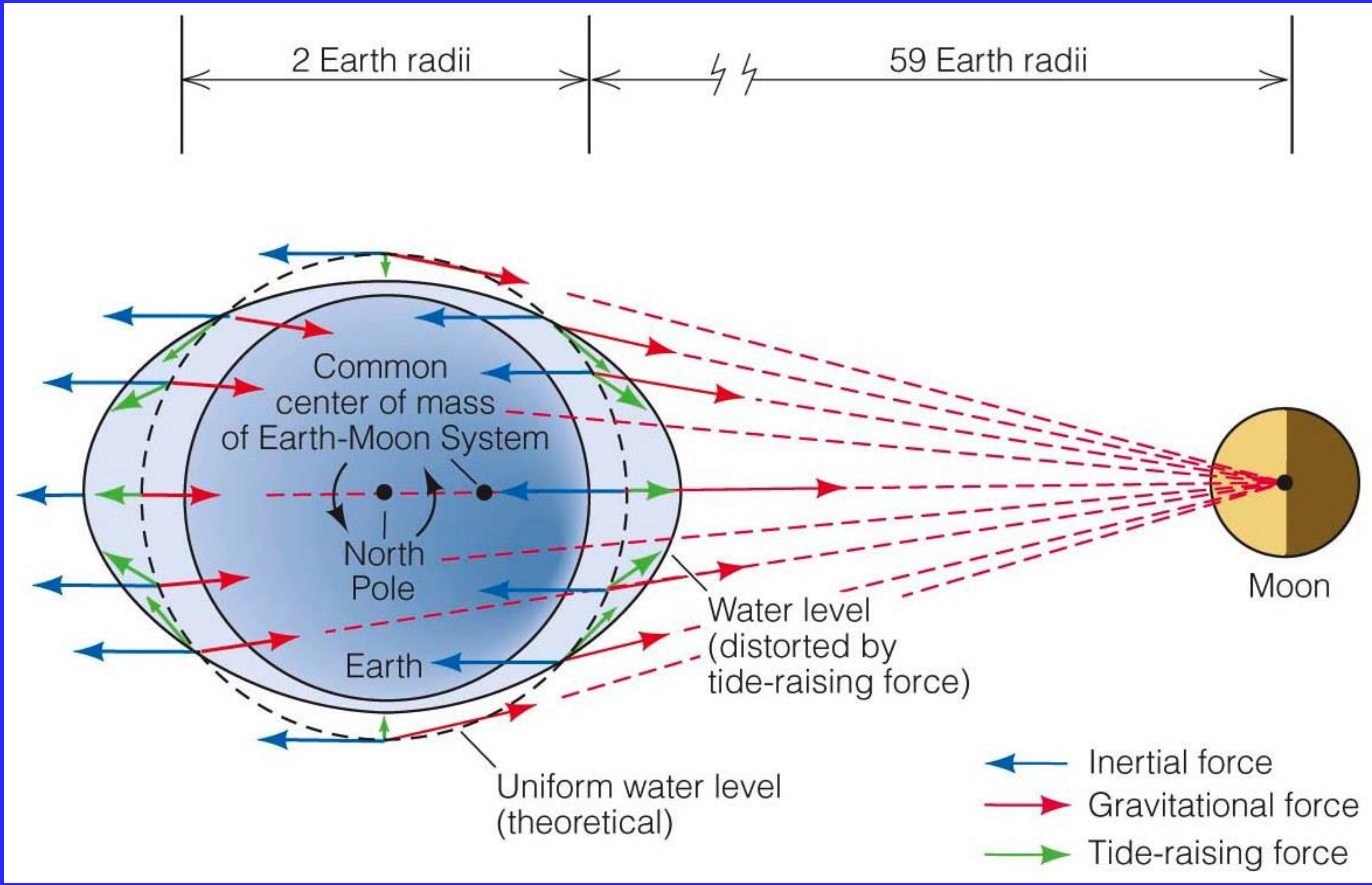
Friday, March 11

Ocean Tides

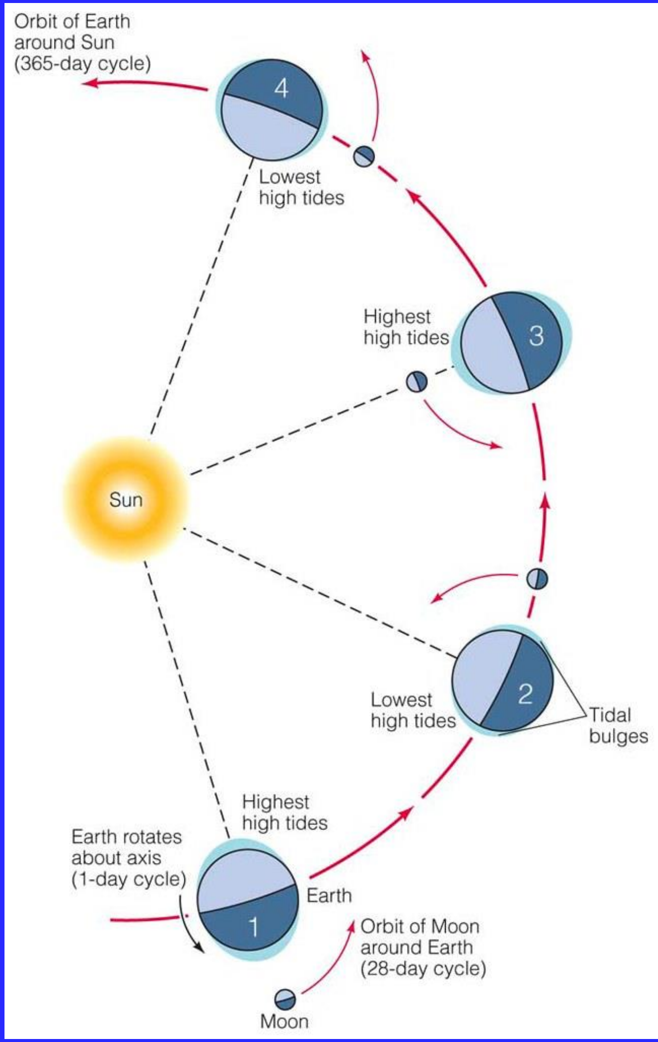
- Rhythmic, twice-daily rise and fall of ocean water along coastlines
- Caused by gravitational attraction between the Earth and Moon, and to a lesser extent, the Sun
- Generates tidal bulges due to gravitational pull and inertial force
  - Highest and lowest tides when sun and moon are aligned
  - Least tidal range when sun and moon are not

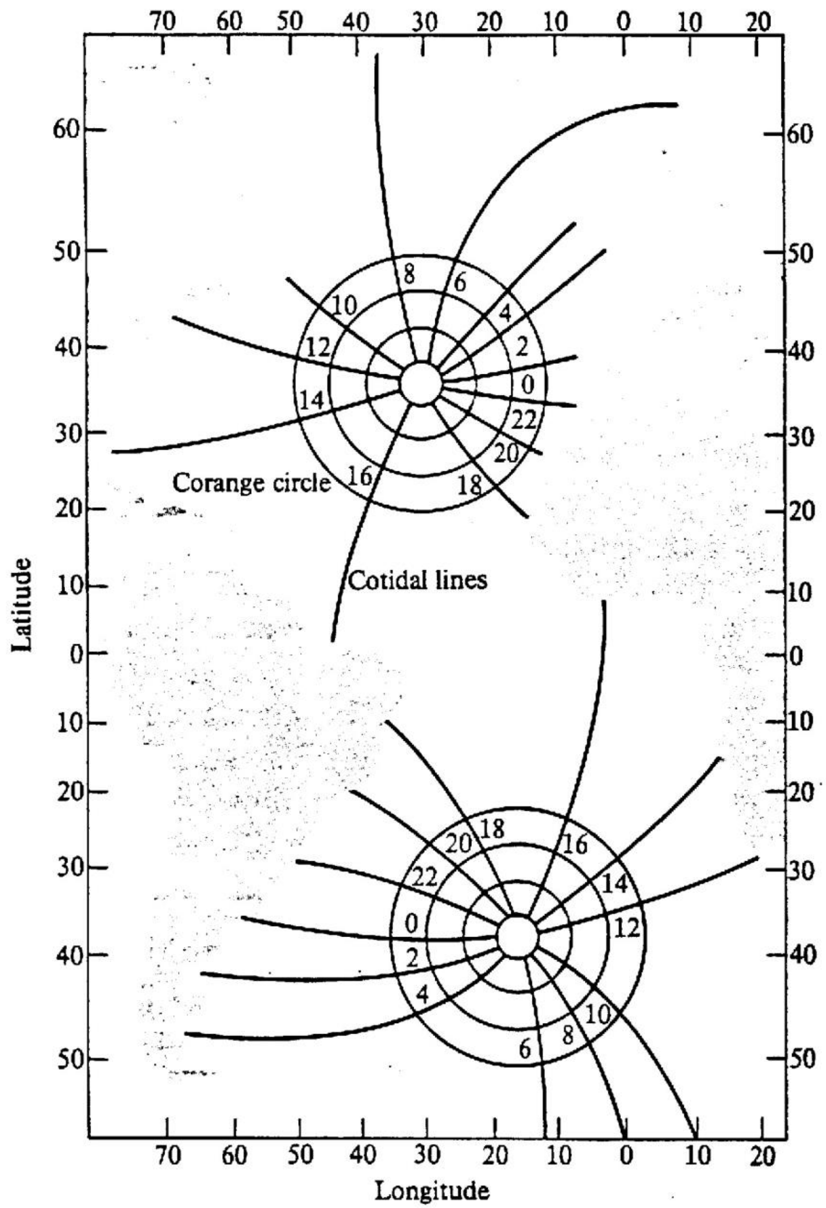
Ocean Tides



2 Earth radii
59 Earth radii
Common
center of mass
of Earth-Moon System
North
Pole
Earth
Moon
Water level
(distorted by
tide-raising force)
Uniform water level
(theoretical)
Inertial force
Gravitational force
Tide-raising force

Ocean Tides


Orbit of Earth
around Sun
(365-day cycle)
4
Lowest
high tides
Highest
high tides
3
Sun
Lowest
high tides
2
Tidal
bulges
Highest
high tides
Earth rotates
about axis
(1-day cycle)
Earth
1
Orbit of Moon
around Earth
(28-day cycle)
Moon


Corange circle
Cotidal lines
Latitude
Longitude

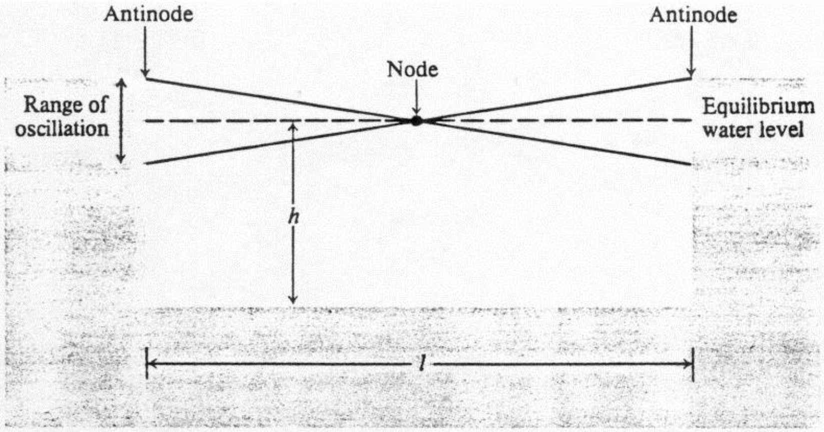


Fig. 17.11a The fundamental standing wave in a closed basin has a central node where no vertical motion of the free surface occurs. Maximum water-level change occurs at the antinodes. The basin's length (l) is $\frac{1}{2}$ of the wavelength.

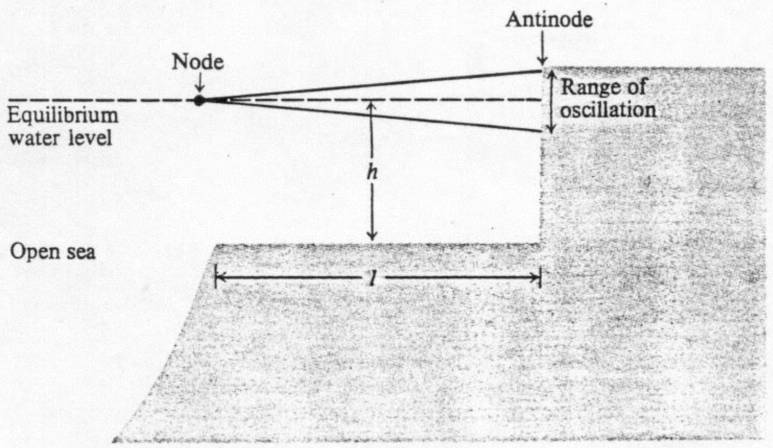


Fig. 17.11b The fundamental standing wave in an open-ended basin has a node at the basin's mouth. Maximum change in water level occurs at the antinode. The basin's length (l) is $\frac{1}{4}$ of the wavelength.