Gelombang Laut
(Ocean Waves)

Definisi

- Undulasi (naik-turunnya) muka laut akibat transmisi (perjalanan) energi
- Mediumnya tidak ikut bergerak (berpindah) bersama energi, tetapi partikel yang menyusun media hanya bergerak naik-turun dan maju mundur (pola orbit) saat energi melintas

Properti (karakter) Gelombang

1) Memindahkan goncangan (disturbance) dari satu bagian dari medium ke bagian lainnya.

2) Goncangan (disturbance) bergerak melintasi medium tanpa adanya pergerakan menyeluruh dari medium tersebut.

3) Goncangan juga bergerak tanpa distorsi (perubahan) yang berarti terhadap bentuk gelombang.

4) Goncangan kelihatannya bergerak dengan kecepatan yang tetap.

Gelombang Lepas Pantai
Kangean, Jawa Timur

Gelombang Pantai
Pelabuhan Ratu, Jabar

Kenapa perlu mempelajari gelombang?

Giant Kelp, Teluk California

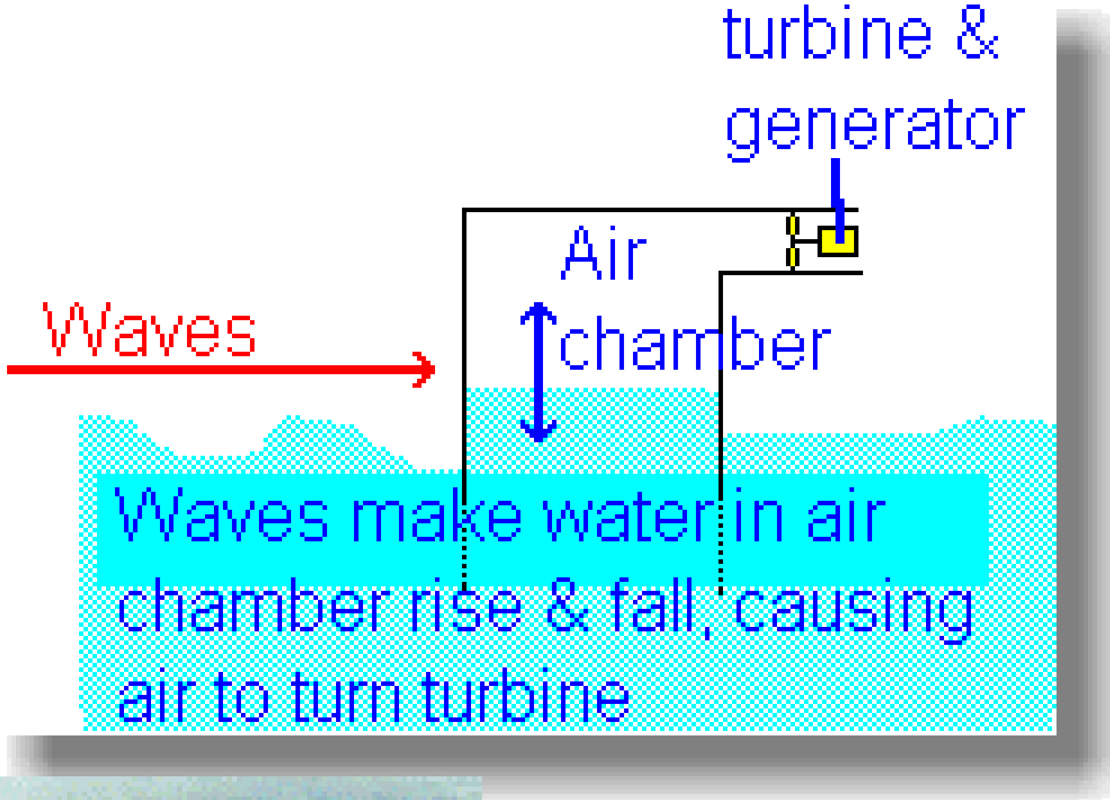
Abrasi Pantai di Carita, Anyer

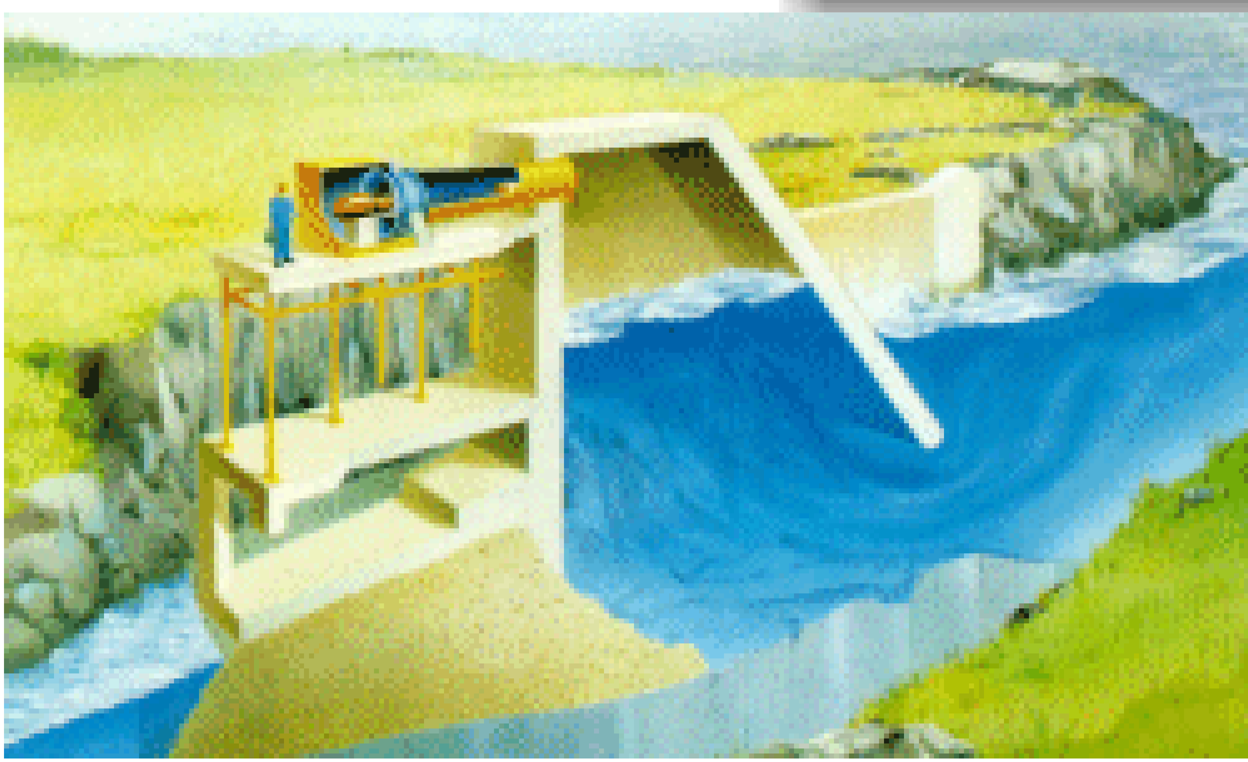
Contoh lain: Sediment Resuspension

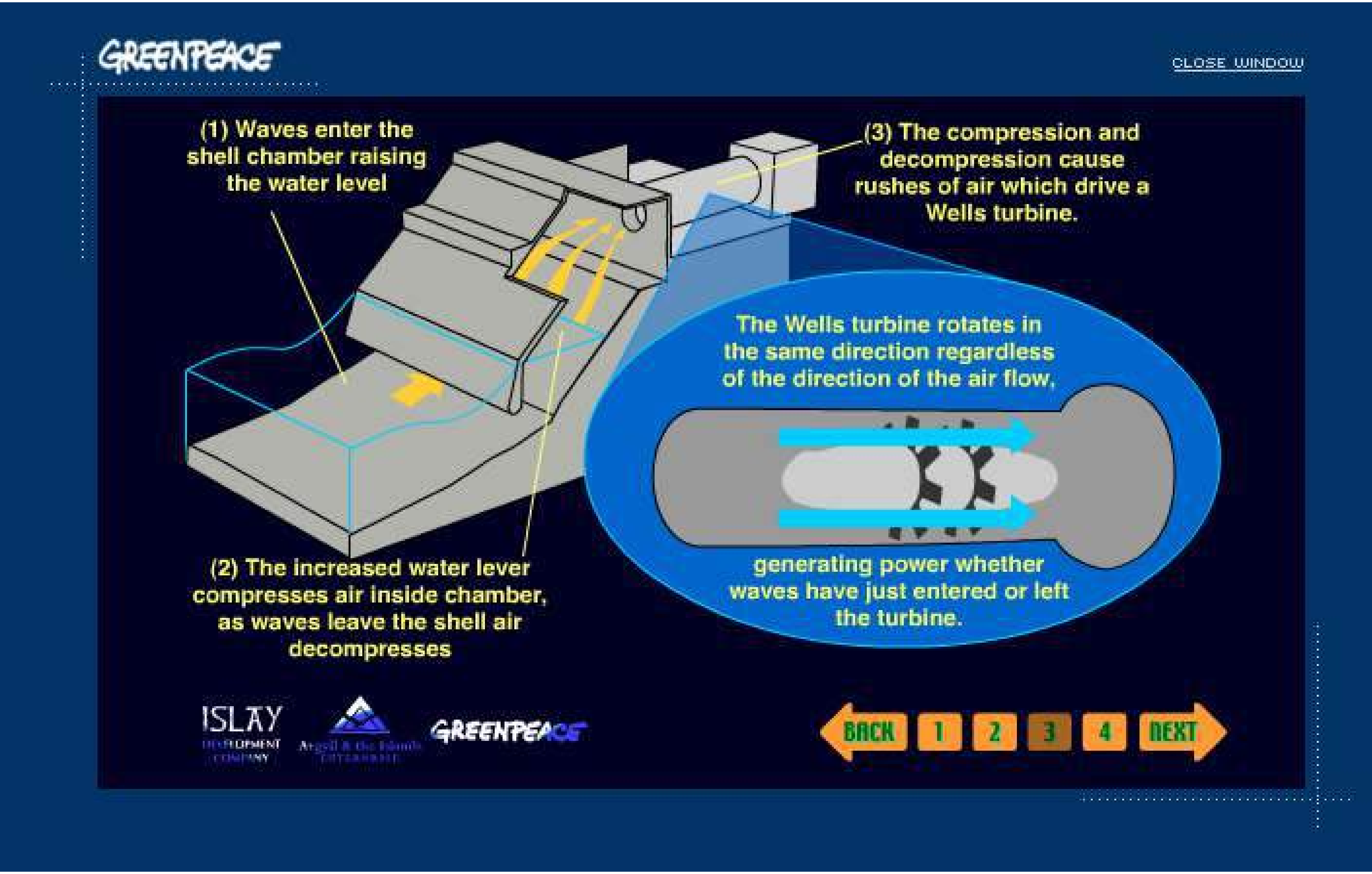
Resuspensi sedimen adalah suspensi dan redistribusi partikel sedimen yang sebelum-nya diendapkan di kolom air karena gaya hidrodinamik.

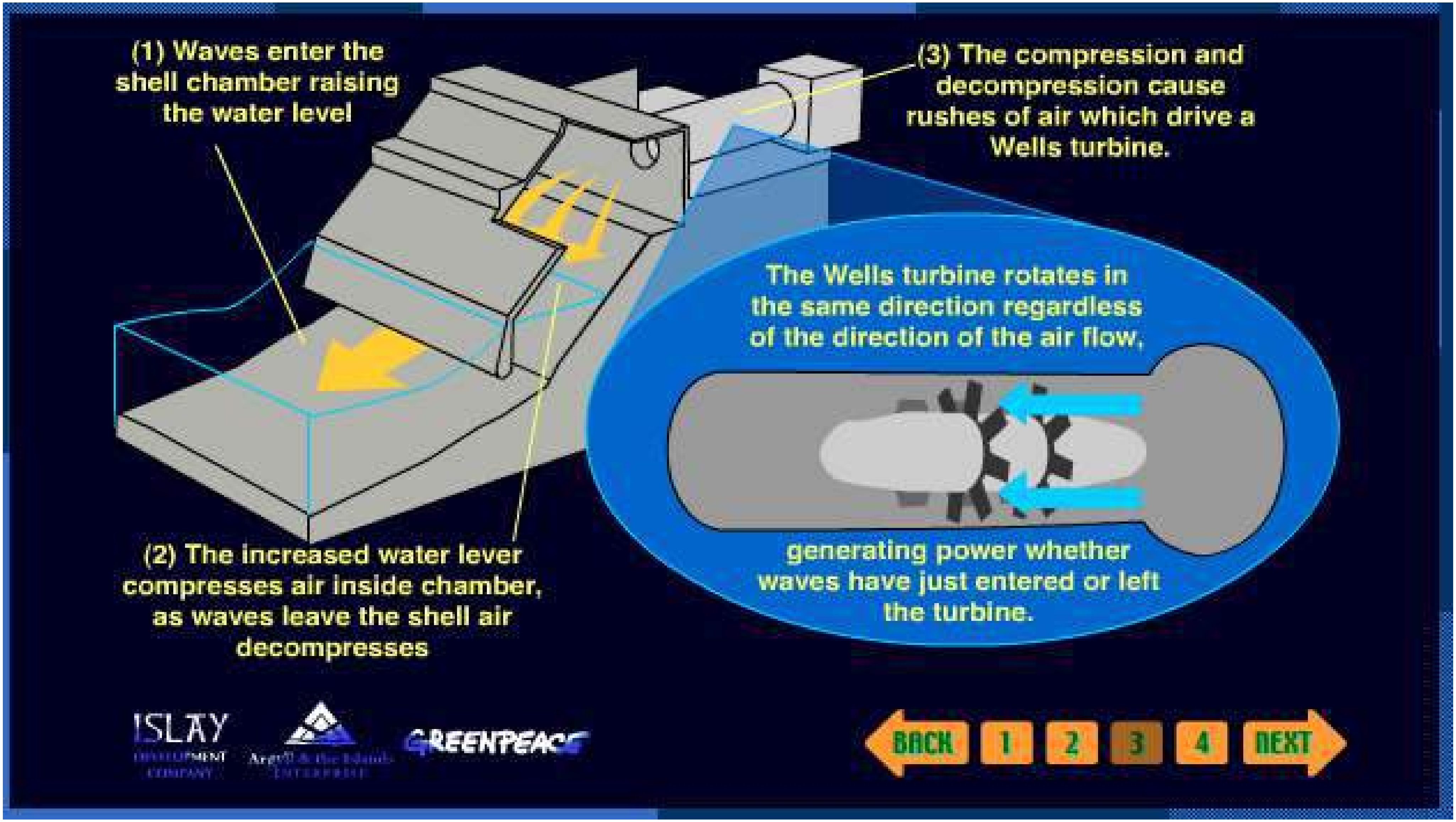
Suspensi sedimen adalah mobilisasi dan perangkap partikel sedimen dari dasar perairan karena gaya hidrodinamik.

Sumber Energi






GREENPEACE
CLOSE WINDOW
(1) Waves enter the shell chamber raising the water level
(2) The increased water lever compresses air inside chamber, as waves leave the shell air decompresses
(3) The compression and decompression cause rushes of air which drive a Wells turbine.
The Wells turbine rotates in the same direction regardless of the direction of the air flow,
generating power whether waves have just entered or left the turbine.
ISLAY DEVELOPMENT COMPANY
GREENPEACE
BACK
1
2
3
4
NEXT


(1) Waves enter the shell chamber raising the water level
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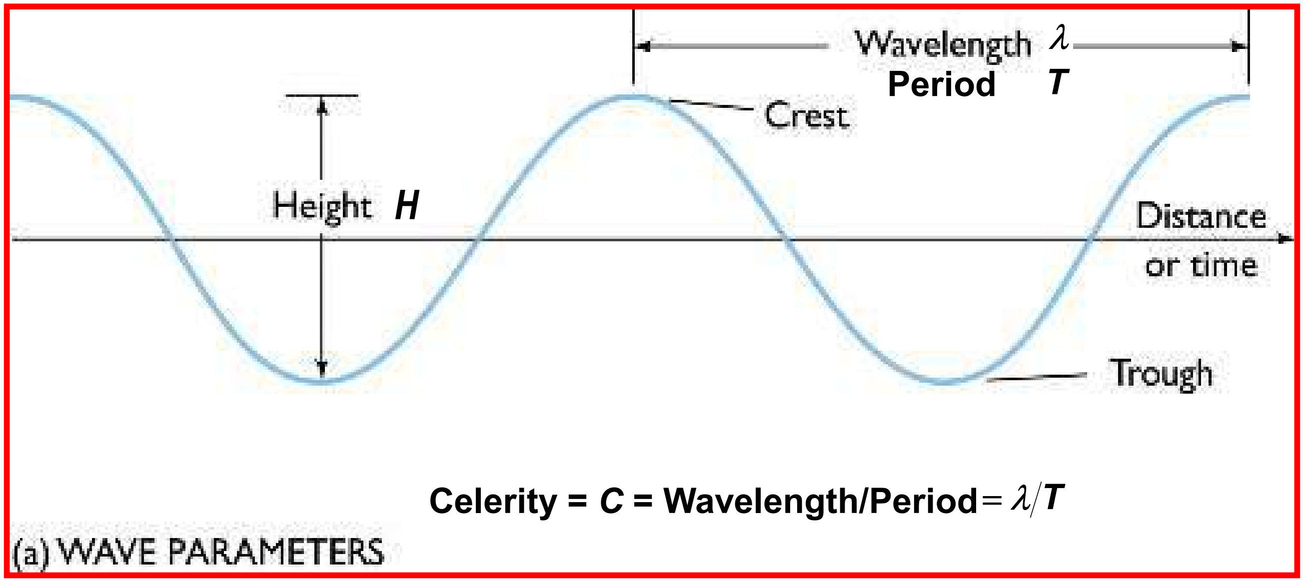
The Wells turbine rotates in the same direction regardless of the direction of the air flow,
generating power whether waves have just entered or left the turbine.
(2) The increased water lever compresses air inside chamber, as waves leave the shell air decompresses
ISLAY DEVELOPMENT COMPANY
Argyll & the Islands ENTERPRISE
GREENPEACE
BACK
1
2
3
4
NEXT

Sifat Dasar Gelombang



Frekuensi Gelombang

$$\omega = \frac{2\pi}{T}$$

Bilangan Gelombang

$$\kappa = \frac{2\pi}{\lambda}$$

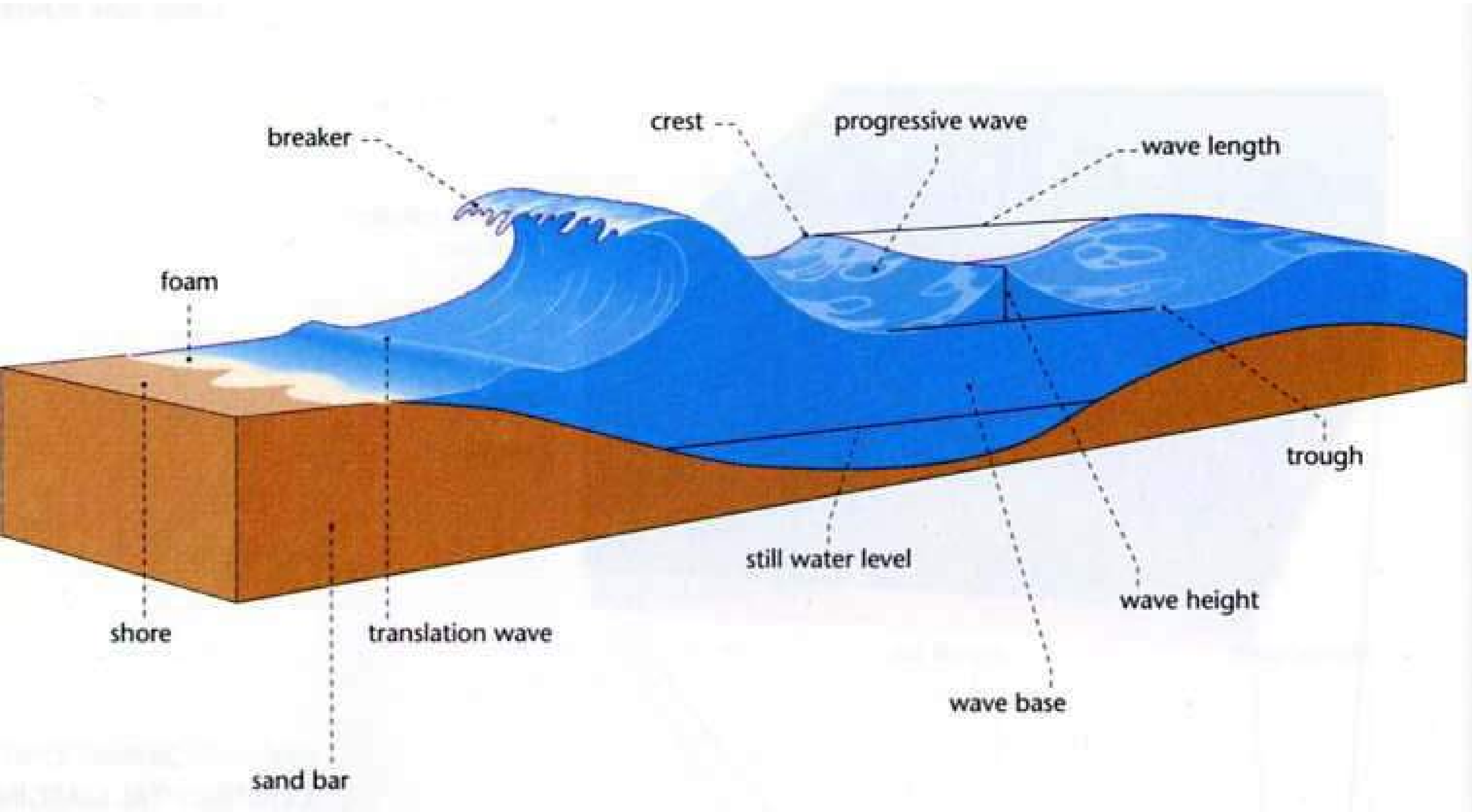
Kecepatan (fase) gel

$$\Rightarrow C = \frac{\omega}{\kappa}$$

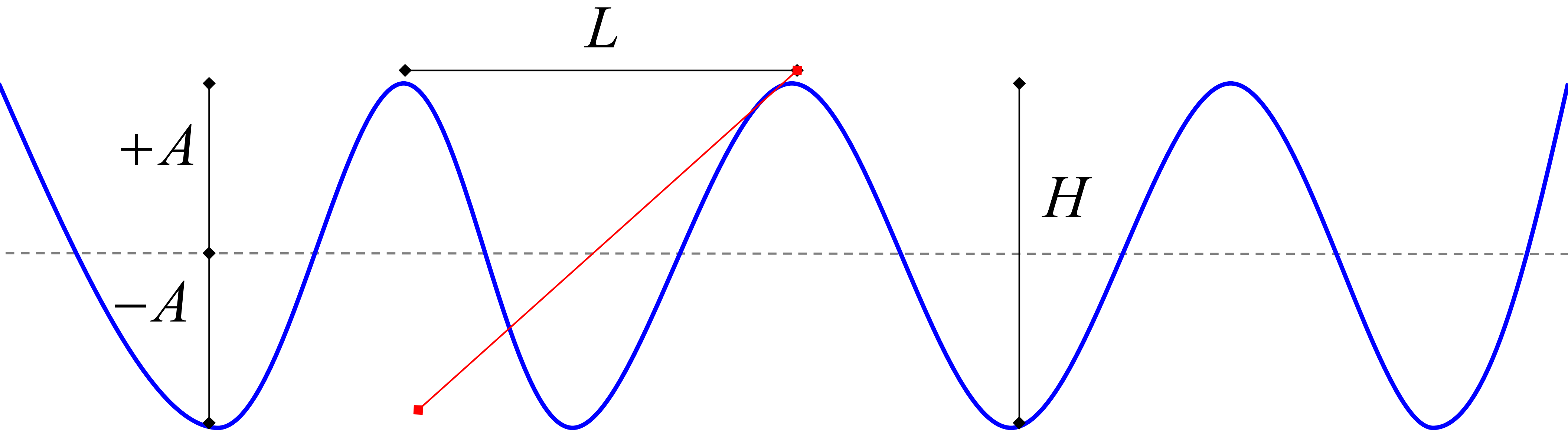
Catatan: Definisi in berlaku juga untuk gelombang radio, sinar gamma dan gel cahaya.

Pada kasus ini, perbatasan (interface) adalah antara lautan dan atmosfie atau antara dua lapisan yang berbeda densitasnya

Refraksi Gelombang dan Gelombang pecah (bila **(H / λ) < 1 / 7 or H / d ~ 0.8**



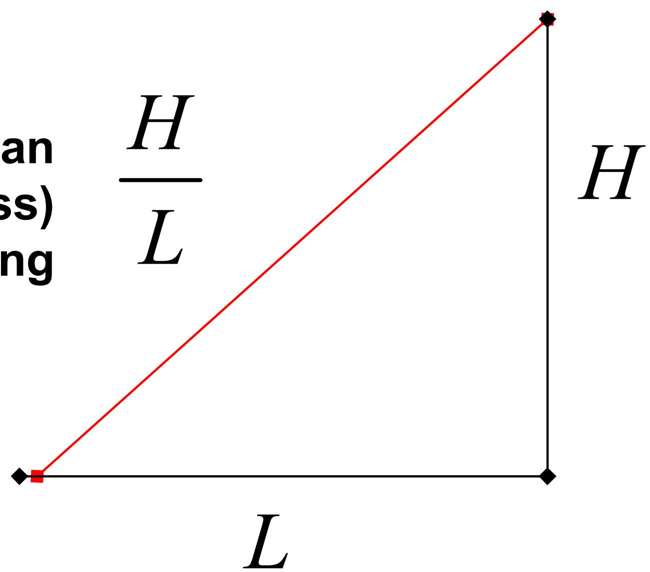
Gelombang permukaan laut



Definisi:

Kecuraman (Steepness) gelombang

$$\frac{H}{L}$$



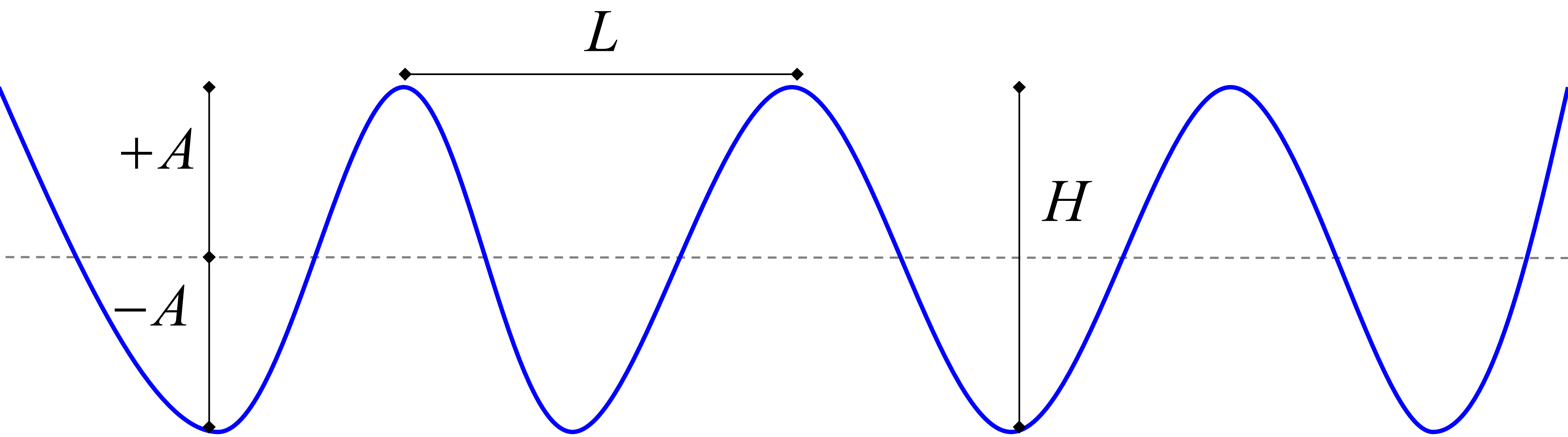
Bilangan (number) gel

$$k = \frac{\text{number of peaks}}{\text{length}}$$

Frekuensi

$$\omega = \frac{\text{number of peaks}}{\text{time}}$$

Gelombang Permukaan Laut



Definisi lainnya:

The energy of the wave

$$E = \frac{1}{8}\rho g H^2$$

Progressive Wave

if moves energy through the water

Ocean Surface Wave

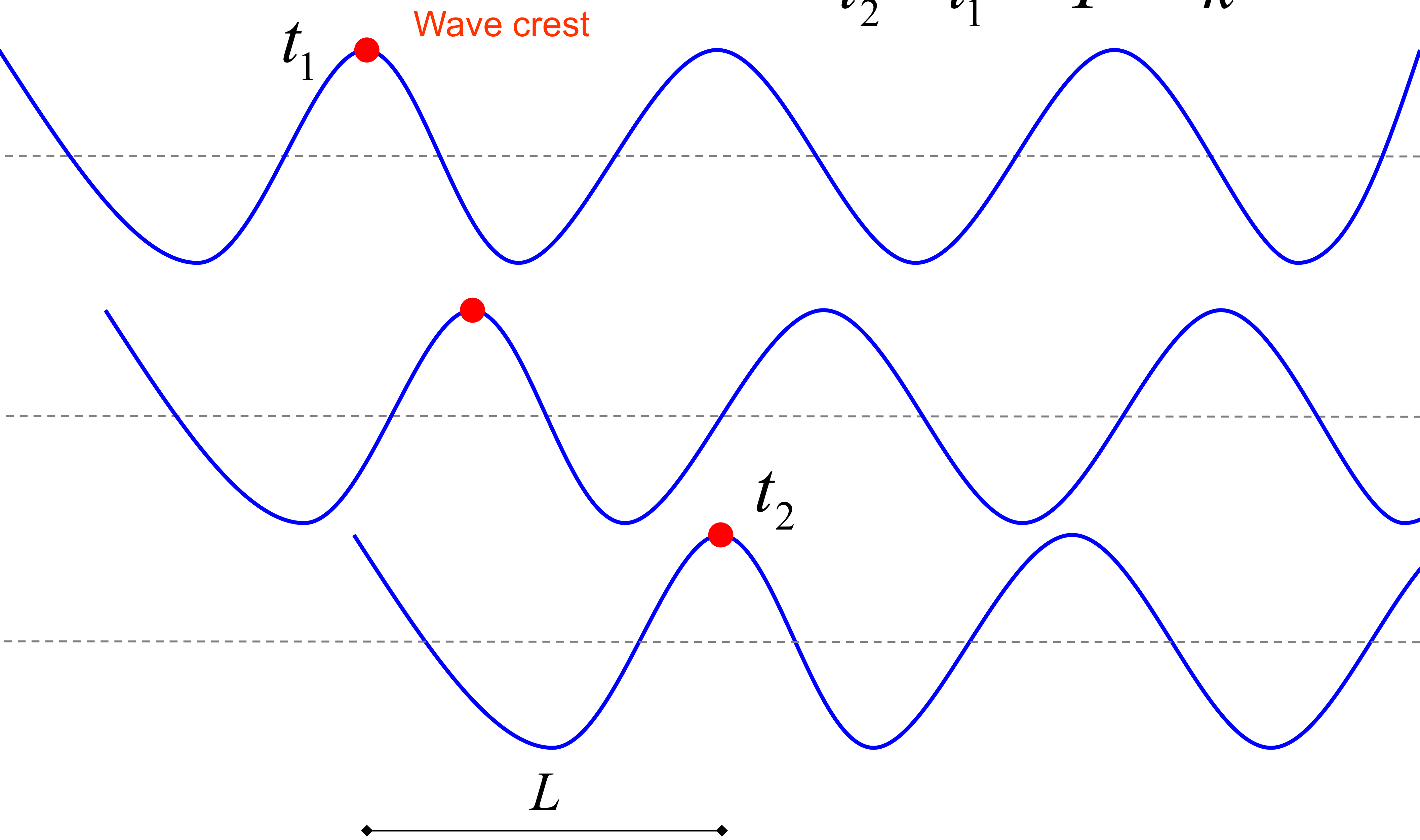
exist because of 2 restoring forces

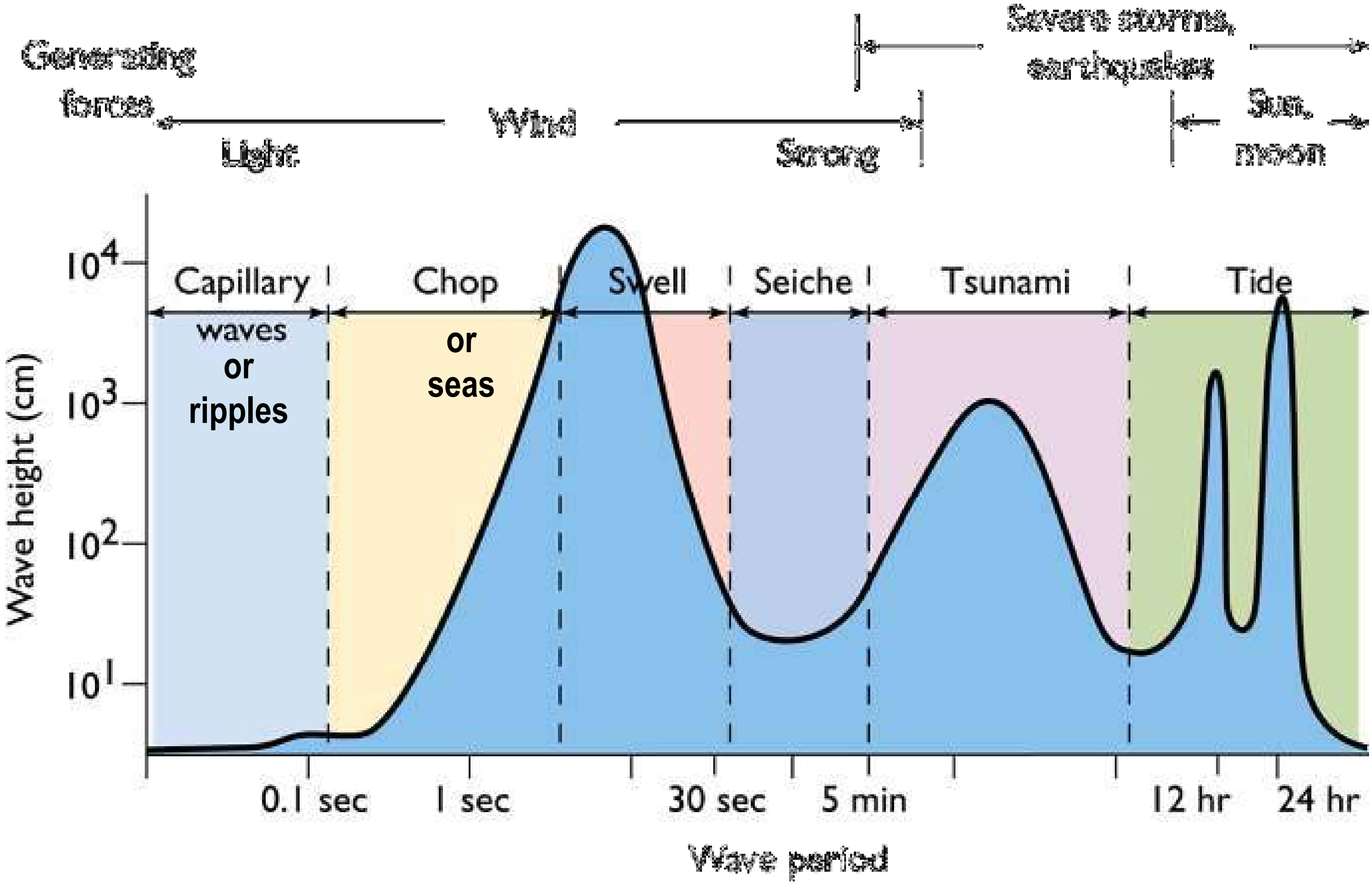
gravity

surface tension

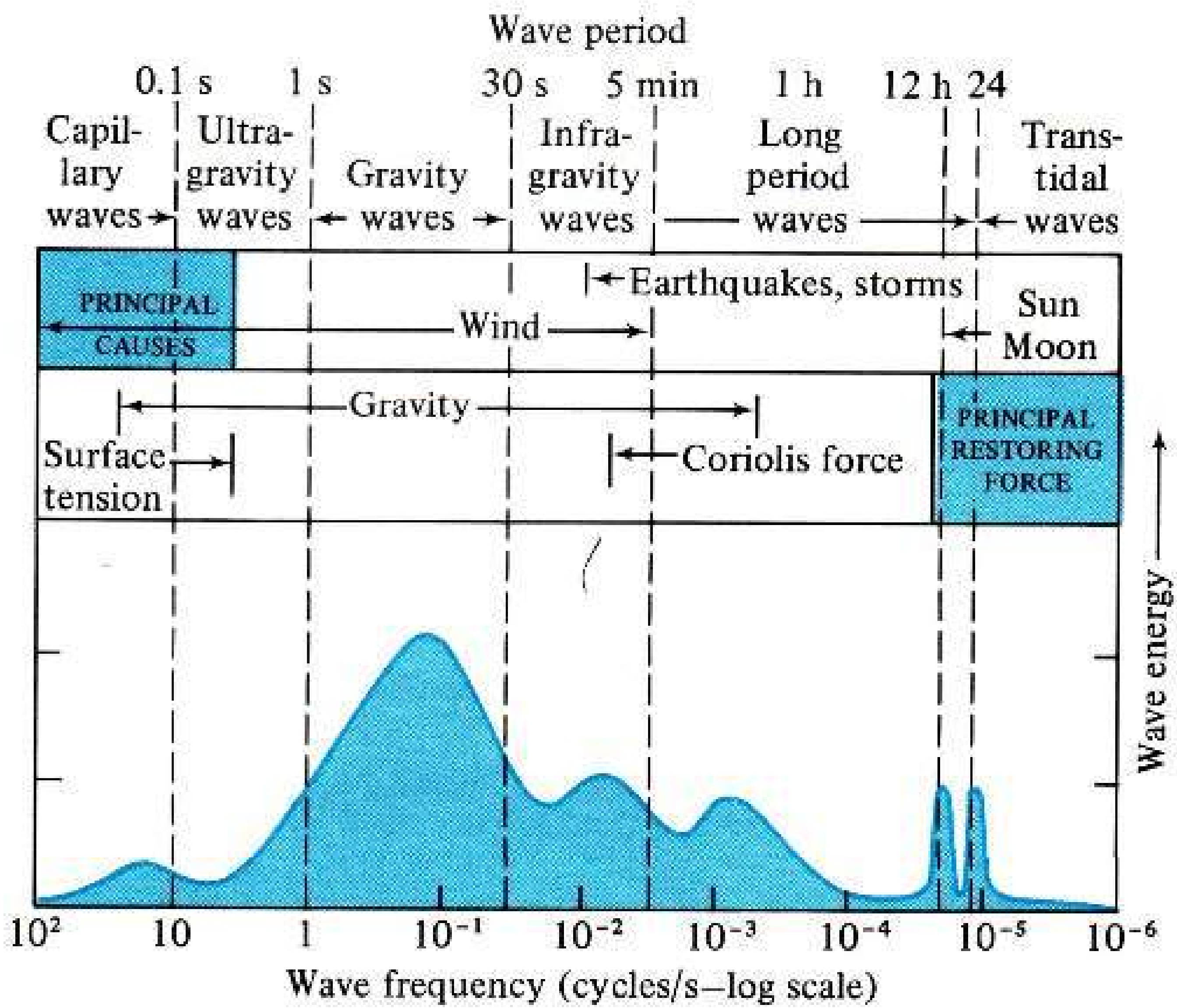
Wave Speed

$$c = \frac{L}{t_2 - t_1} = \frac{L}{T} = \frac{\omega}{k}$$





(b) IDEALIZED WAVE SPECTRUM



(After Blair Kinsman, *Wind waves: their generation and propagation on the ocean surface*, © 1965. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.)

Figure 11–4 Wave Classification by Wave Period

Periode Gelombang tidak berubah

Panjang Gelombang: fungsi dari periode

Kecepatan (celerity): fungsi panjang gelombang

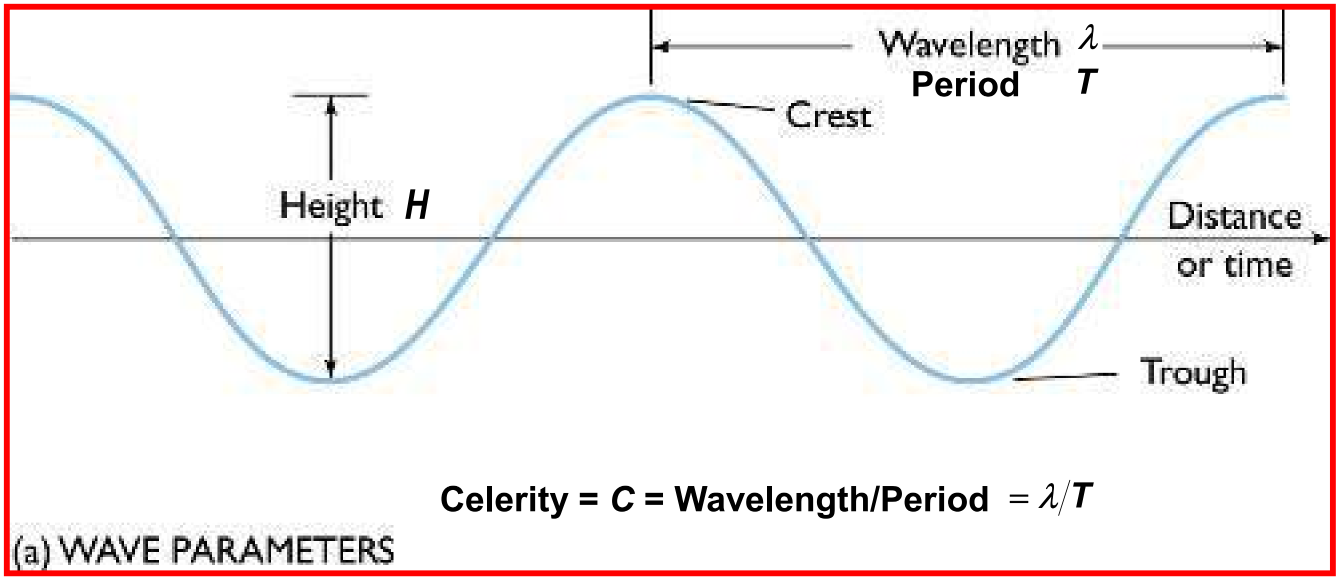
$$\boldsymbol{C} = \frac{\lambda}{\boldsymbol{T}}$$

Gel panjang bergerak lebih cepat dari gel pendek

Teory Gelombang Linier:

"Small Amplitude" Waves(Gel amplitudo kecil): $\boxed{H/\lambda < 1/20}$

Kenyataan, kecuraman (steepness) gel amplitudo kecil (H/λ) < 1 / 50



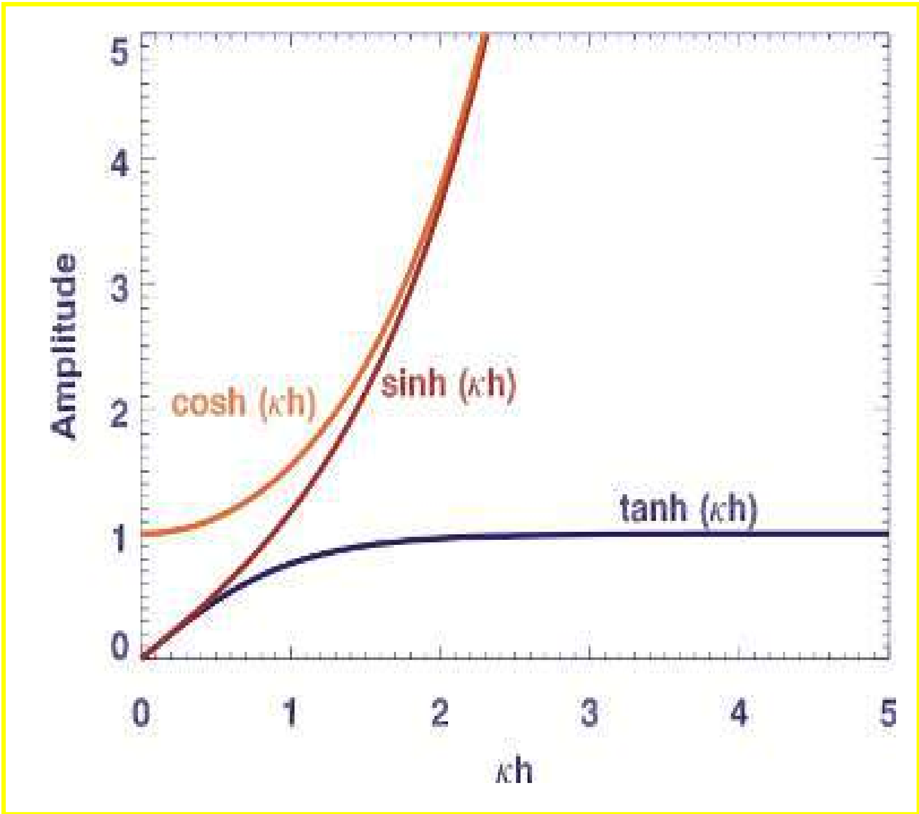
1): Undulasi muka laut (η)

$$\boxed{\eta = A\cos\left[\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right] = A\cos\left[\kappa\, x - \omega\, t\right]}$$

2) Kecepatan fase gelombang (Celerity)

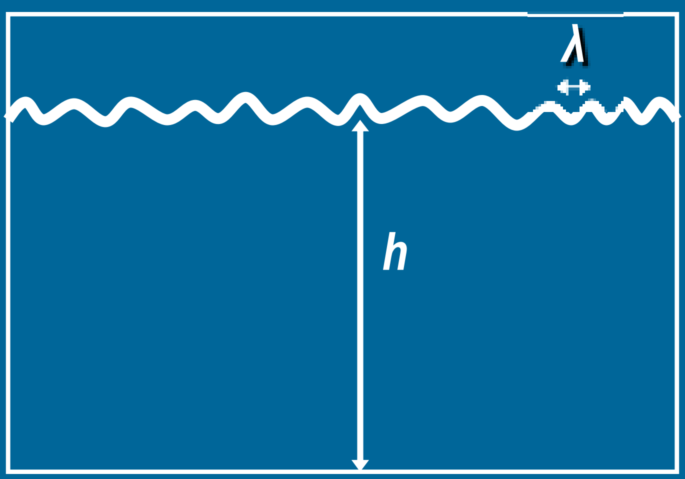
$$\boxed{C = \left[g \frac{\lambda}{2\pi} \tanh\left(\frac{2\pi}{\lambda} h \right) \right]^{1/2} = \left[\frac{g}{\kappa} \boxed{\tanh(\kappa h)} \right]^{1/2}}$$

C=kec fase gelombang progressive (bergerak), incompressible dan irrotational



Penyederhanaan:

$$C = \left[\frac{g}{\kappa}\tanh(\kappa h)\right]^{1/2}$$

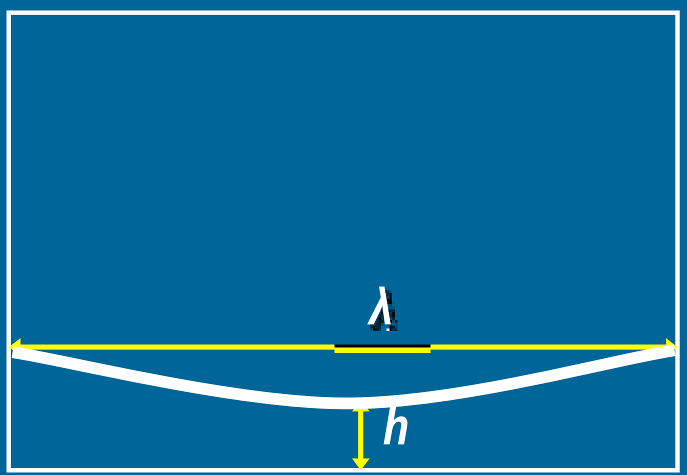


Deep water wave: $\lambda < 2h$ (h is depth) or Short wave

This means that λ is small and κh is large

$$\tanh(\kappa h) \approx 1$$

$$C = \left[\frac{g}{\kappa}\right]^{1/2} = \sqrt{g\frac{\lambda}{2\pi}} = \sqrt{\frac{g}{\kappa}} = \sqrt{g\frac{CT}{2\pi}} = g\frac{T}{2\pi}$$



Shallow water wave: $\lambda > 20h$ (h is depth) or Long wave

This means that λ is large and κh is small

$$\tanh(\kappa h) \approx \kappa h$$

$$C = \left[\frac{g}{\kappa}(\kappa h)\right]^{1/2} = \sqrt{gh}$$

Dua batas dalam kec gel (C)

$$\frac{d}{L} >> 1$$

(L<2d)

DEEP OCEAN

$$c = \sqrt{\frac{gL}{2\pi}}$$

C tergantung panjang gel

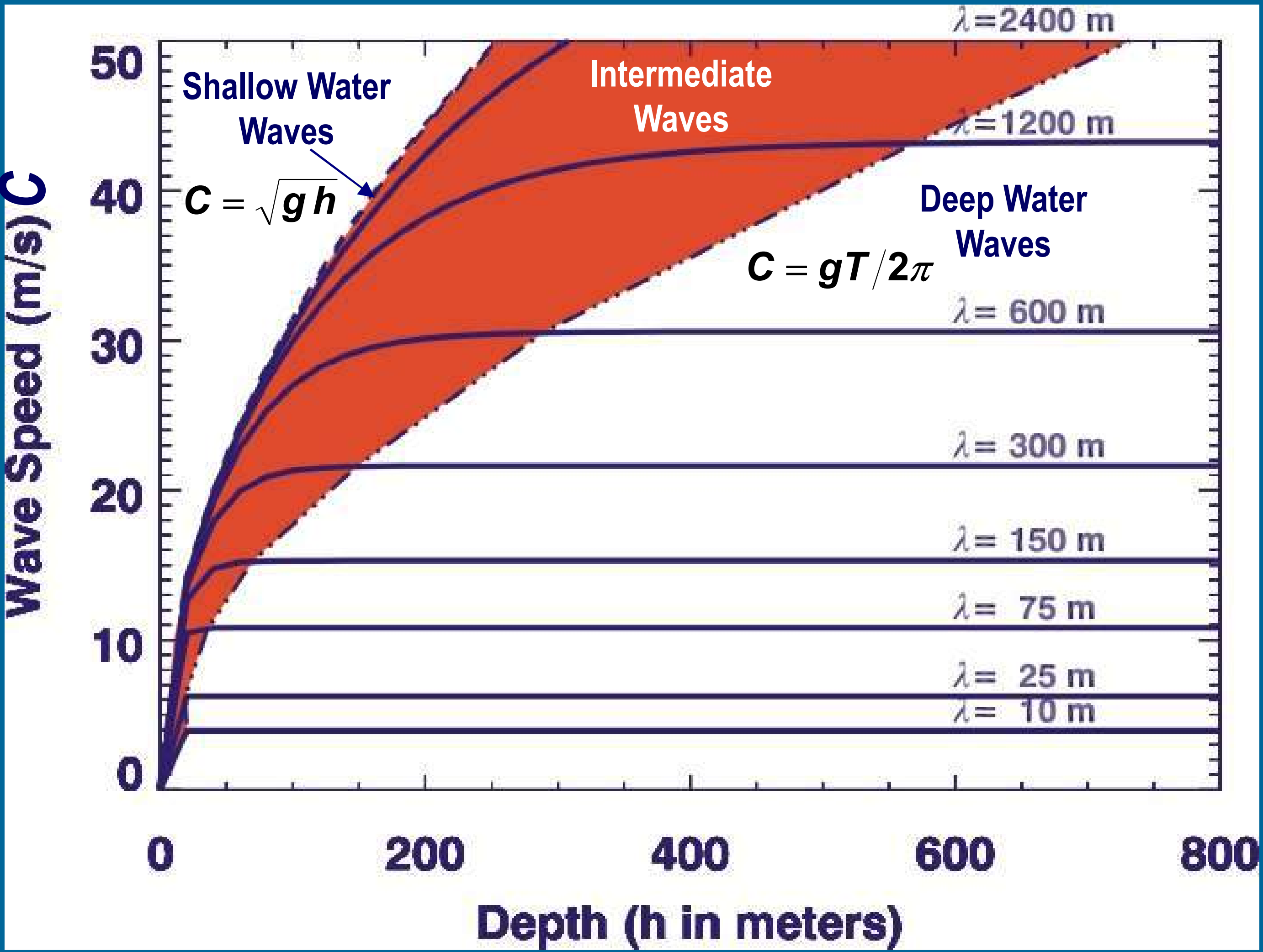
$$\frac{d}{L} << 1$$

(L>20d)

SHALLOW WATERS

$$c = \sqrt{gd}$$

C tdk tgt panjang gel



$$C = \frac{\omega}{\kappa} = \left[\frac{g}{\kappa}\tanh(\kappa h)\right]^{1/2}$$

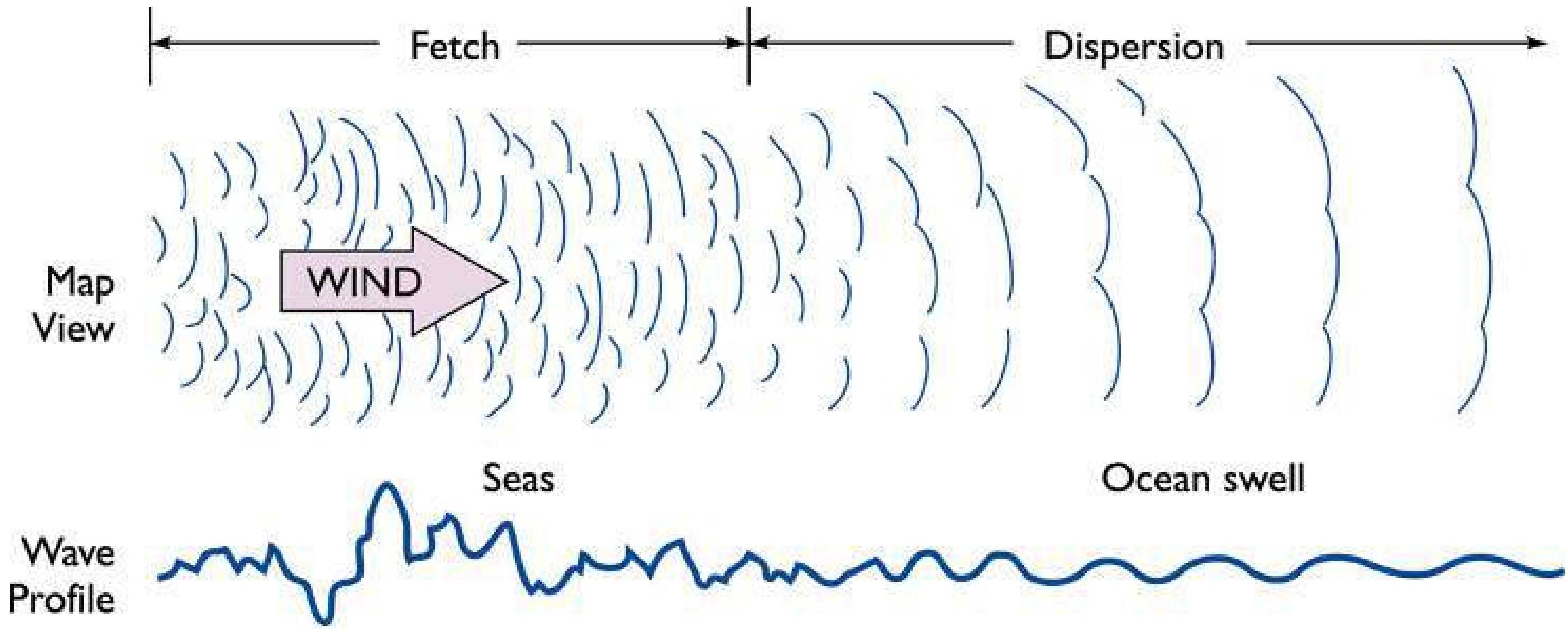
$$\omega^2 = g\kappa \tanh(\kappa h)$$

Dispersion relation
(hubungan antara frequency dan bilangan gel)

Deep waves are dispersive

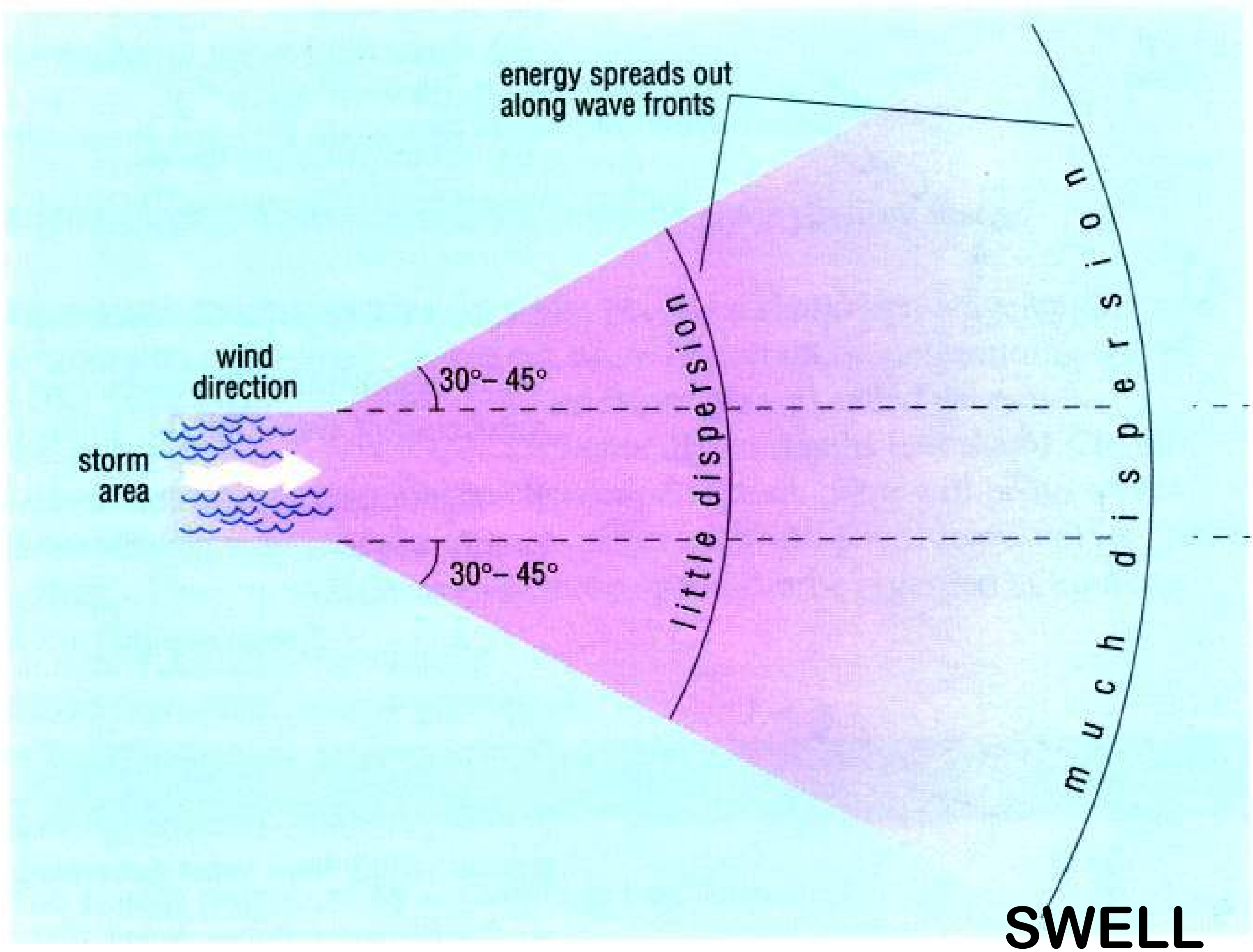
Shallow waves are non-dispersive

Perambatan Gelombang (Transformasi gelombang)



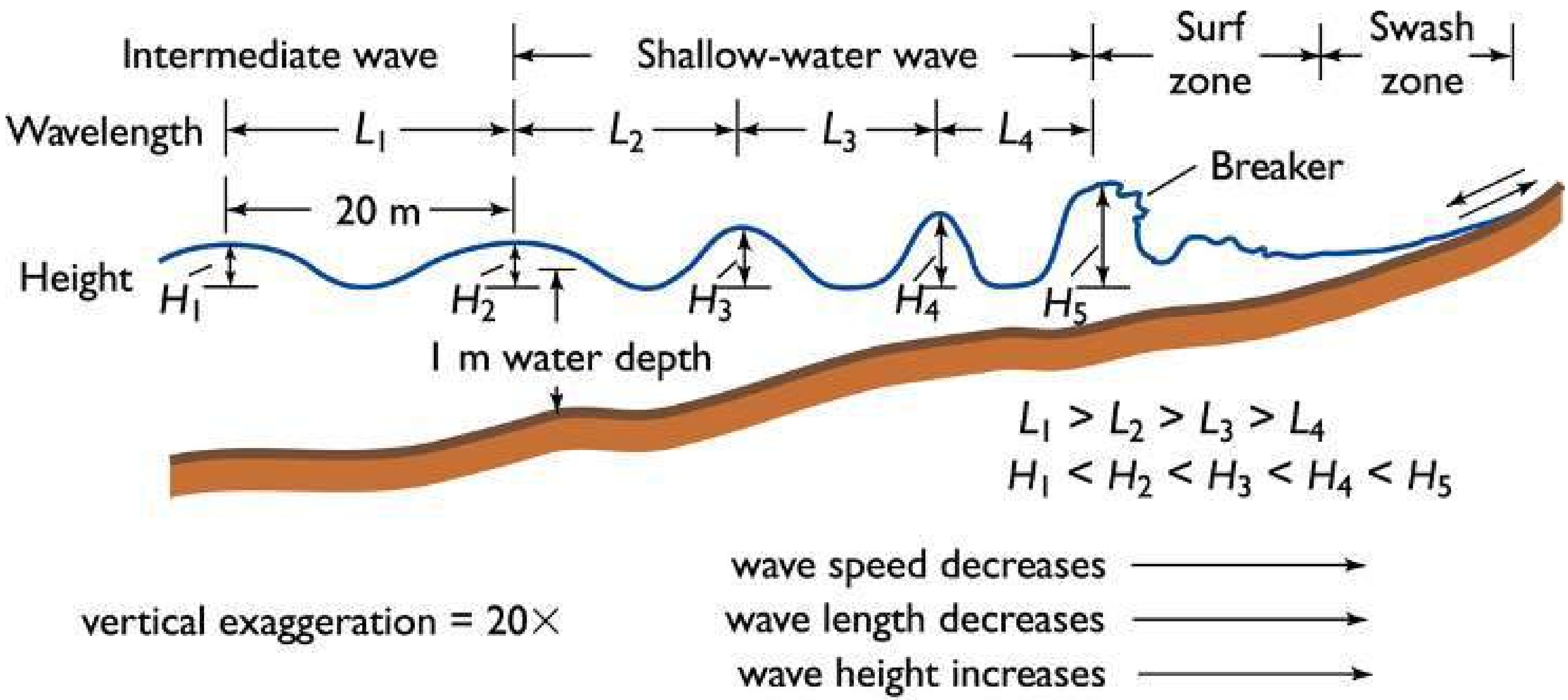
(a) DEEP-WATER WAVE TRANSFORMATIONS

Pengaruh Dispersi Gelombang (in deep water)



* **Dispersi gelombang** adl perubahan bentuk **gelombang** ketika merambat melalui satu medium

Gelombang memasuki perairan dangkal



(b) SHALLOW-WATER WAVES IN PROFILE

Pembentukan, perambatan dan gelombang pecah di pantai

Kelompok Gelombang (Group Wave)

Waves in the area of the fetch

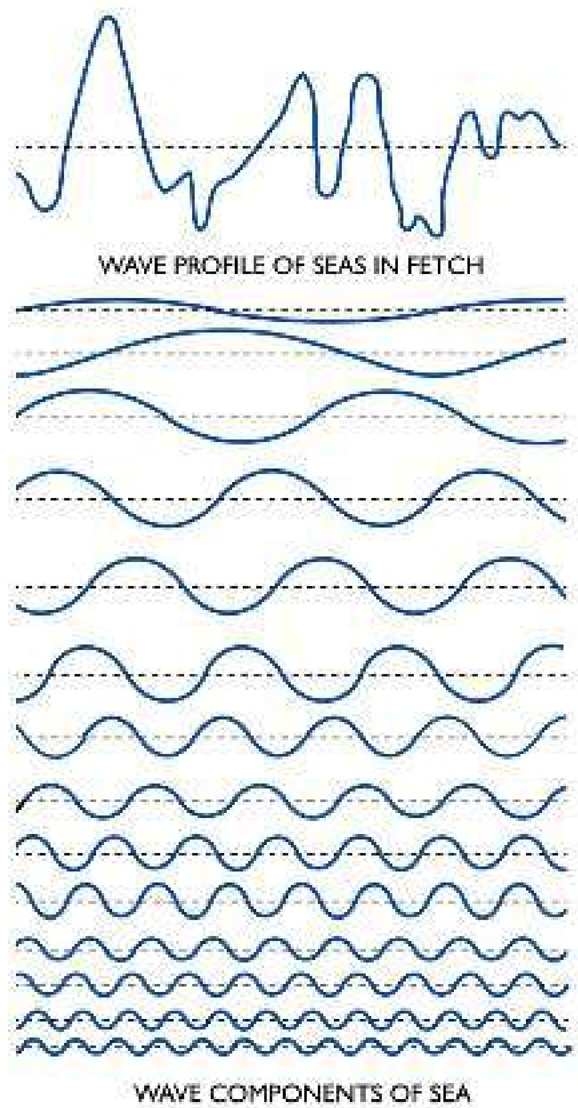
Group Velocity C_g = Velocity of the wave envelope

$$C_g = \frac{C}{2}\left[1 + \frac{2\kappa h}{\sinh(2\kappa h)}\right] = \frac{\partial \omega}{\partial \kappa}$$

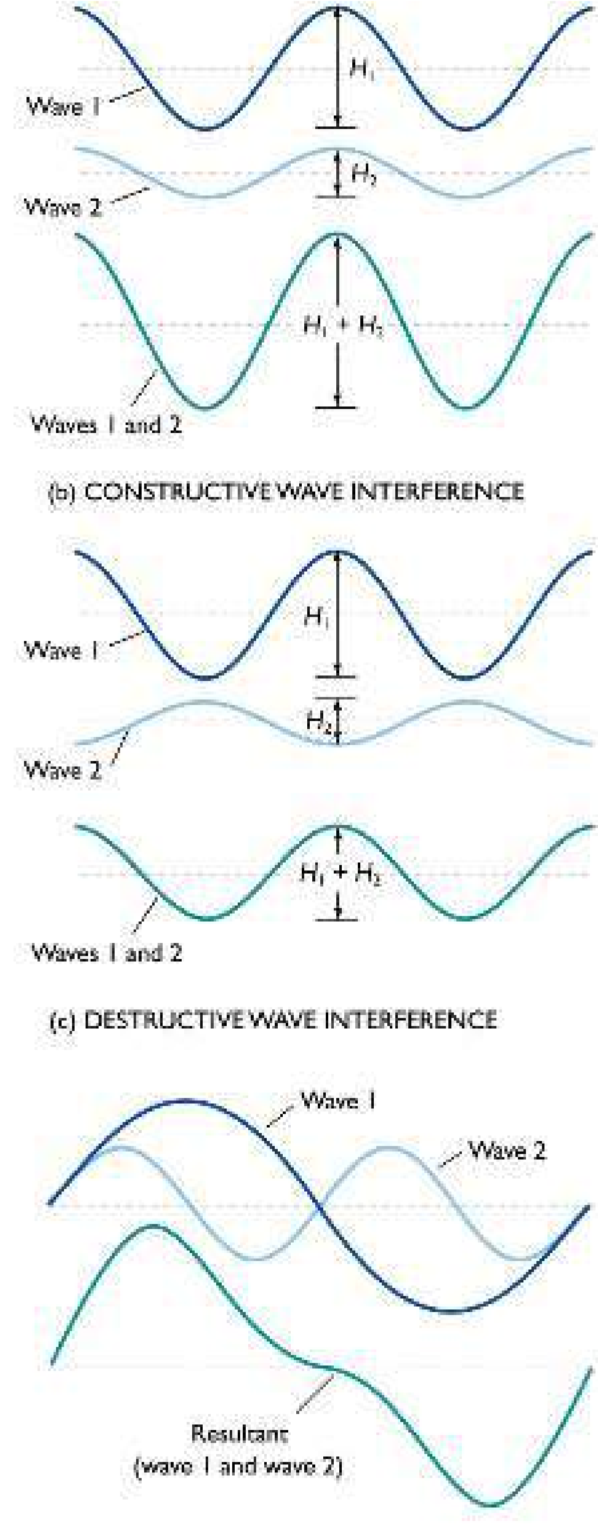
In deep waters:

$C_g = 0.5\ C$

In shallow waters:
$C_g = C$

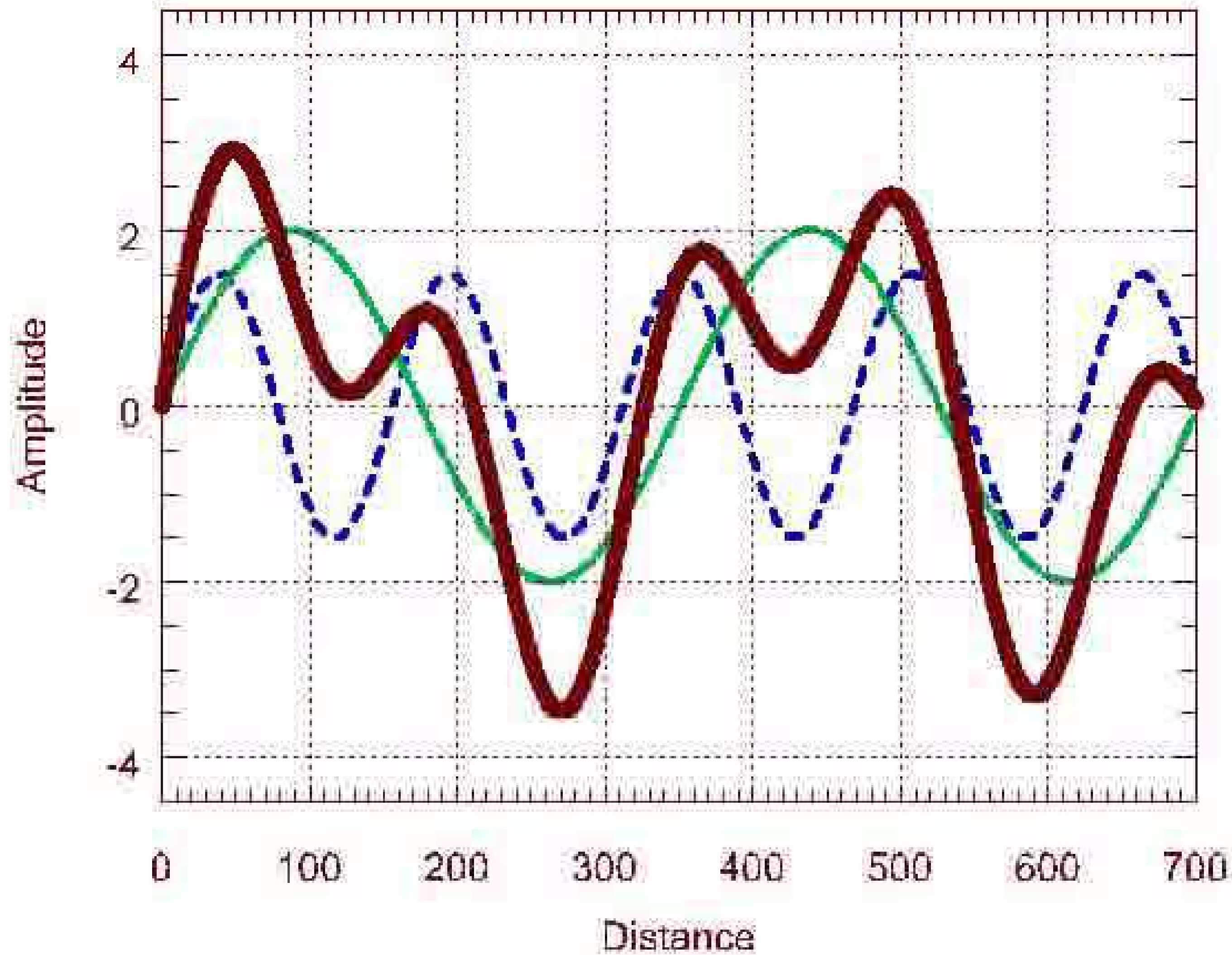


(a) ANALYSIS OF CHAOTIC SEAS



(d) COMPLEX WAVE INTERFERENCE

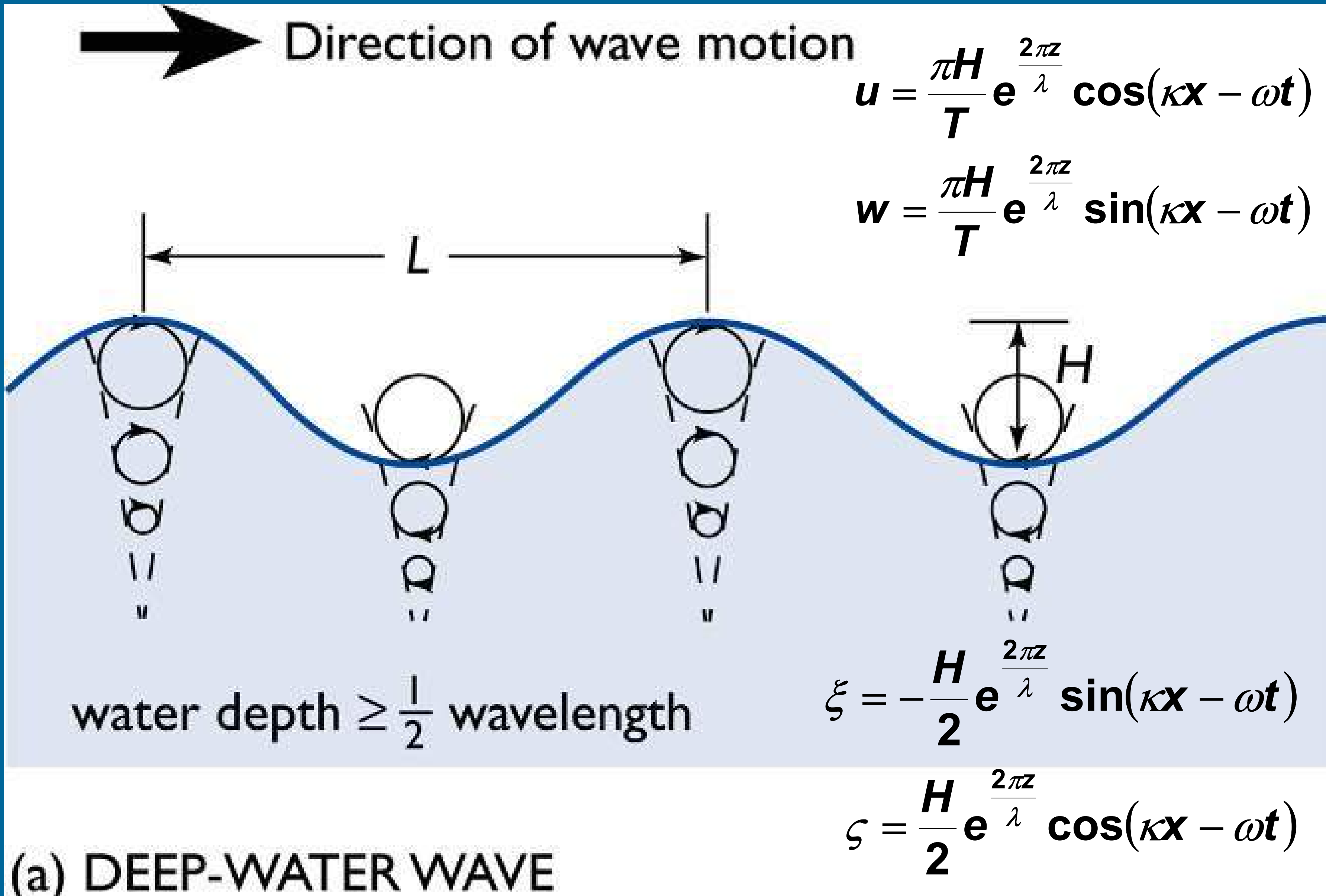
Gel hijau bergerak ke kanan dan gel biru bergerak ke kiri: Perjumlahannya Gel Merah (gel kelompok atau amplop gelombang atau wave envelope)



Pergerakan partikel gelombang (u) dan (w):

Motion of the Wave Form

Circular Motion



$$u = \frac{\pi H}{T} e^{\frac{2\pi z}{\lambda}} \cos(\kappa x - \omega t)$$

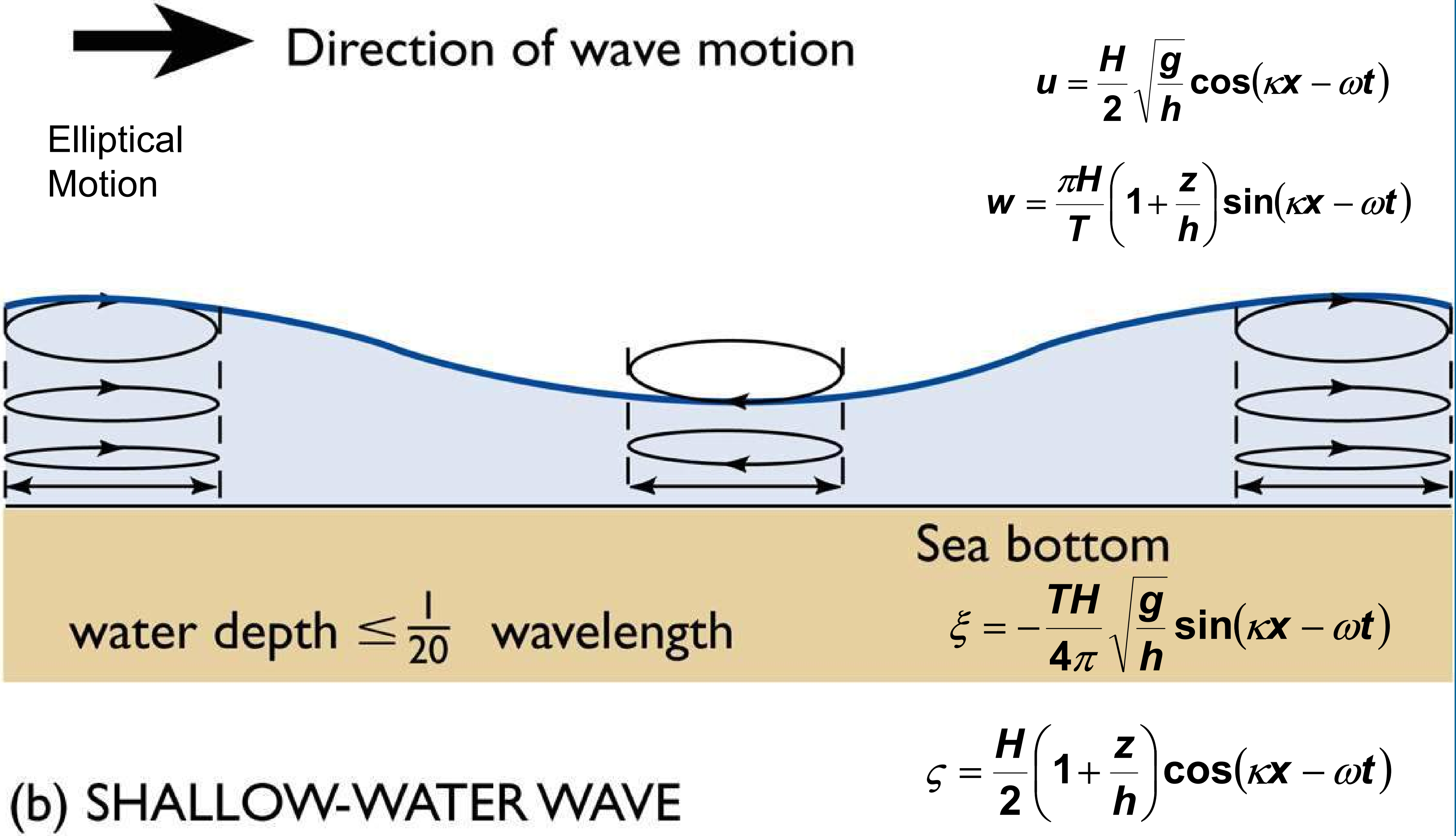
$$w = \frac{\pi H}{T} e^{\frac{2\pi z}{\lambda}} \sin(\kappa x - \omega t)$$

$$\xi = -\frac{H}{2} e^{\frac{2\pi z}{\lambda}} \sin(\kappa x - \omega t)$$

$$\varsigma = \frac{H}{2} e^{\frac{2\pi z}{\lambda}} \cos(\kappa x - \omega t)$$

Short Deep Water Waves

wind waves and swell offshore



Elliptical Motion

$$u = \frac{H}{2}\sqrt{\frac{g}{h}}\cos(\kappa x - \omega t)$$

$$w = \frac{\pi H}{T}\left(1 + \frac{z}{h}\right)\sin(\kappa x - \omega t)$$

$$\xi = -\frac{TH}{4\pi}\sqrt{\frac{g}{h}}\sin(\kappa x - \omega t)$$

$$\varsigma = \frac{H}{2}\left(1 + \frac{z}{h}\right)\cos(\kappa x - \omega t)$$

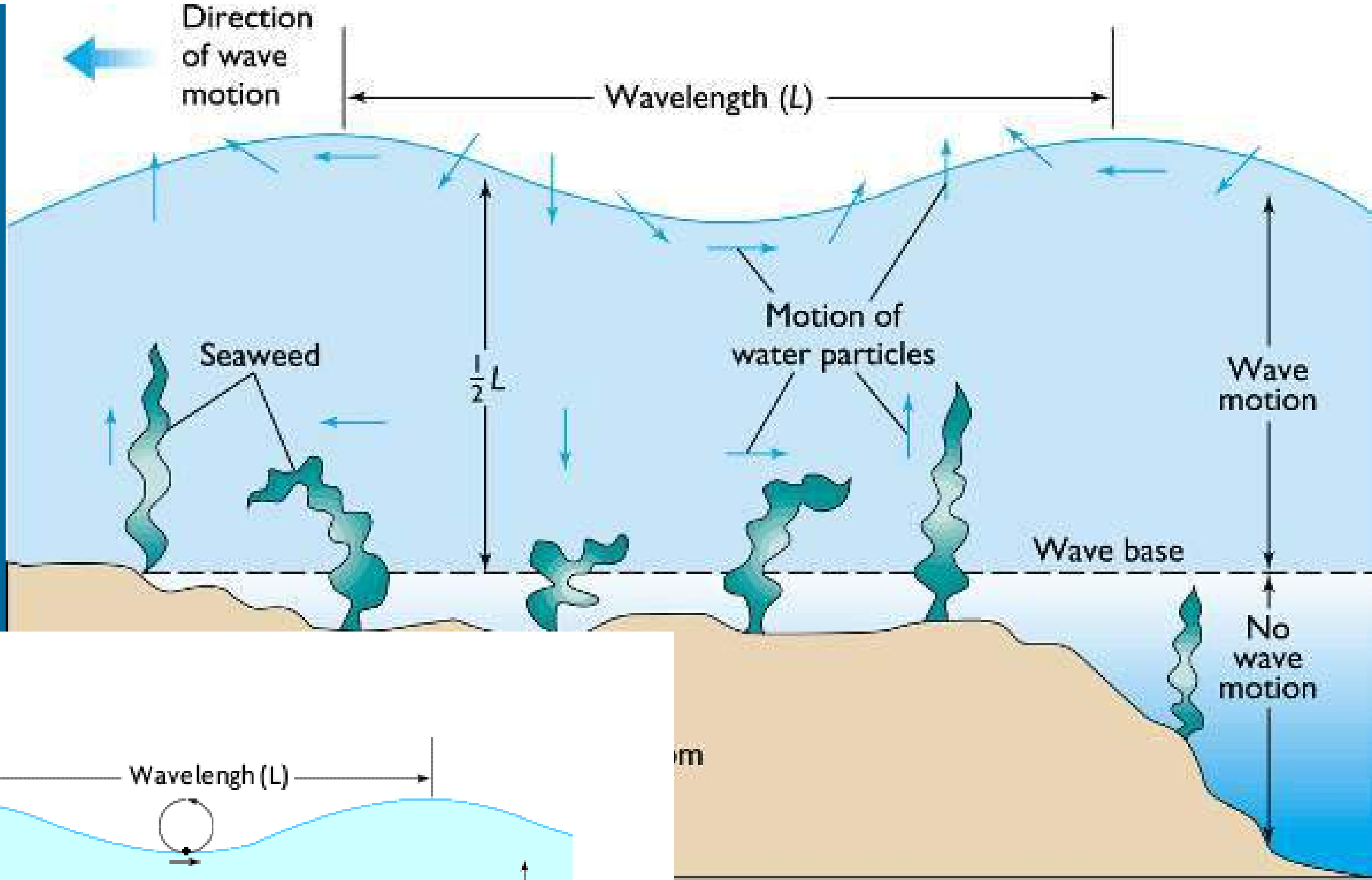
Long Shallow Water Waves

Tides, Tsunamis, Seiches, waves in shallow water

What about INTERMEDIATE WATER WAVES?

Motion of water particles beneath waves --

energy travels across the surface, not water particles



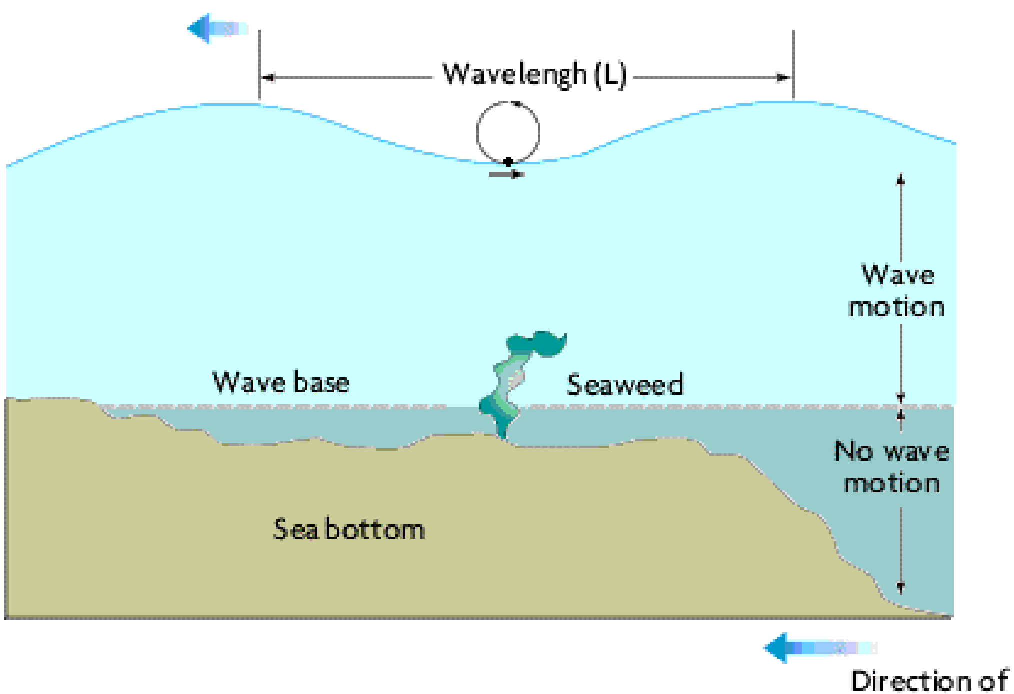
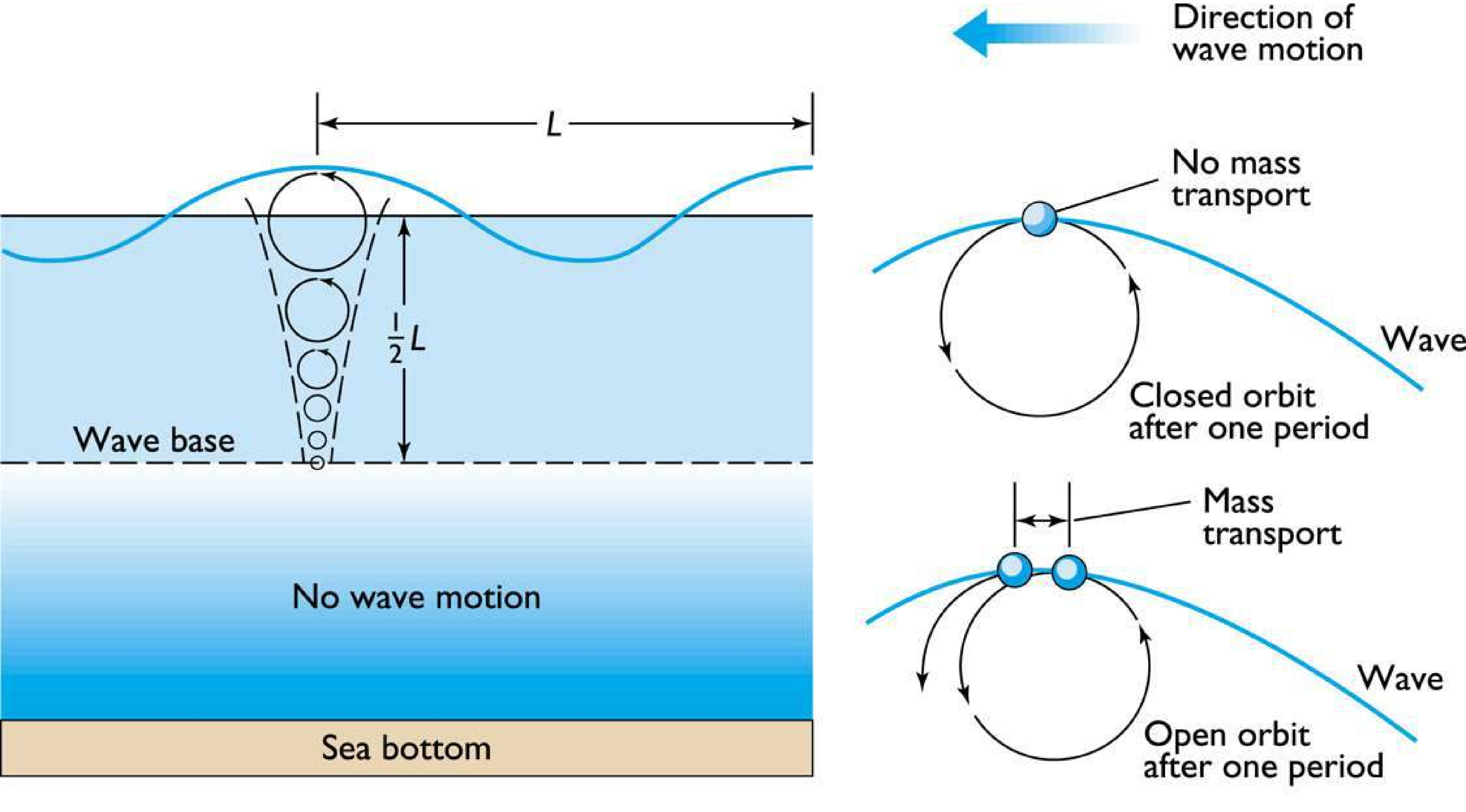


Fig. 7-3 The Motion of Water Particles Beneath Waves



(b) ORBITS OF WATER PARTICLES

(c) STOKES DRIFT

Orbits of water particles are not quite closed -- net displacement = STOKES DRIFT

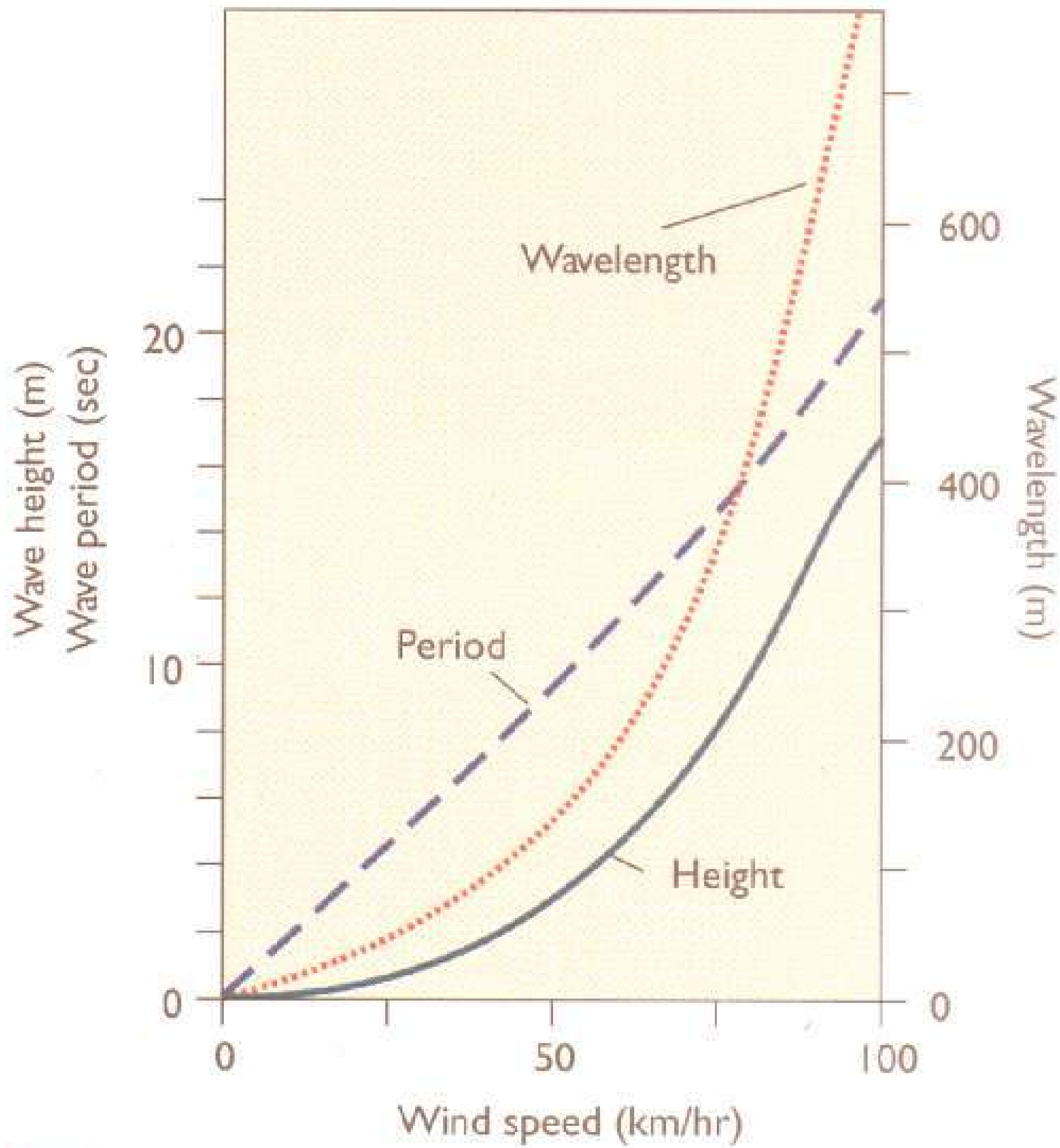
Ada 4 faktor yang mempengaruhi tinggi dan bentuk dari gelombang yang dibangkitkan angin (wind wave)

- **Kecepatan Angin**: Proporsional
- **Lamanya angin bertiup**: mis. synoptic vs. angin darat-laut (sea-breeze)
- **Fetch**: Jarak dimana angin bertiup .
- **Kondisi (status) awal (Original Sea State)**: mulai dari permukaan yang rata (smooth surface) atau muka laut beriak/berombak (rough)

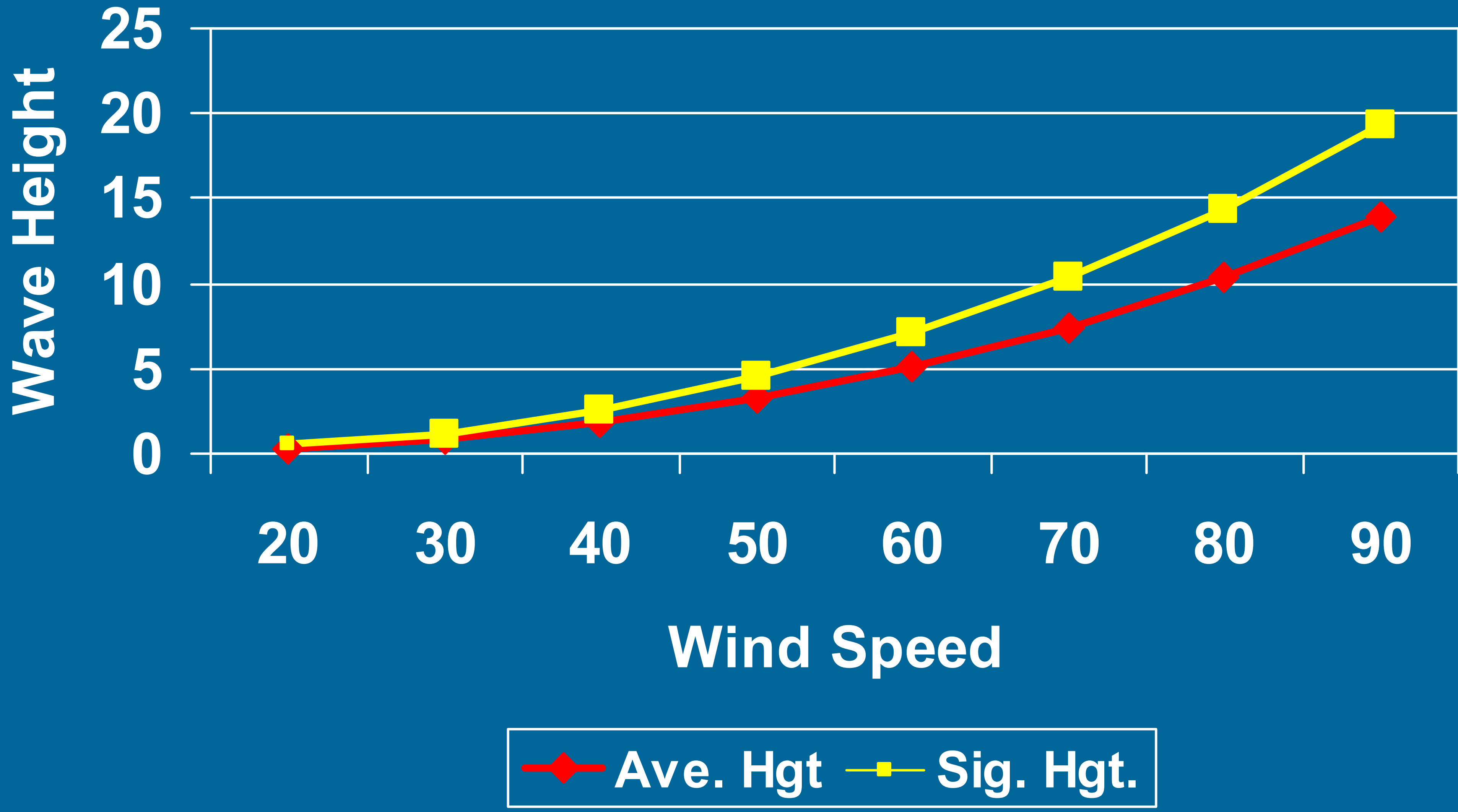
Increased
Wind Speed
causes
waves with
increased
height,
wavelength
and period

Fully
developed
sea --

waves can
no longer
grow

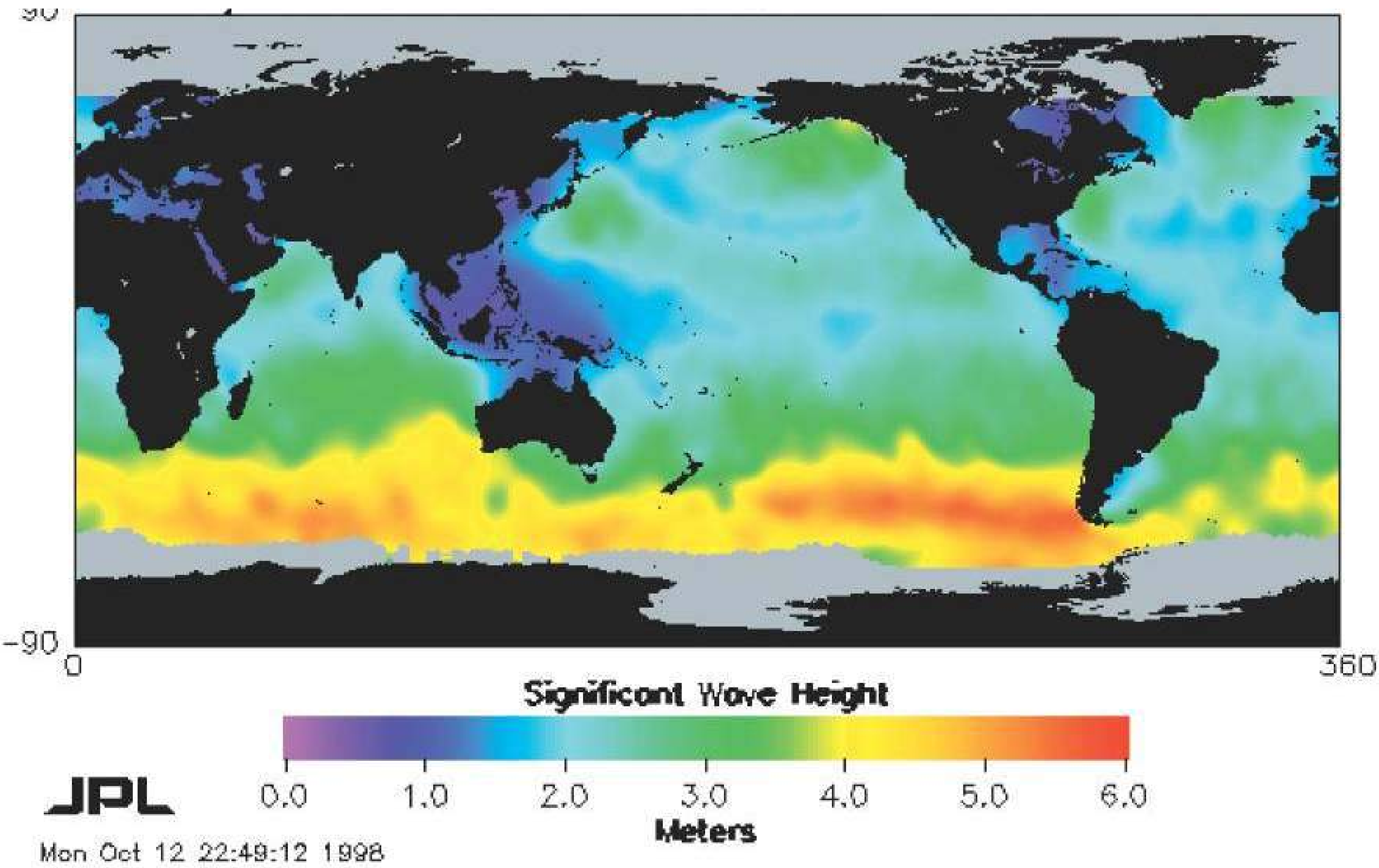


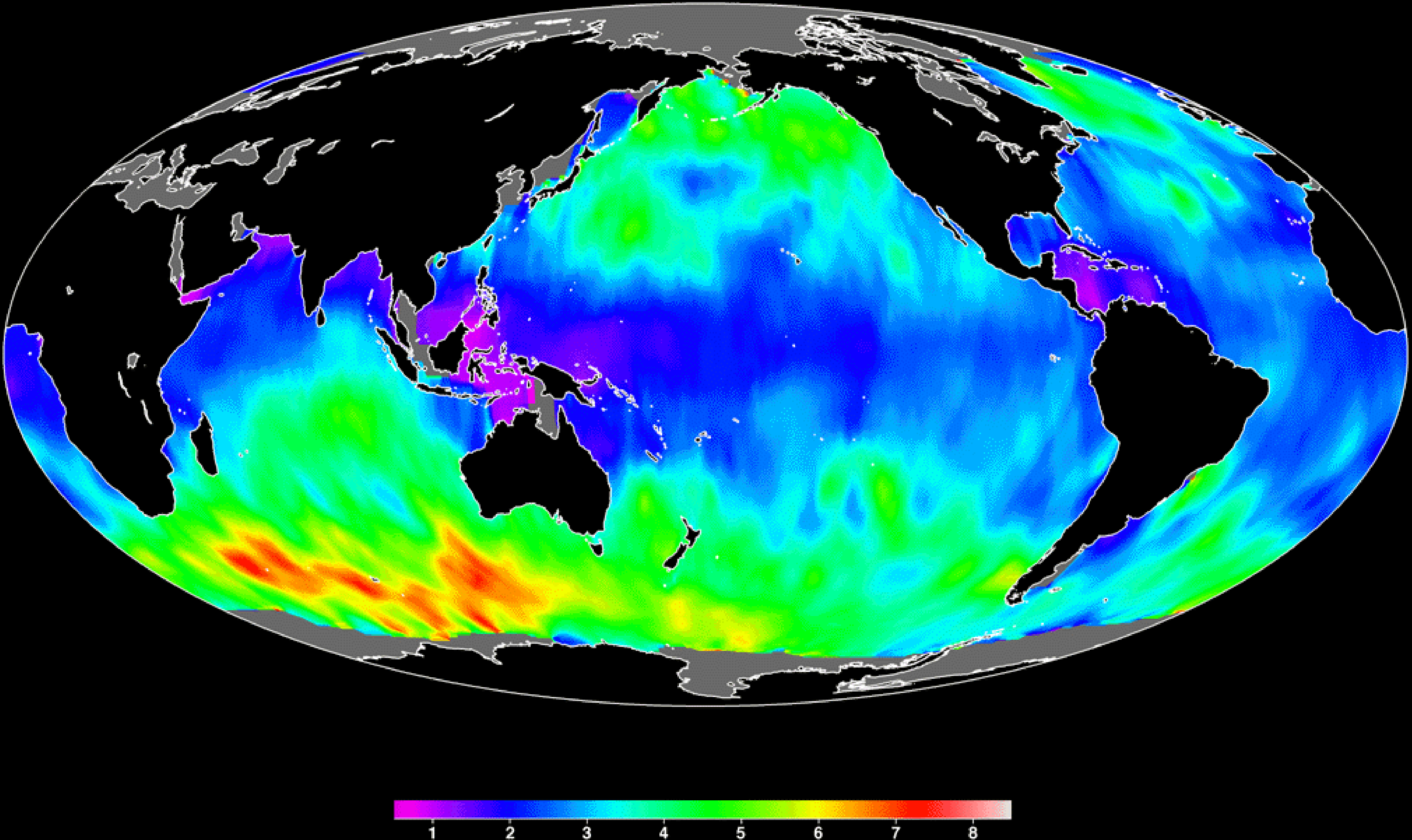
Average and Significant Wave Height



Significant Wave Height = average of highest 1/3 of the waves.

Significant Wave Height



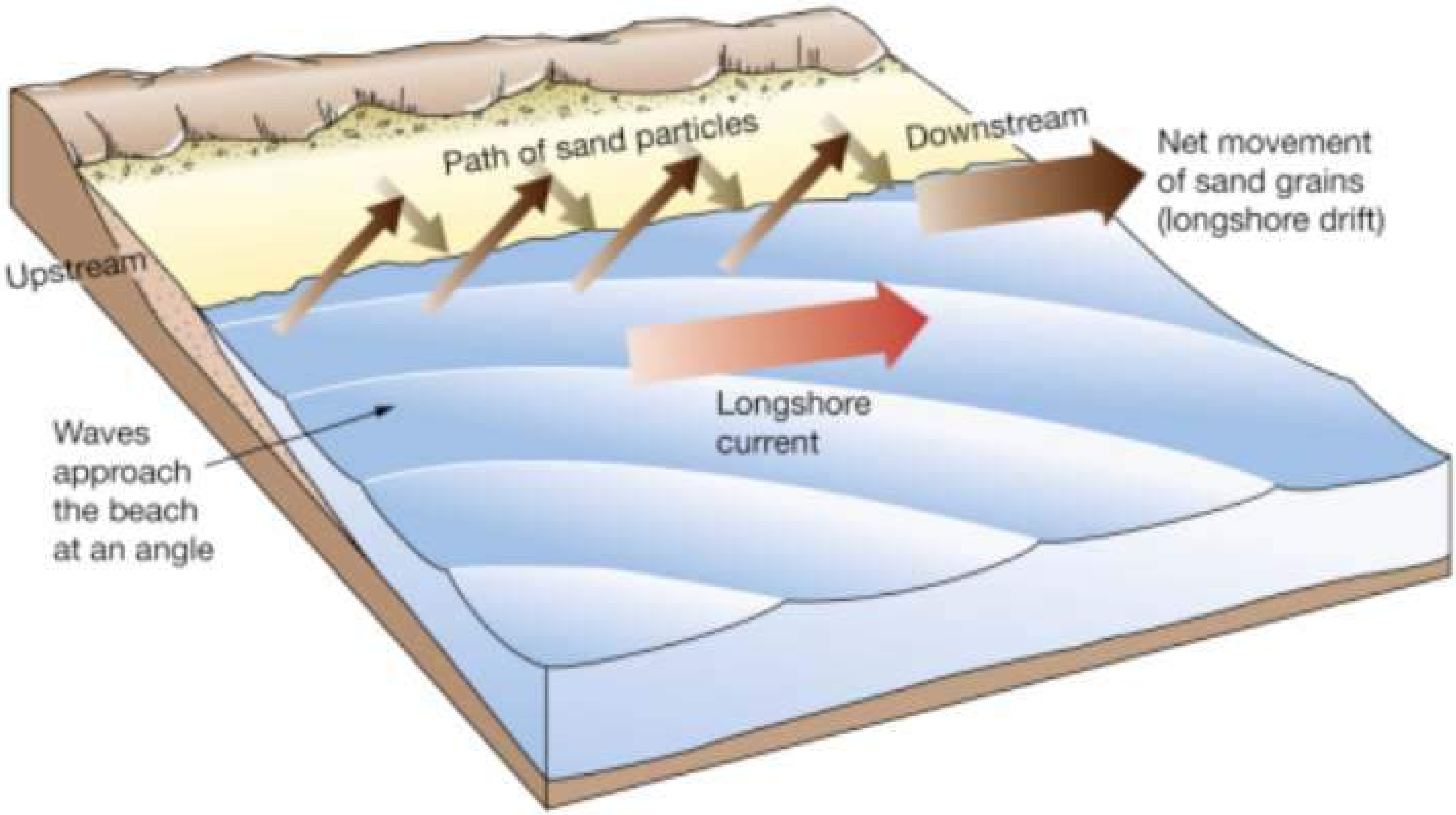


Wave Height (m)   Sept 25 - Oct 4, 1992

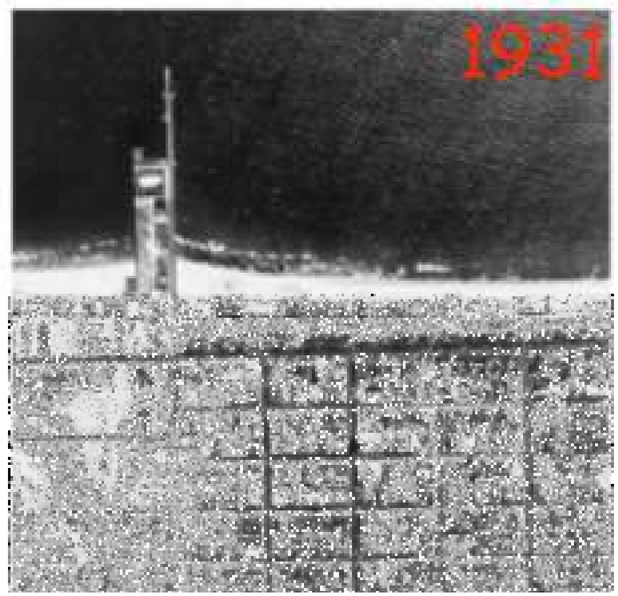
Small amplitude waves: Steepness < 1/20 (1/50 in real ocean)

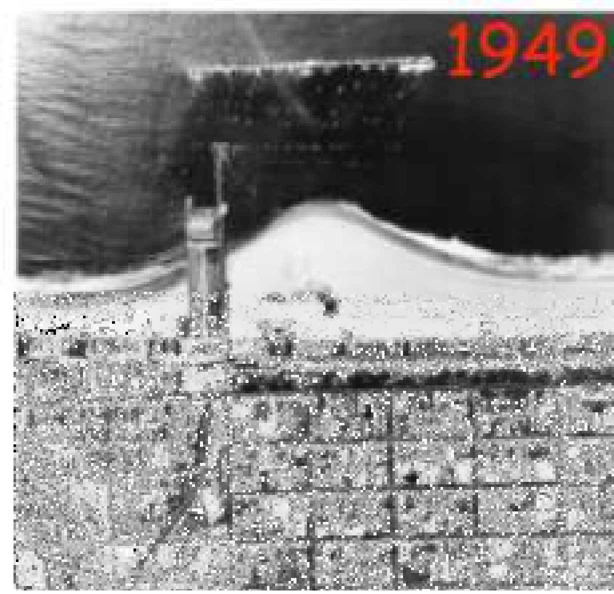
$\eta = A\cos(\kappa x - \omega t)$; $A = H/2$, $\kappa = 2\pi/\lambda$, $\omega = 2\pi/T$

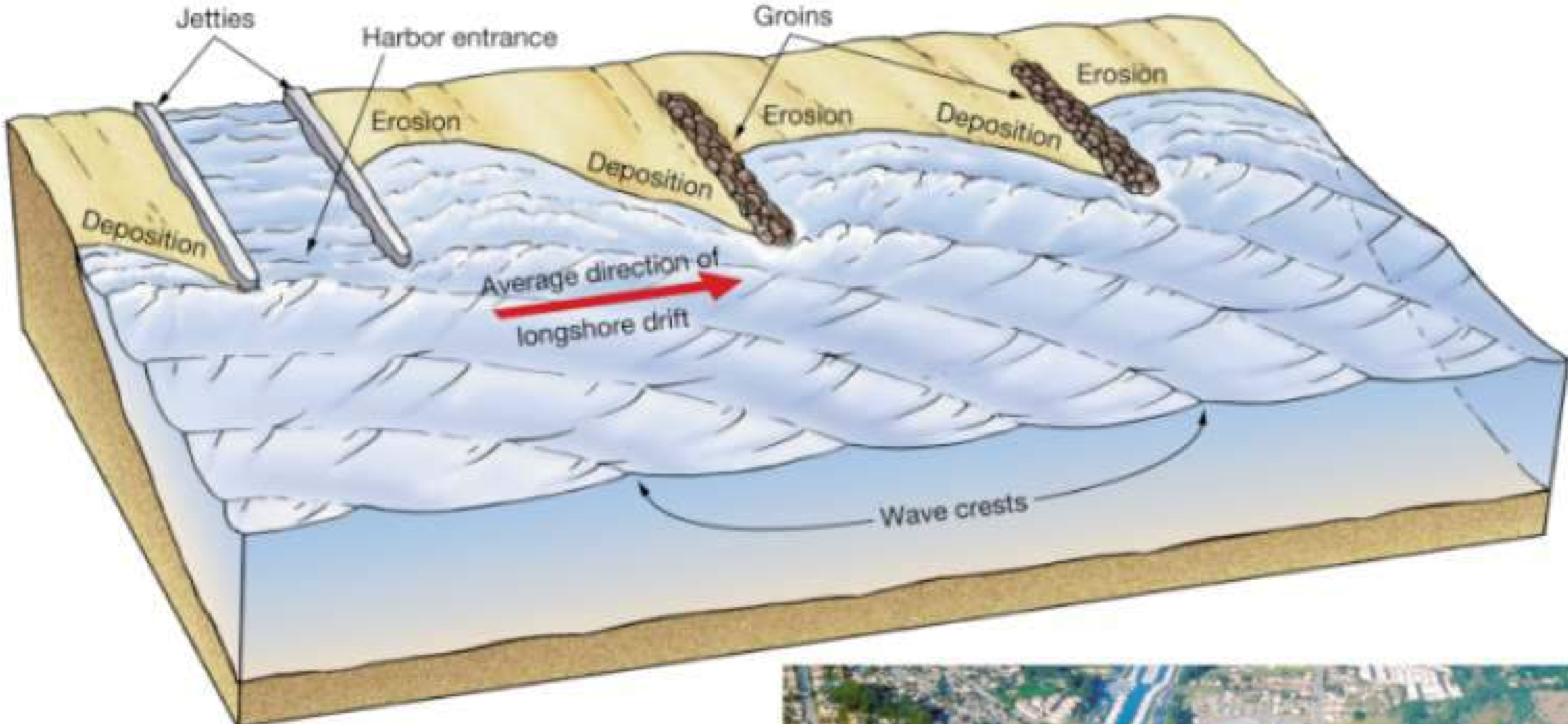
	deep waves (short) $\lambda < 2h$	intermediate waves $2h < \lambda < 20h$	shallow waves (long) $\lambda > 20h$
Phase speed or wave celerity C	$C = \frac{gT}{2\pi} = \sqrt{\frac{g}{\kappa}} = \frac{g}{\omega}$	$C = \left[\frac{g}{\kappa}\tanh(\kappa h)\right]^{1/2} \Rightarrow \omega^2 = g\kappa\tanh(\kappa h)$	$C = [gh]^{1/2}$
wavelength	$\lambda = \frac{gT^2}{2\pi}$	$\lambda = \frac{gT^2}{2\pi}\tanh(\kappa h)$	$\lambda = CT$
Group velocity C_g	$C_g = 0.5C$ $(\kappa h >> 1)$	$C_g = \frac{C}{2}\left[1 + \frac{2\kappa h}{\sinh(2\kappa h)}\right]$	$C_g = C$ $(\kappa h << 1)$
Wave particle horizontal velocity u	$u = \frac{\pi H}{T} e^{\frac{2\pi z}{\lambda}} \cos(\kappa x - \omega t)$	$u = \frac{H}{2}\frac{gT}{\lambda}\frac{\cosh(2\pi[h+z]/\lambda)}{\cosh(2\pi h/\lambda)}\cos(\kappa x - \omega t)$	$u = \frac{H}{2}\sqrt{\frac{g}{h}}\cos(\kappa x - \omega t)$
vertical velocity w	$w = \frac{\pi H}{T} e^{\frac{2\pi z}{\lambda}} \sin(\kappa x - \omega t)$	$w = \frac{H}{2}\frac{gT}{\lambda}\frac{\sinh(2\pi[h+z]/\lambda)}{\cosh(2\pi h/\lambda)}\sin(\kappa x - \omega t)$	$w = \frac{\pi H}{T}\left(1 + \frac{z}{h}\right)\sin(\kappa x - \omega t)$
Horizontal displacements	$\xi = -\frac{H}{2} e^{\frac{2\pi z}{\lambda}} \sin(\kappa x - \omega t)$	$\xi = -\frac{H}{2}\frac{\cosh(2\pi[h+z]/\lambda)}{\cosh(2\pi h/\lambda)}\sin(\kappa x - \omega t)$	$\xi = -\frac{TH}{4\pi}\sqrt{\frac{g}{h}}\sin(\kappa x - \omega t)$
Vertical displacements	$\varsigma = \frac{H}{2} e^{\frac{2\pi z}{\lambda}} \cos(\kappa x - \omega t)$	$\zeta = \frac{H}{2}\frac{\sinh(2\pi[h+z]/\lambda)}{\cosh(2\pi h/\lambda)}\cos(\kappa x - \omega t)$	$\varsigma = \frac{H}{2}\left(1 + \frac{z}{h}\right)\cos(\kappa x - \omega t)$
Subsurface pressure	$p = \rho g \eta e^{\frac{2\pi z}{\lambda}} - \rho g z$	$p = \rho g \eta \frac{\cosh(2\pi[h+z]/\lambda)}{\cosh(2\pi h/\lambda)} - \rho g z$	$p = \rho g(\eta - z)$

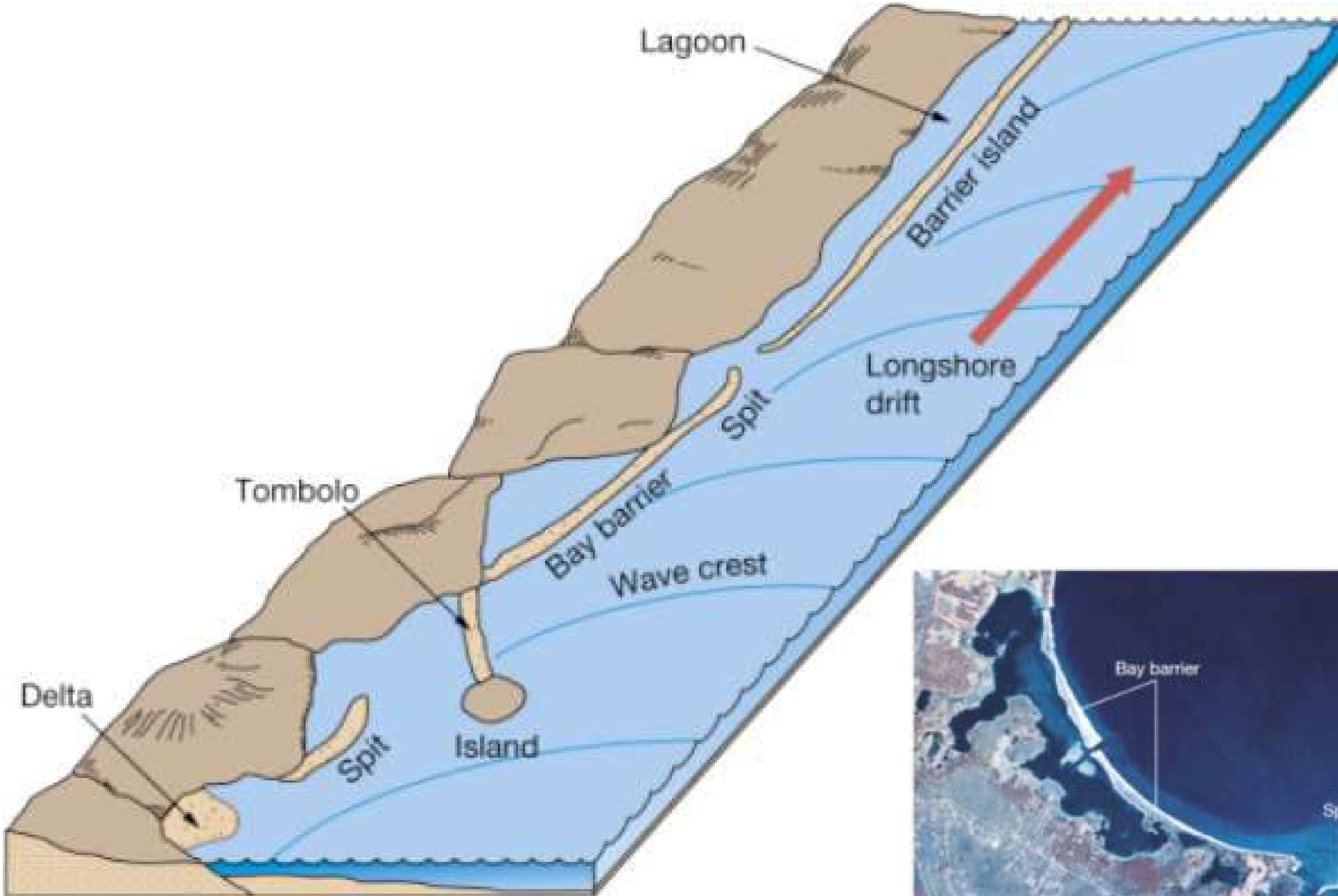

Path of sand particles
Downstream
Net movement
of sand grains
(longshore drift)
Upstream
Longshore
current
Waves
approach
the beach
at an angle


Santa Barbara Harbor
Dredge discharge
Breakwater
Dredge
Old sea cliff
Area threatened by erosion after harbor breakwater was built
Pier
New deposition
Wave crest
Average direction of longshore drift


1931


1949


Jetties
Harbor entrance
Groins
Erosion
Erosion
Erosion
Deposition
Deposition
Deposition
Deposition
Average direction of longshore drift
Wave crests

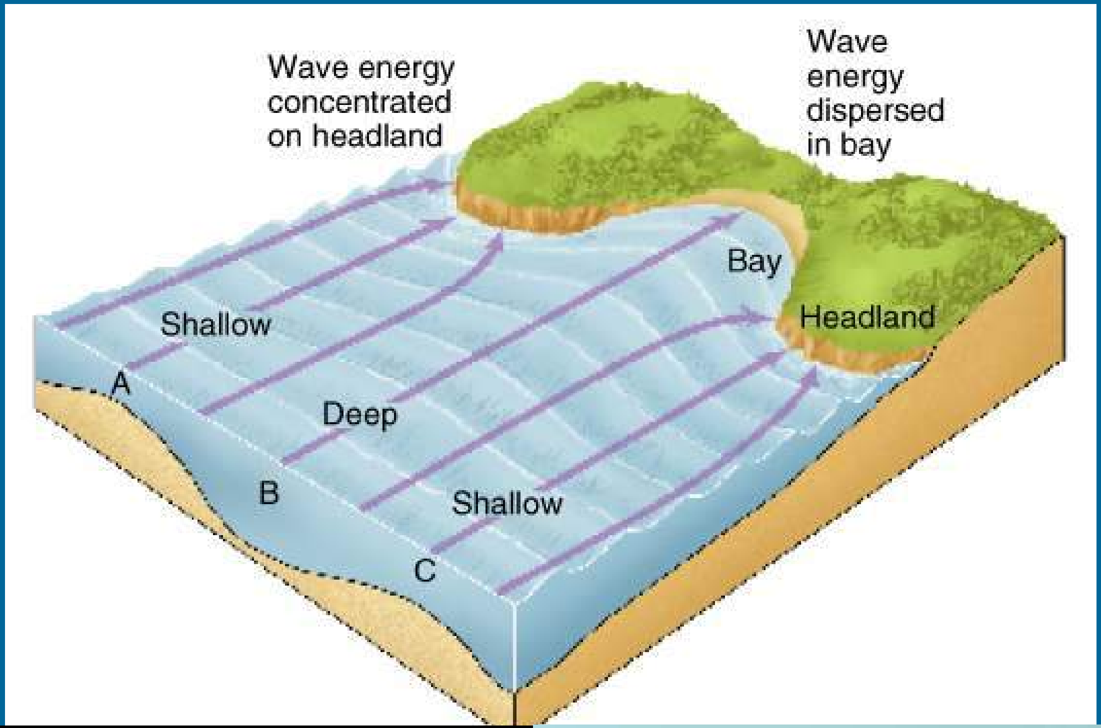

Lagoon
Barrier island
Longshore drift
Spit
Tombolo
Bay barrier
Wave crest
Delta
Spit
Island


Bay barrier
Spit

In shallow waters, waves refract, diffract, reflect and/or break

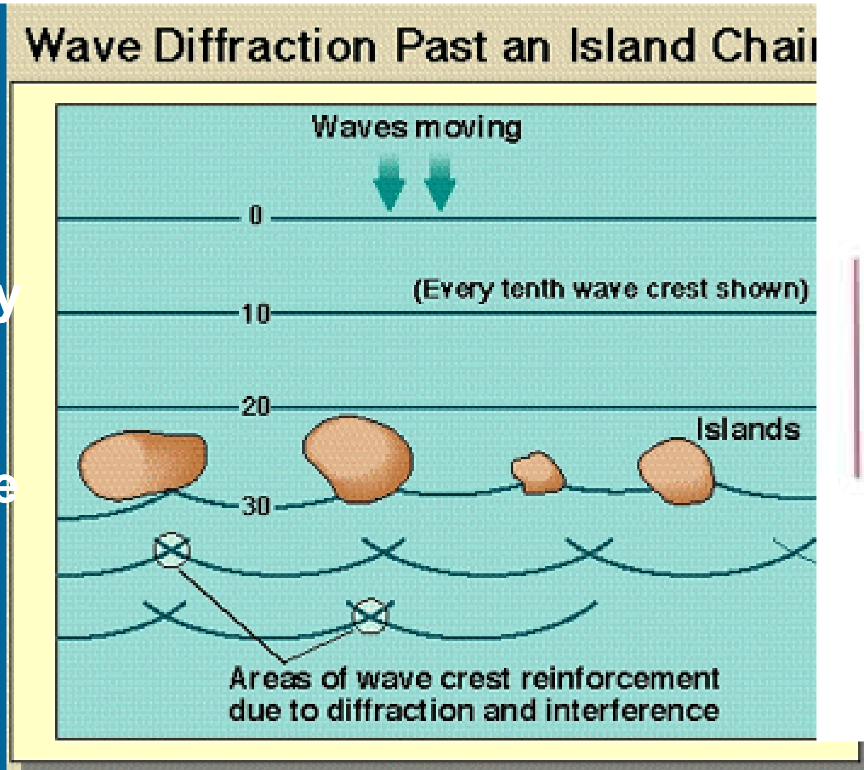
Refraction

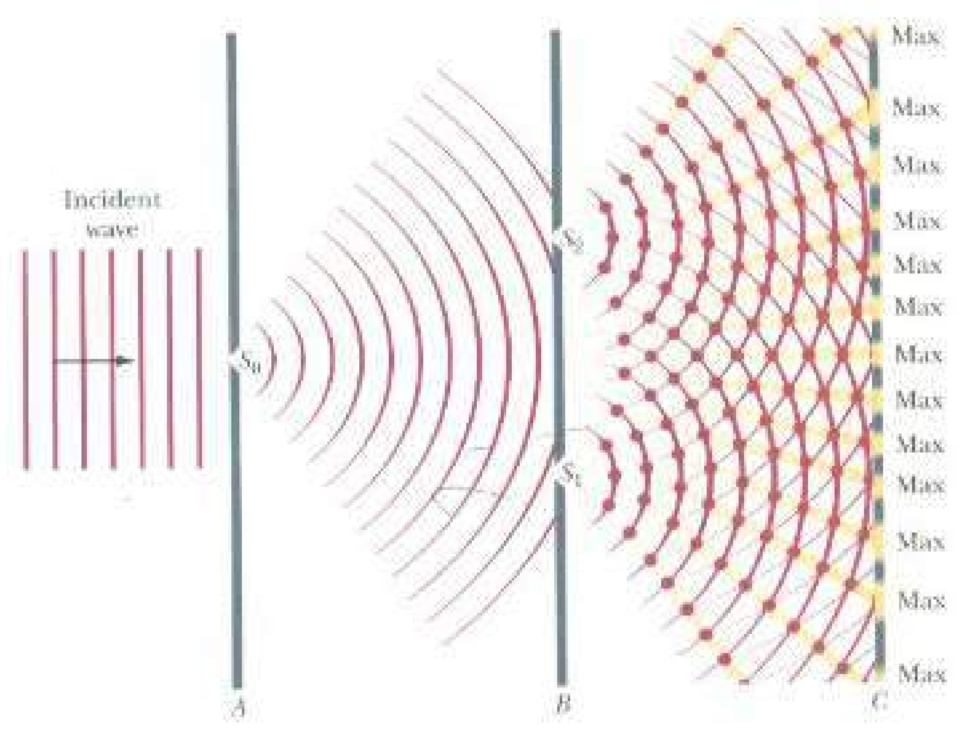
Change of wave celerity (bending of rays) due to changes in bathymetry

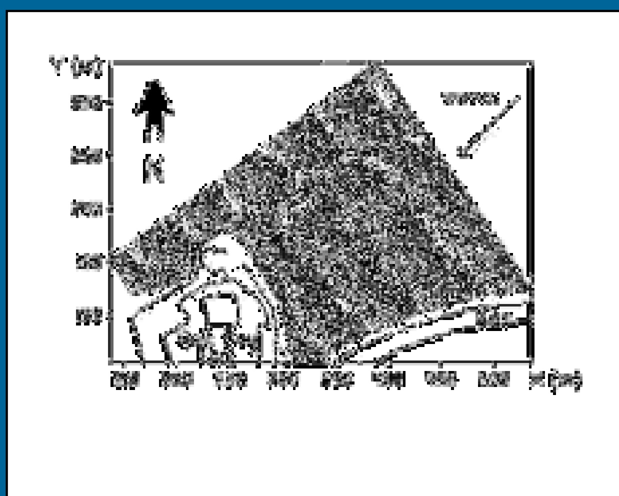


Diffraction

Change of wave celerity (bending of rays) due to the presence of an obstacle



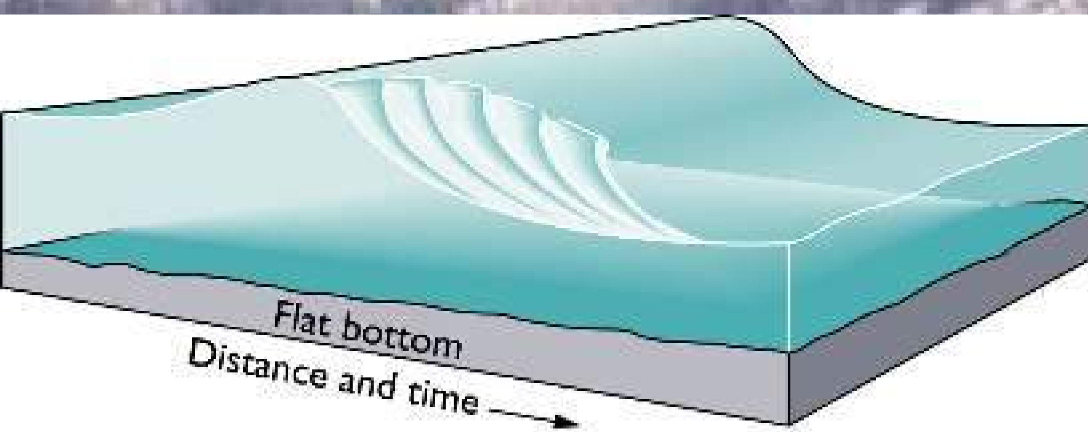




Waves Reflection

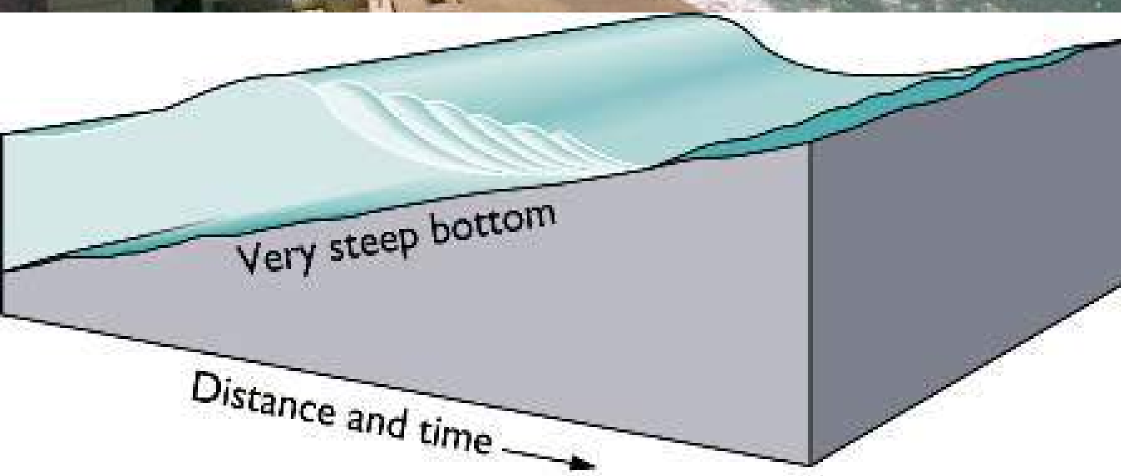
Waves break when steepness (H / λ) < 1 / 7 or H / d ~ 0.8

Breaking



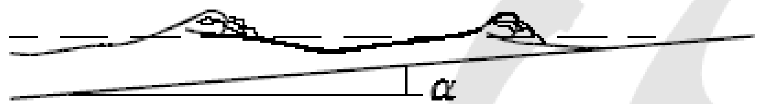
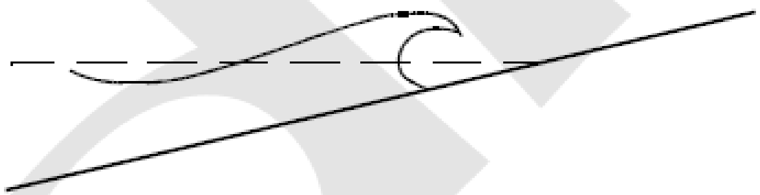
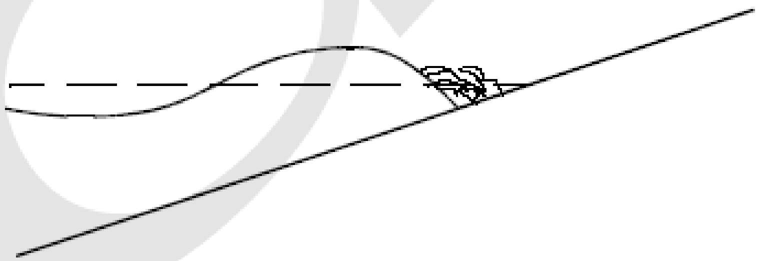
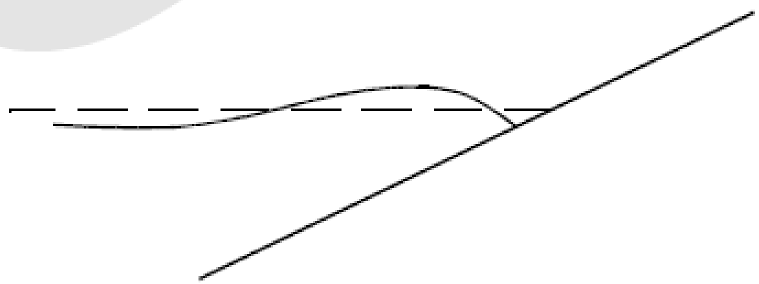
(a) SPILLING BREAKER

(b) PLUNGING BREAKER



(c) SURGING BREAKER

Table VI-5-1
Types of Wave Breaking on Impermeable Slopes and Related ξ_o-Values

	*SPILLING*	$\xi_o < 0.5$
	*PLUNGING*	$0.5 < \xi_o < 3$
	*COLLAPSING*	$\xi_o \approx 3$ à 3.5
	*SURGING*	$\xi_o > 3.5$

$$\xi_o = \frac{\tan \alpha}{\sqrt{s_o}}$$

where

α = slope angle

s_o = deepwater wave steepness (= H_o / L_o)

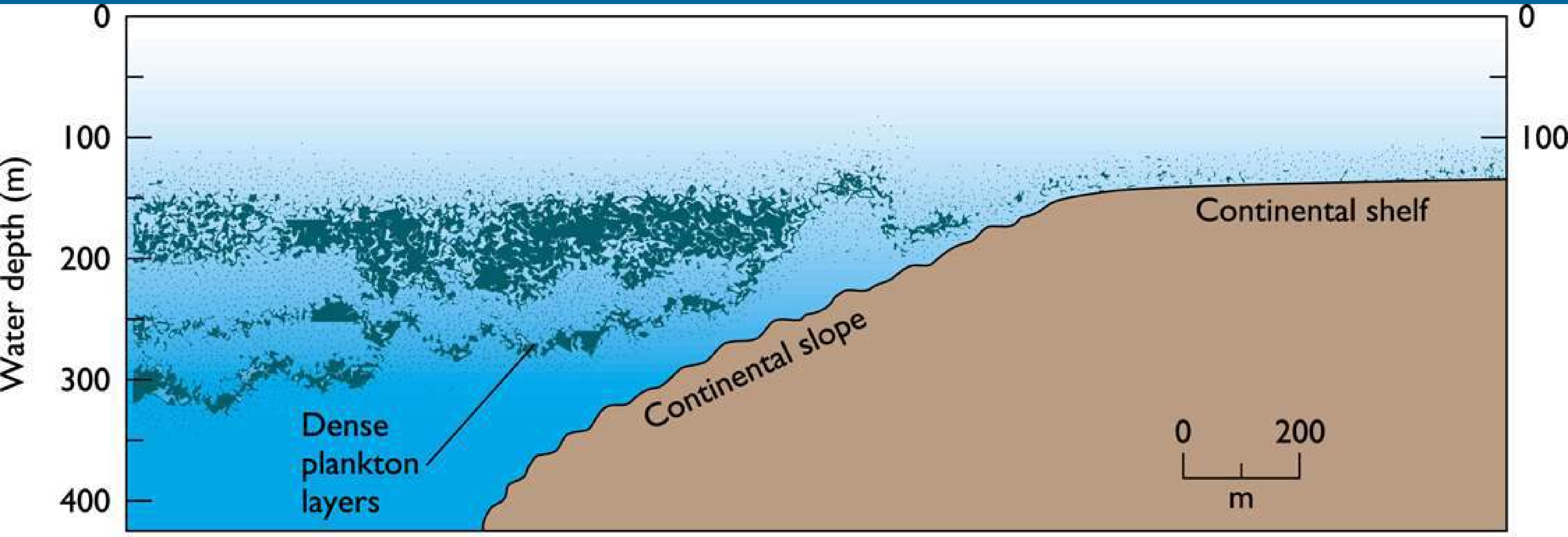
H_o = deepwater wave height

L_o = deepwater wavelength (= $gT^2/2\pi$)

T = wave period

g = acceleration due to gravity

Internal Waves

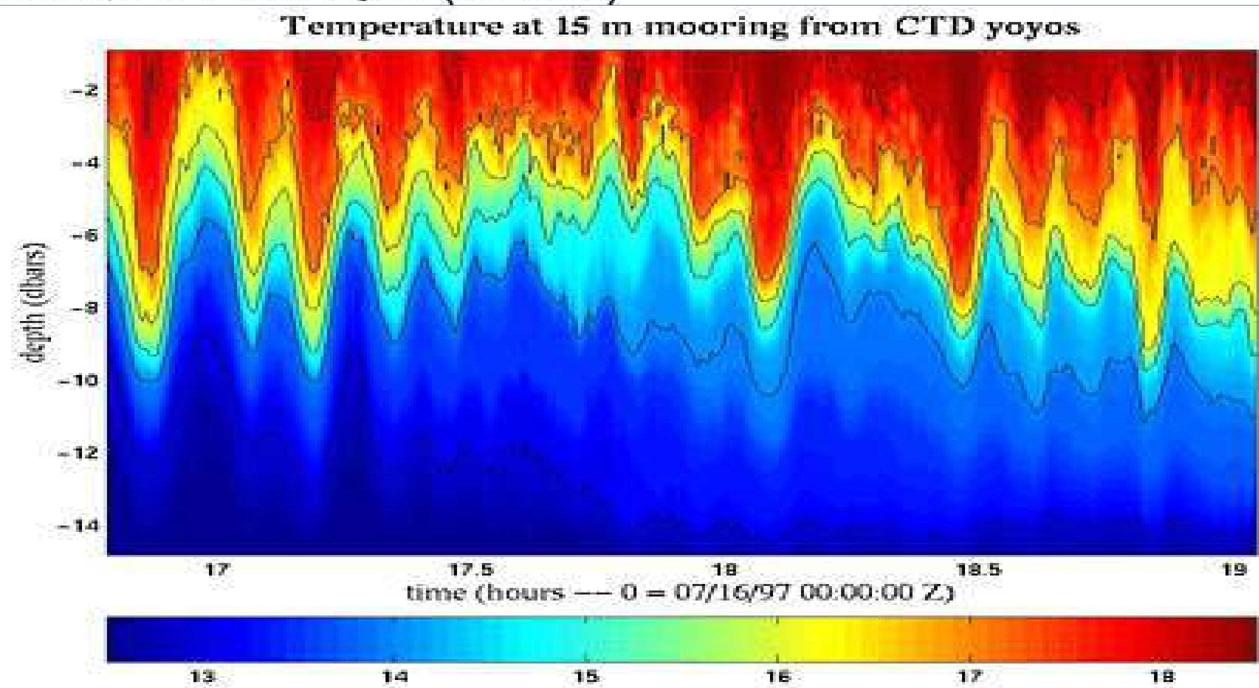


INTERNAL WAVES AND PLANKTON, MOZAMBIQUE (AFRICA)

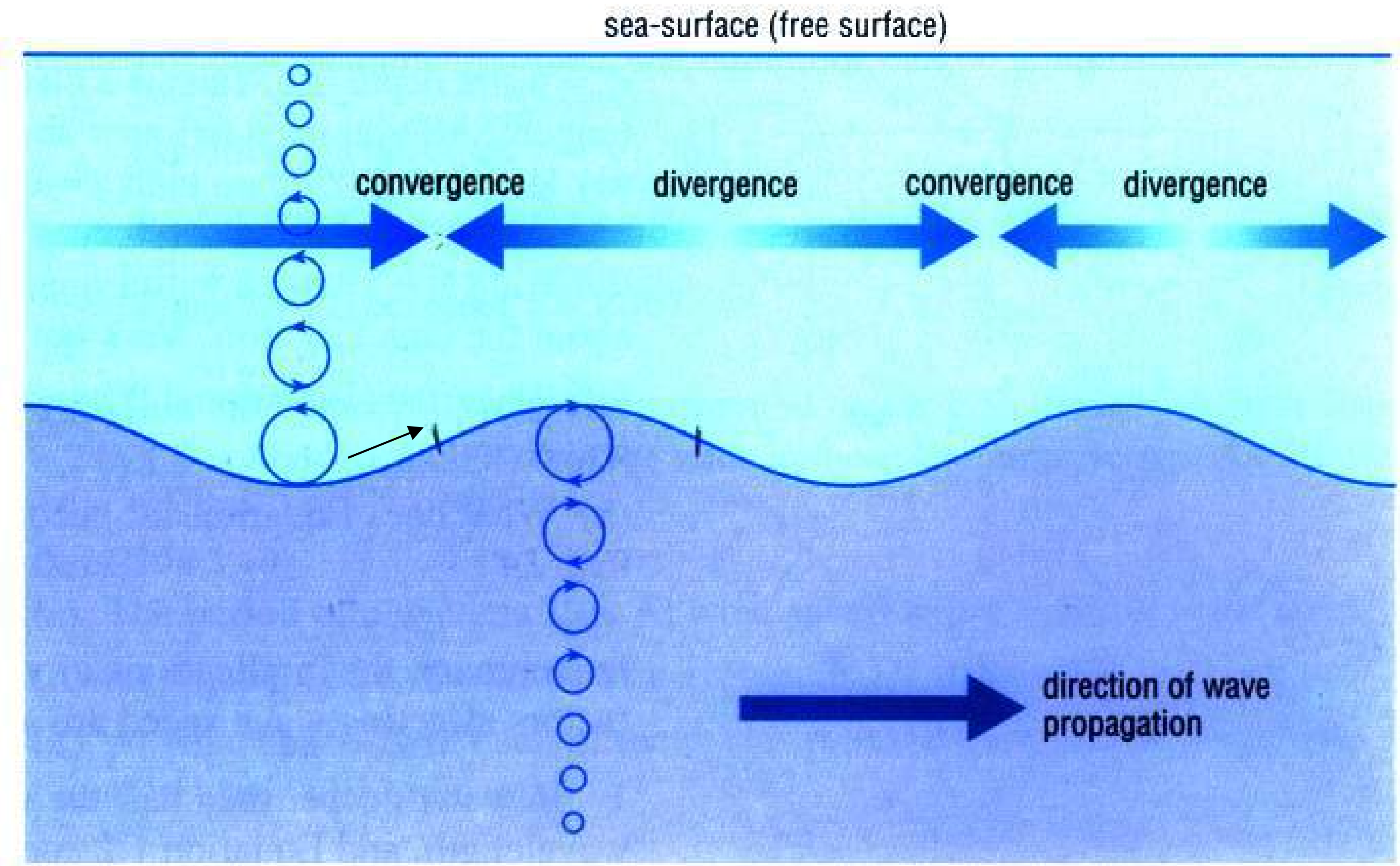
T = min to several hrs

Wave length = 1 - 300 m

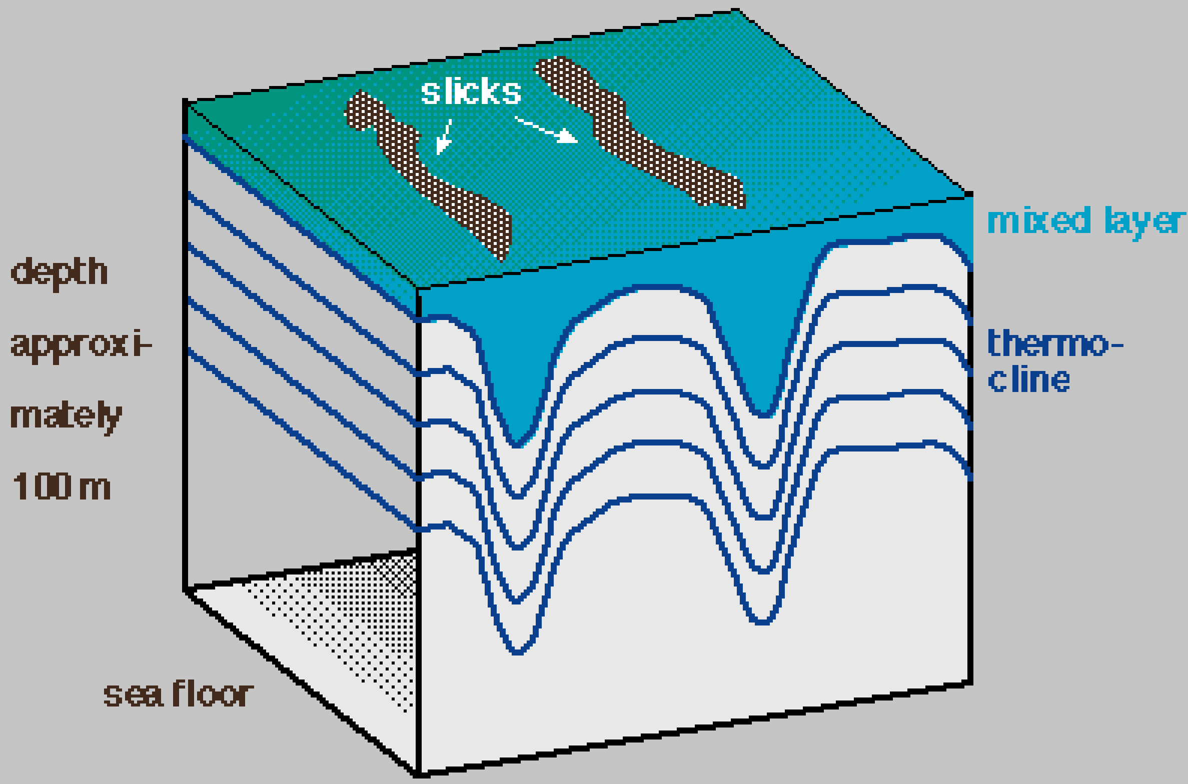
Current shear on stratification

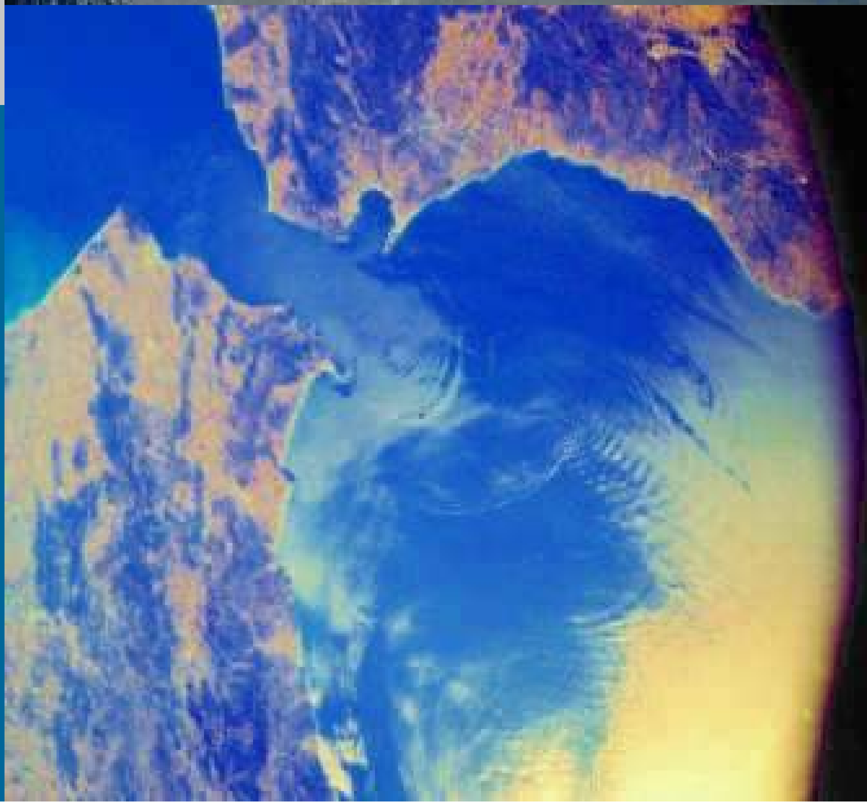


An INTERNAL WAVE
create regions of
convergence and divergence
in the layer between the surface and the internal wave

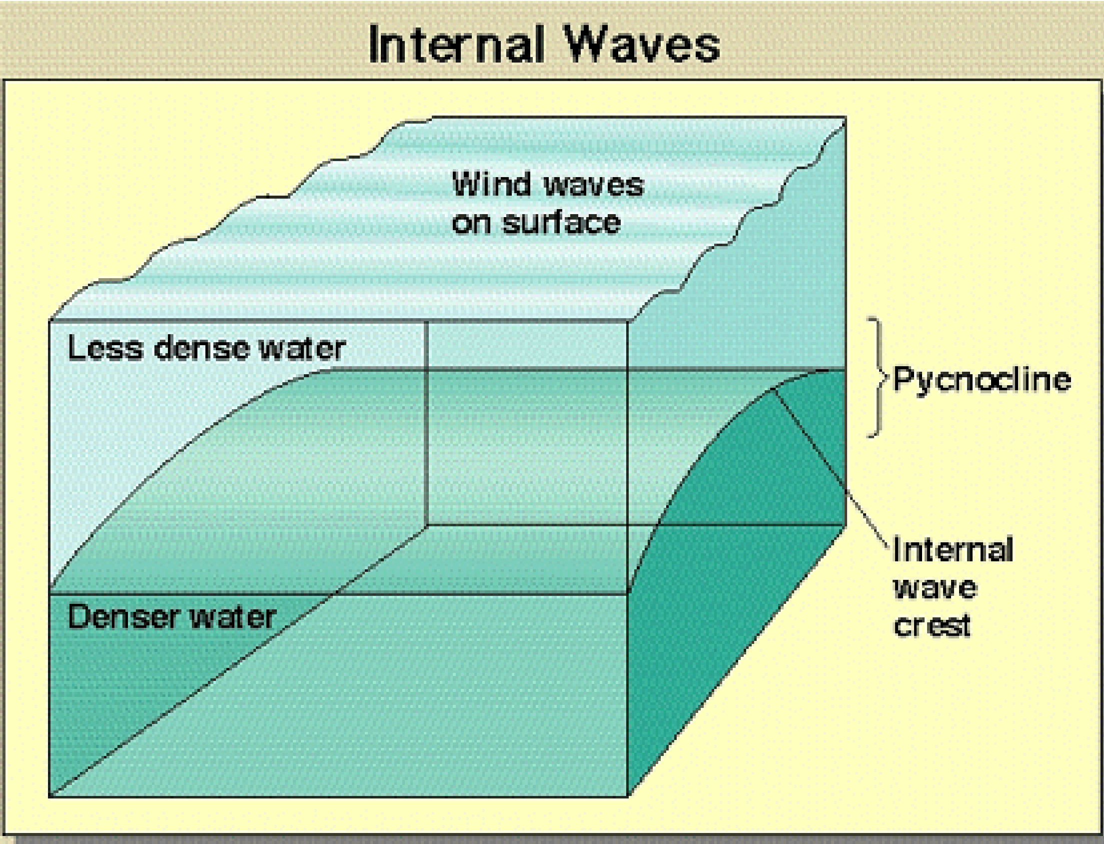


(e)





Convergences at troughs



They propagate roughly like a shallow water wave but the gravity restoring force is reduced by the difference in density.

$$C = \sqrt{g\left(\frac{\rho_2 - \rho_1}{\rho_2}\right)d}$$

$$\rho_2 - \rho_1 = 1$$

$$C = \sqrt{10 \times 0.001 \times 100} = 1\, m/s$$

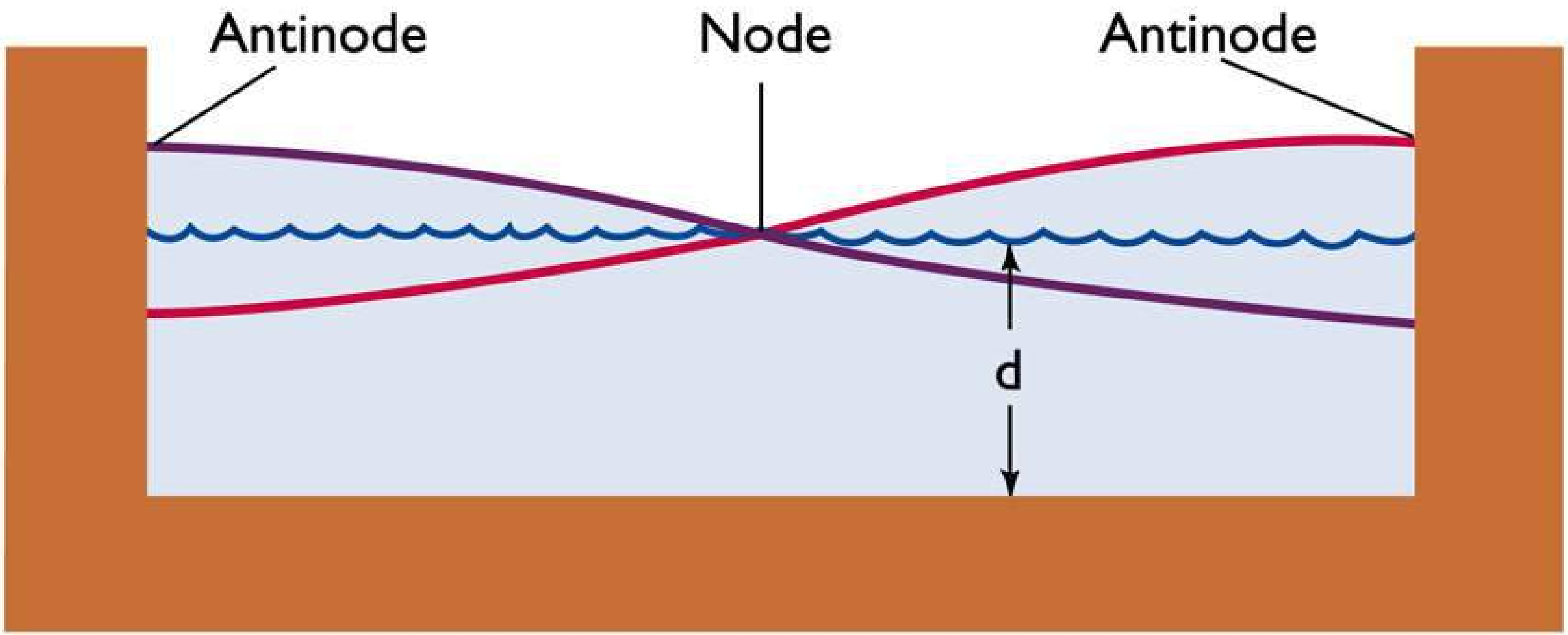
Internal Waves in a closed basin

How about *C* of a surface (wind-induced) wave?

Beberapa hal berkaitan dengan gelombang internal:

- Pulsa energi gelombang internal terjadi di lapisan interface misalnya: lapisan pycnocline di laut
- Ditandai dengan adanya naik-turunnya lapisan air
- Gelombang internal merambat lebih lambat bila dibandingkan dengan gelombang permukaan
- Karakteristiknya menunjukkan periode dan panjang gelombang yang besar
- Ordo tinggi gelombang internal dapat mencapai beberapa meter bahkan dapat mencapai 100 m

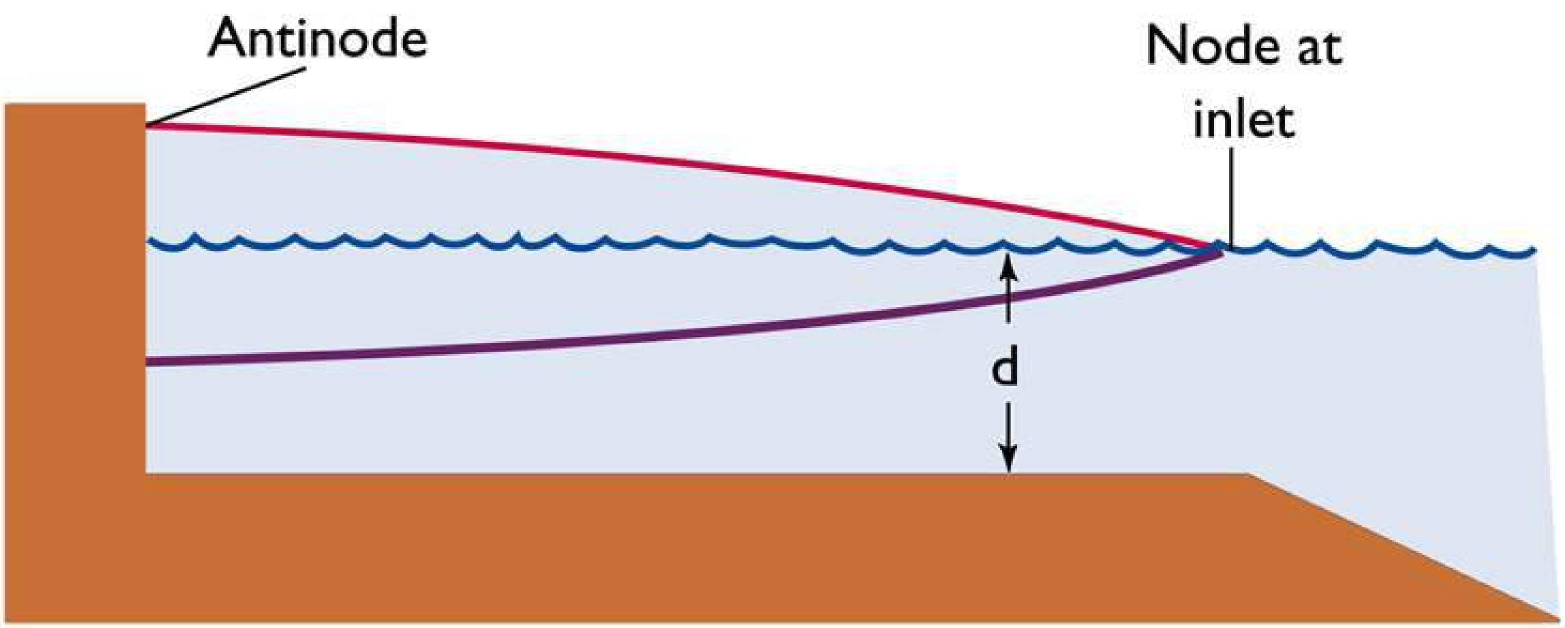
Standing Waves: Perjumlahan 2 gelombang yang sama tetapi berlawanan arah



Closed basins

- teacup
- lake
- ocean basin

$$T = \frac{2l}{\sqrt{gd}} \text{ sec}$$



Open basins

- estuary
- harbor

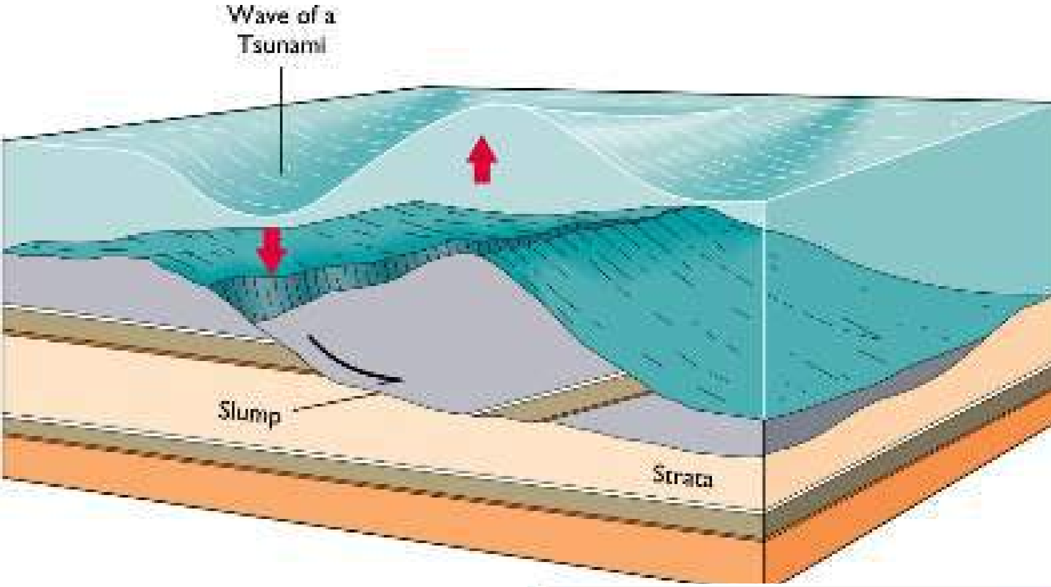
$$T = \frac{4l}{\sqrt{gd}} \text{ sec}$$

Natural standing wave (lake, harbor, estuary) ---- *seiche*

Tsunami

- Created by earthquakes, underwater landslides, meteorites -- cause a series of waves or wave train
- “Harbor wave” definitely not a “tidal wave”
- T = 15 min to 1 hour
- Wave length = 100s of km
- Speed of shallow water surface wave

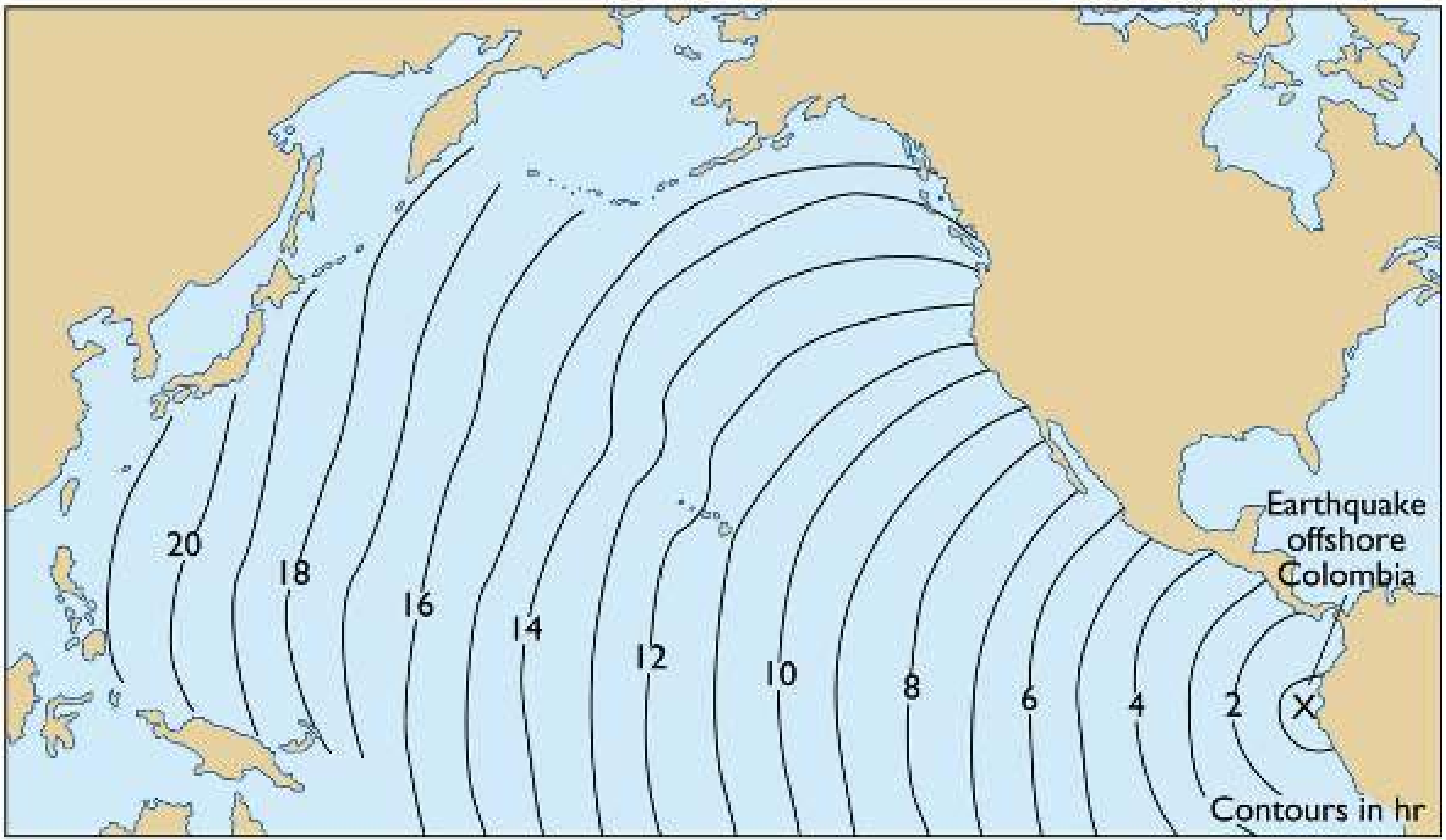
$$C = \sqrt{g \times d} = \sqrt{10 \times 4000} = 200 m/s$$



(a) GENERATION OF A TSUNAMI

[Tsunami in Papua New Guinea]

[1960 Chile Tsunami]



(b) REFRACTION PATTERN OF 1979 TSUNAMI

2004 Tsunami in the Indian Ocean

http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake

http://www.digitalglobe.com/tsunami_gallery.html

Terima Kasih