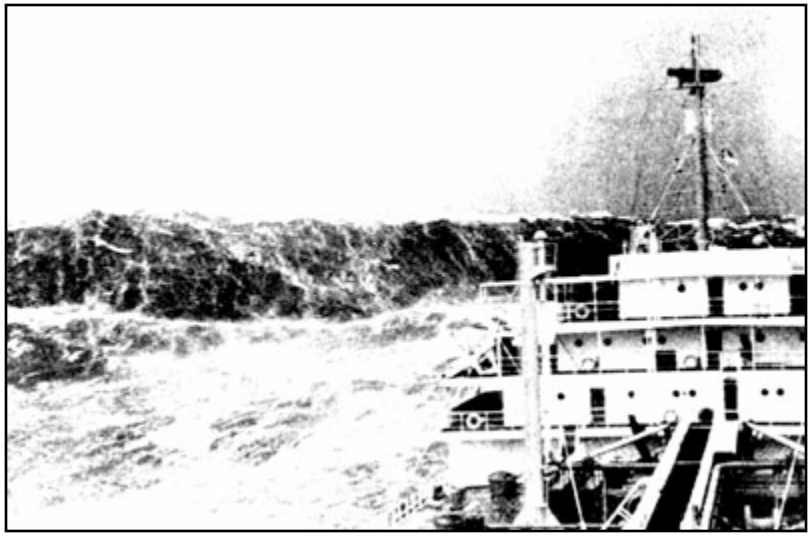
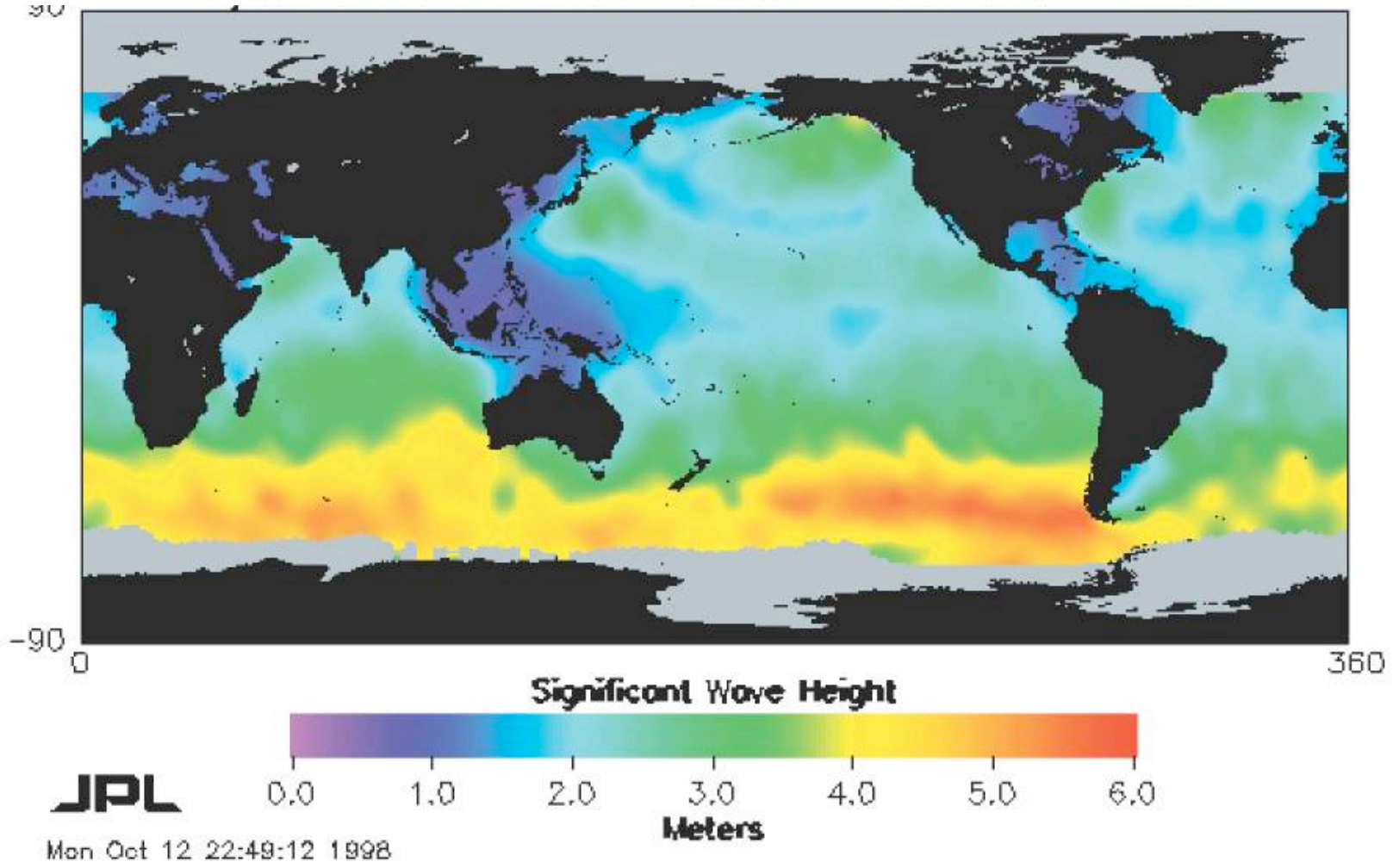
Ocean Waves



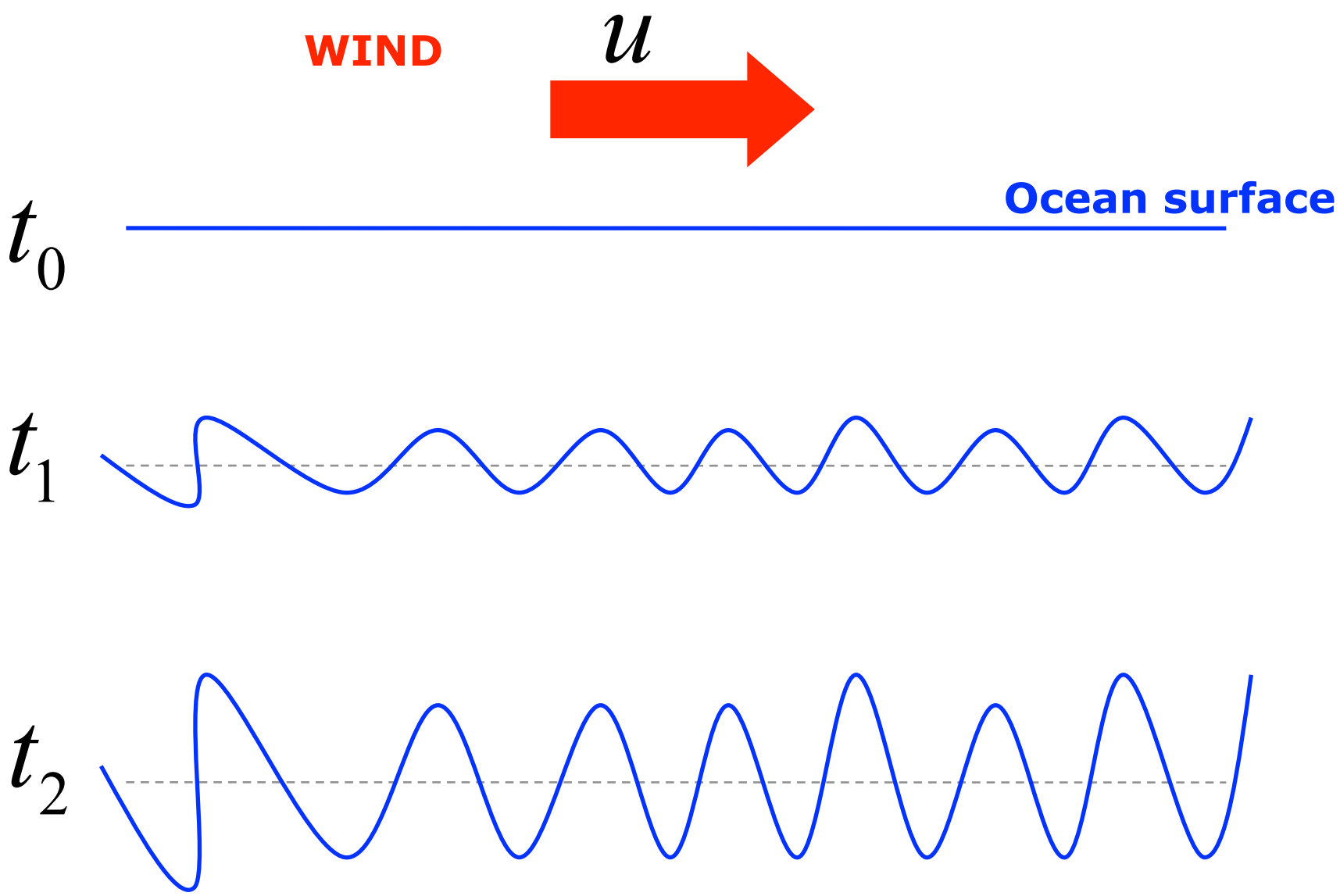
21 July 2004

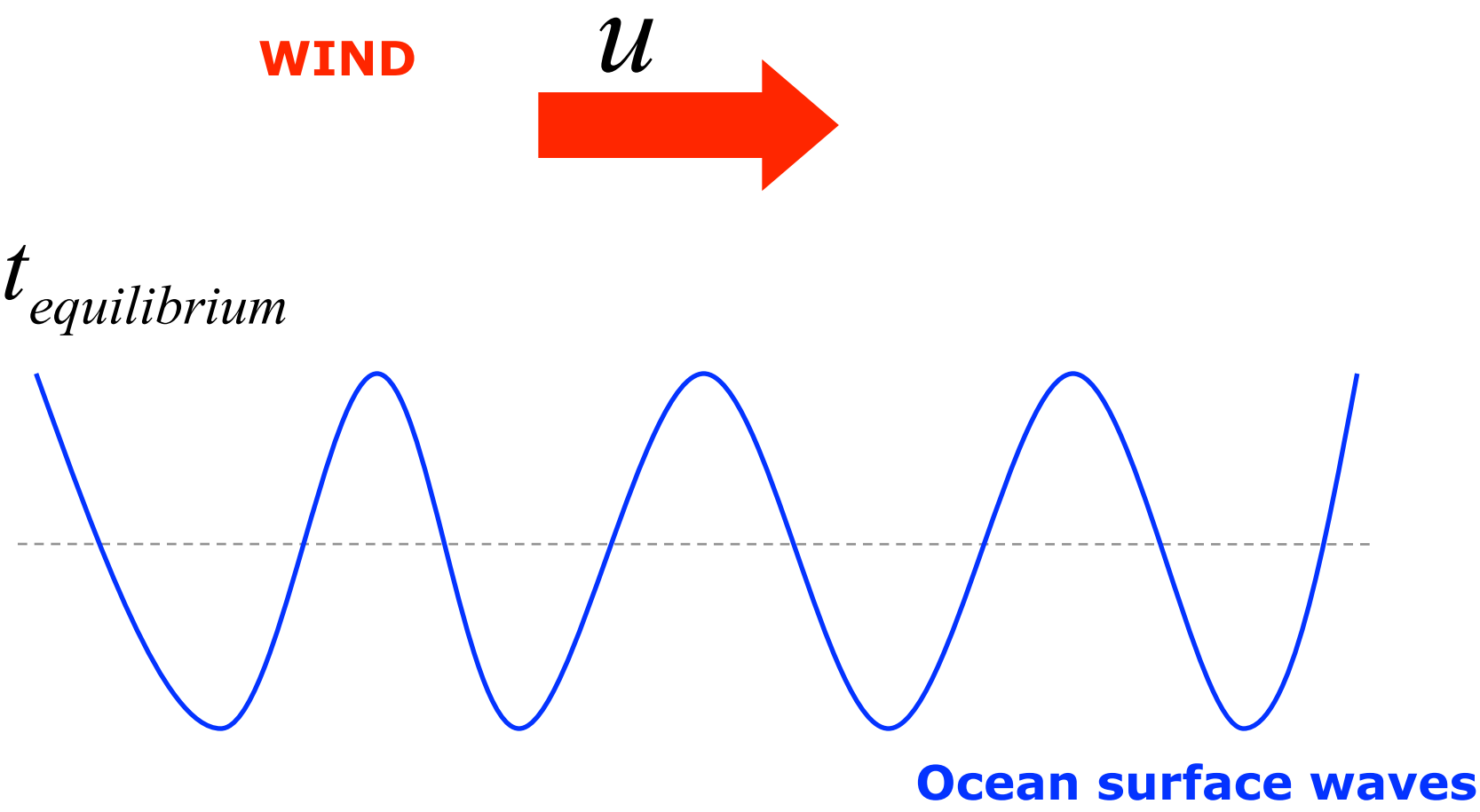
This rare photo of a **rogue wave** was taken by first mate Philippe Lijour aboard the supertanker Esso Languedoc, during a storm off Durban in South Africa in 1980. The mast seen starboard in the photo stands 25 metres above mean sea level. The wave approached the ship from behind before breaking over the deck, but in this case caused only minor damage. The mean wave height at the time was between 5-10 metres.

Significant Wave Height



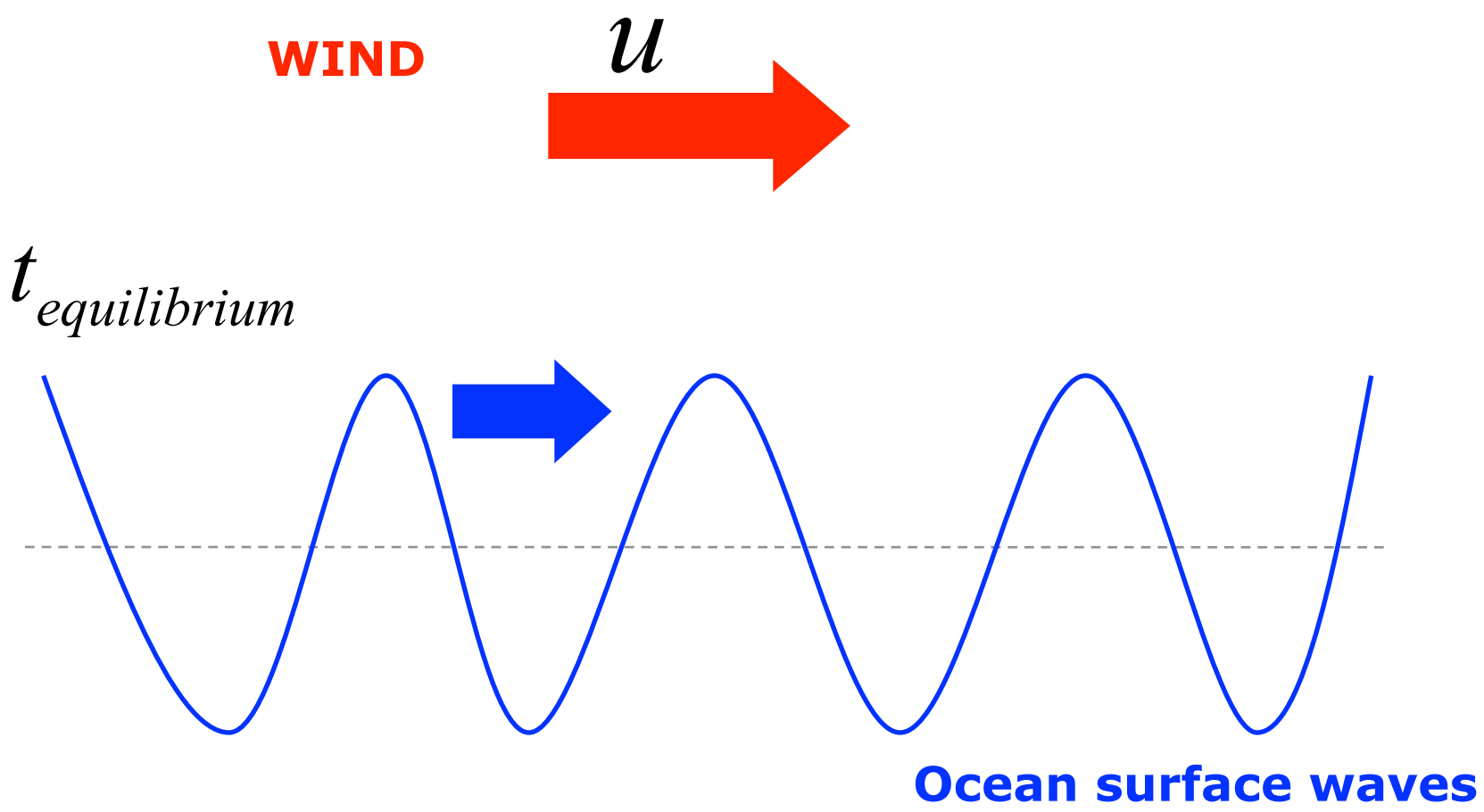
What generates these high waves in the ocean?


WIND
u
Ocean surface
t_0
t_1
t_2



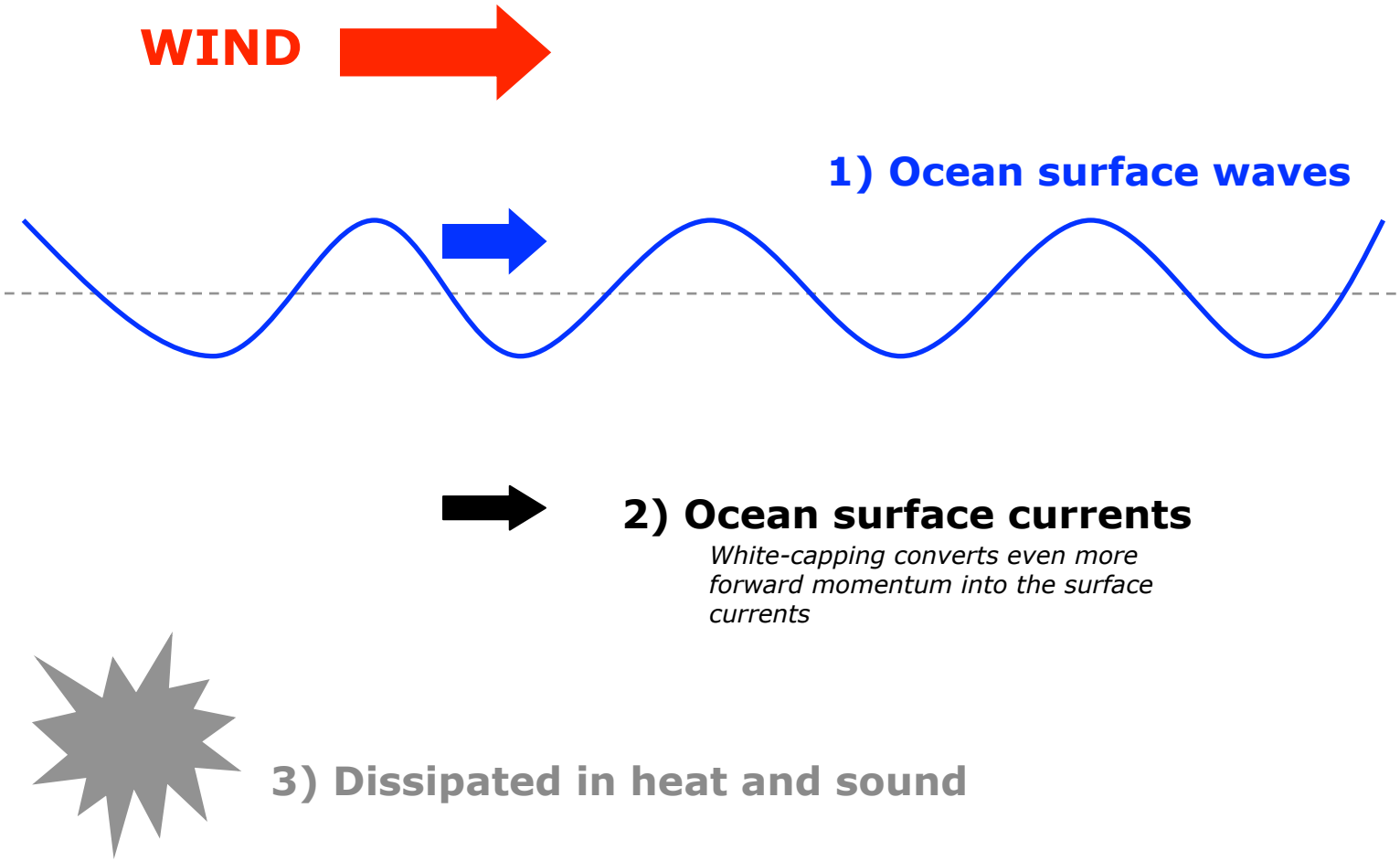
Fully developed sea

Energy input from winds = Energy dissipated by waves

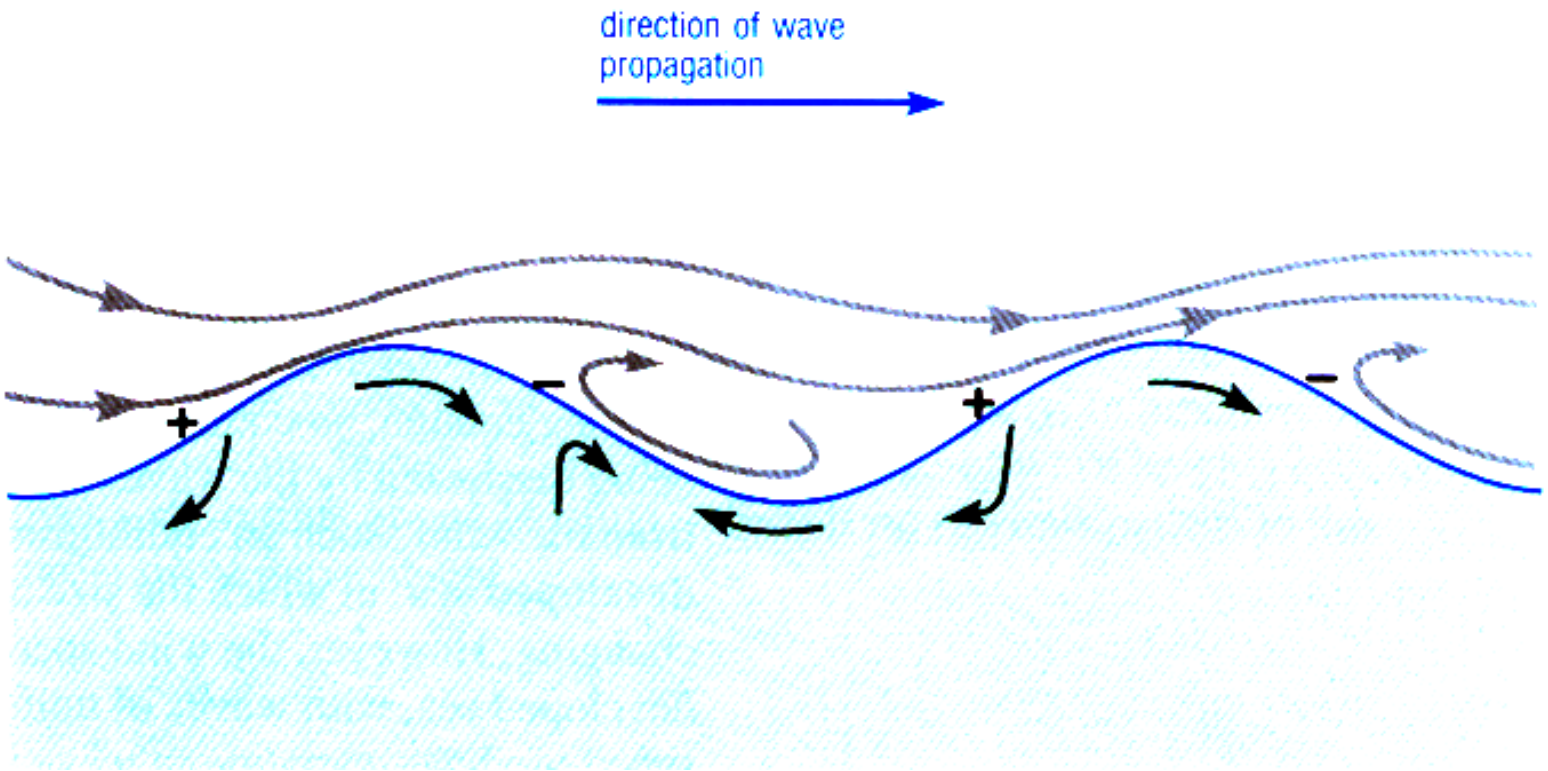


The wave speed never reaches the wind speed.

Where does the energy of the winds go?



Model for Wave generation



Jeffreys' Sheltering model

What are the properties of a wave?

What are the properties of a wave?

1) A wave transfers a disturbance from one part of the material to another.

What are the properties of a wave?

1) A wave transfers a disturbance from one part of the material to another.

2) The disturbance is propagated through the material without any substantial overall motion of the material itself.

What are the properties of a wave?

1) A wave transfers a disturbance from one part of the material to another.

2) The disturbance is propagated through the material without any substantial overall motion of the material itself.

3) The disturbance is propagated without any substantial distortion of the wave form (shape of the wave).

What are the properties of a wave?

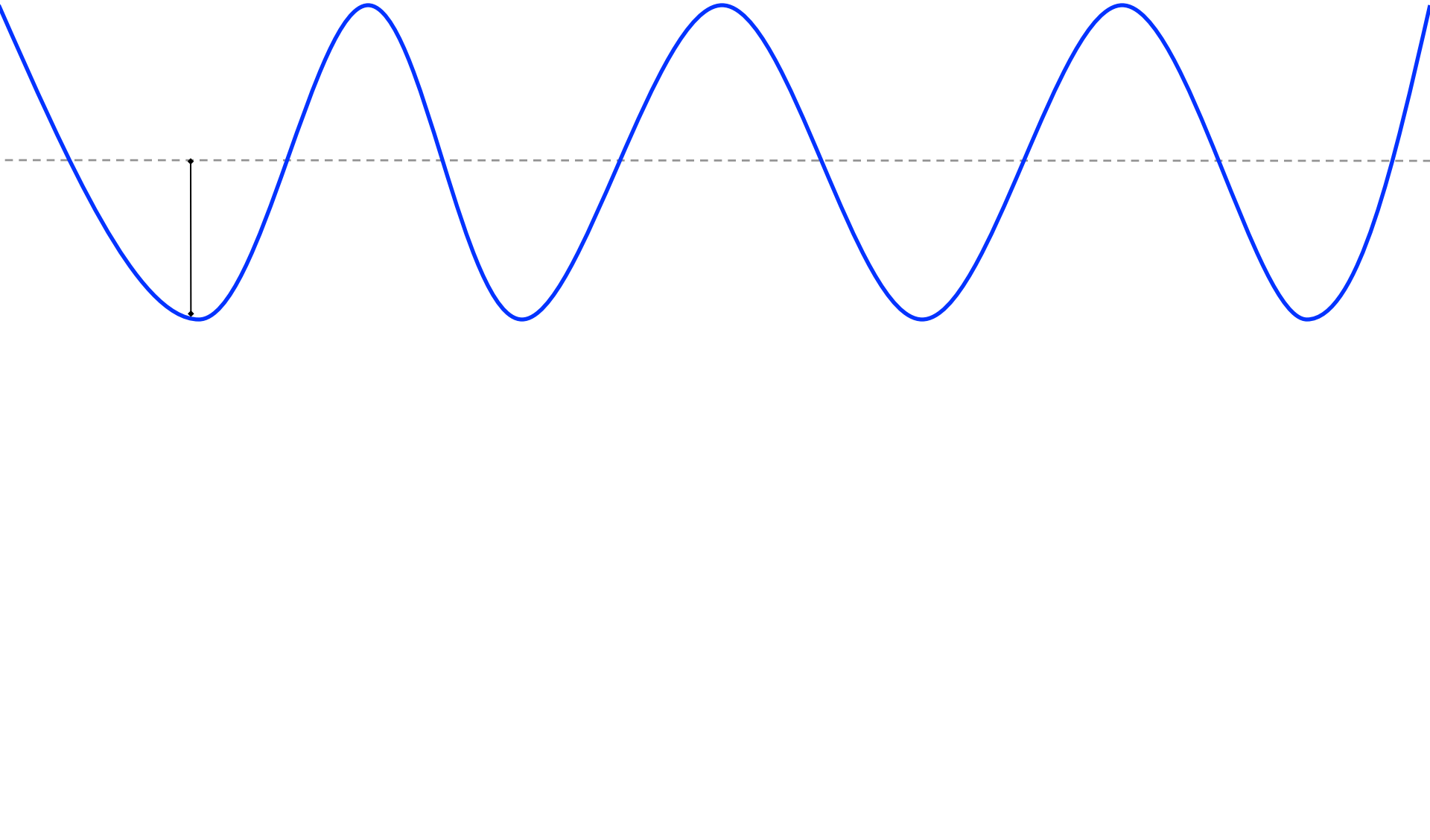
1) A wave transfers a disturbance from one part of the material to another.

2) The disturbance is propagated through the material without any substantial overall motion of the material itself.

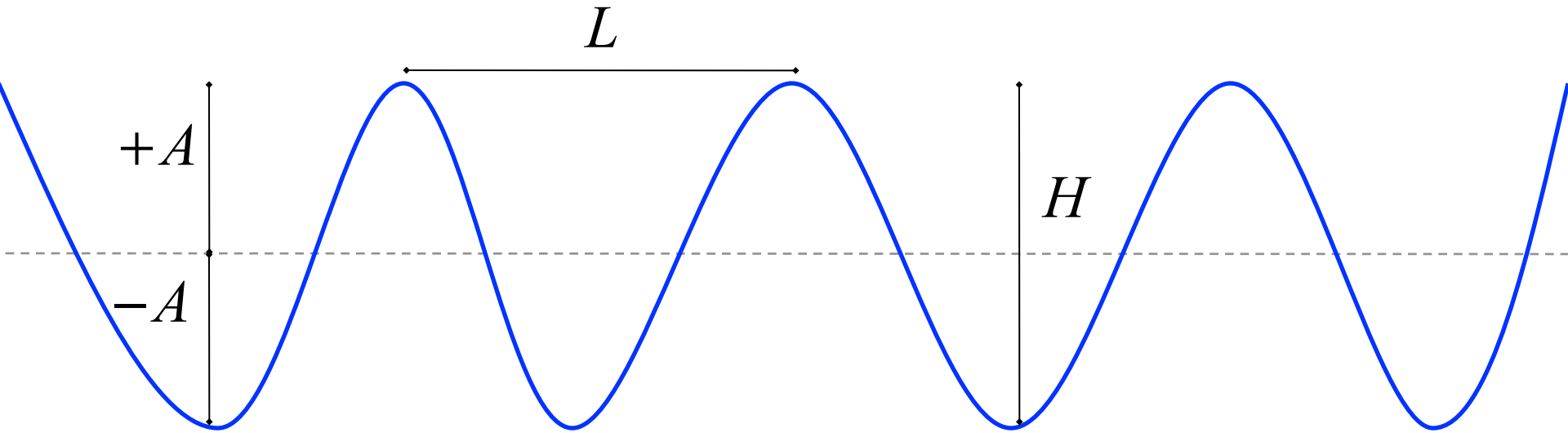
3) The disturbance is propagated without any substantial distortion of the wave form (shape of the wave).

4) The disturbance appears to be propagated with constant speed.

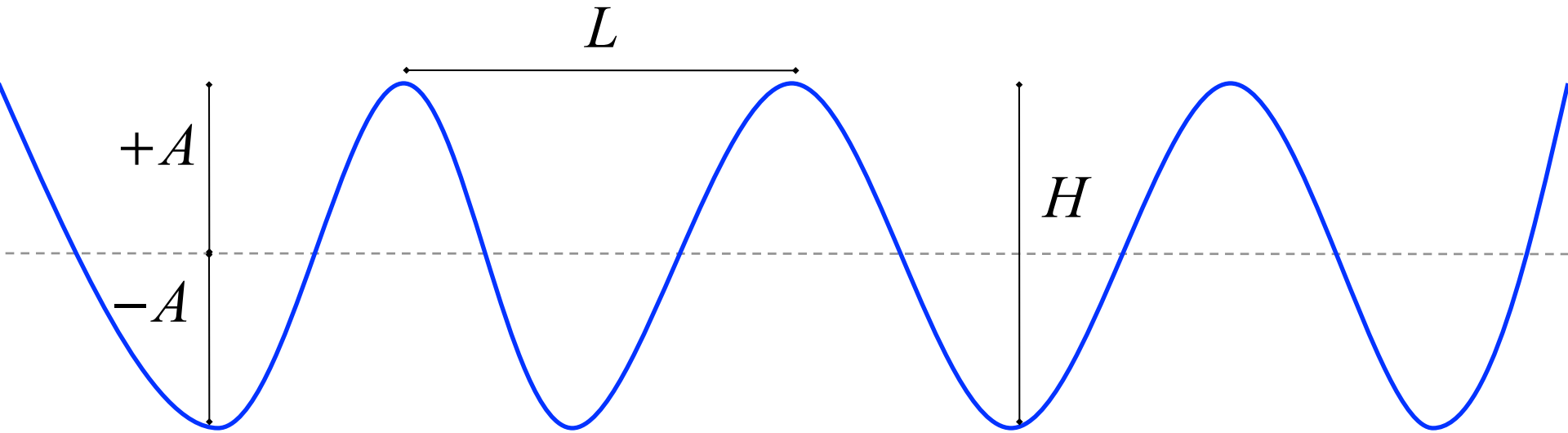
Ocean Surface Wave



Ocean Surface Wave

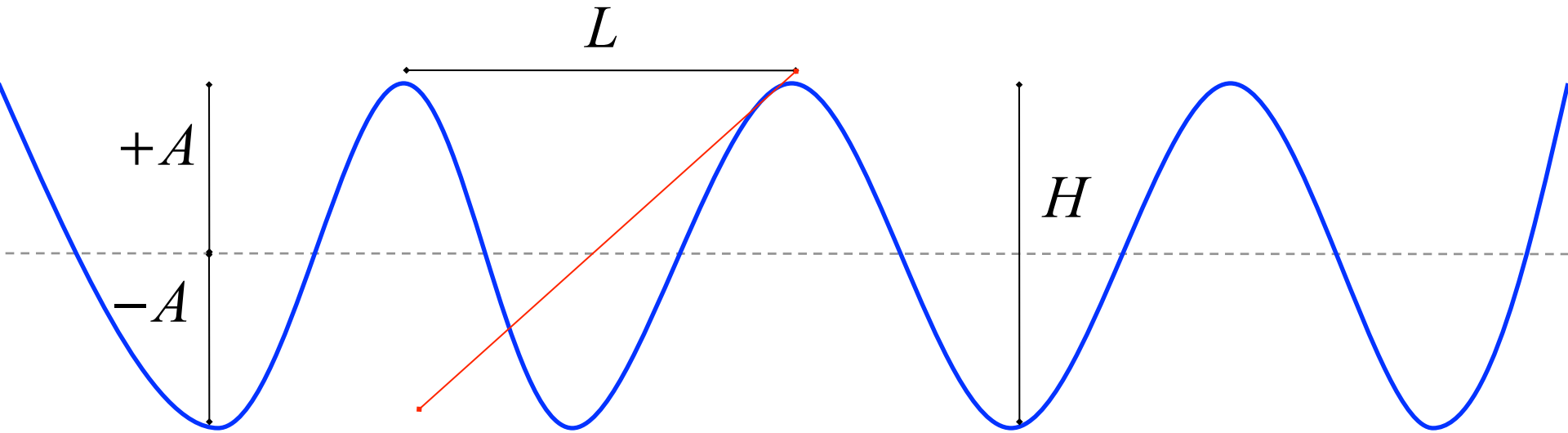


Ocean Surface Wave



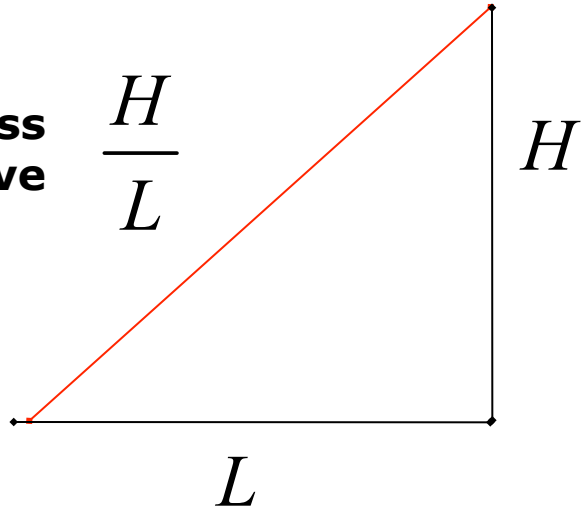
Definitions:

Ocean Surface Wave

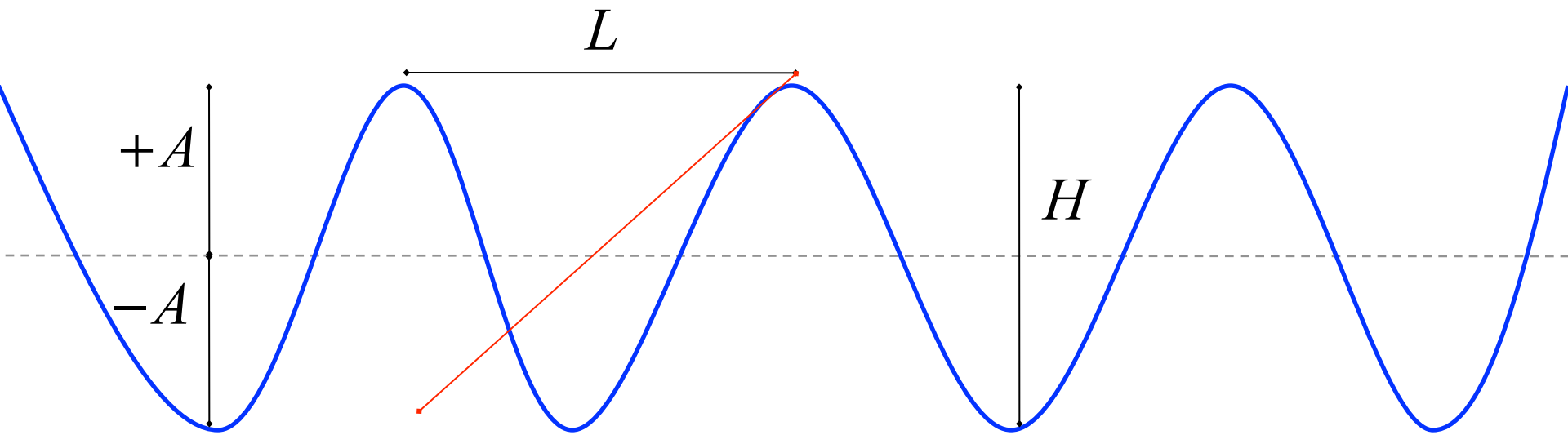


Definitions:

Steepness of the wave $\frac{H}{L}$



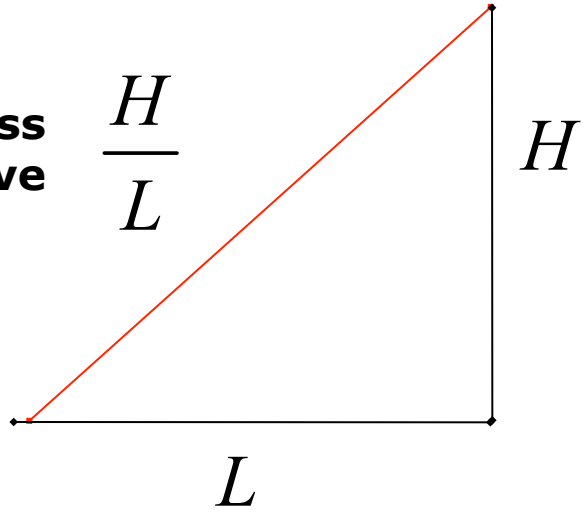
Ocean Surface Wave



Definitions:

Steepness of the wave

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



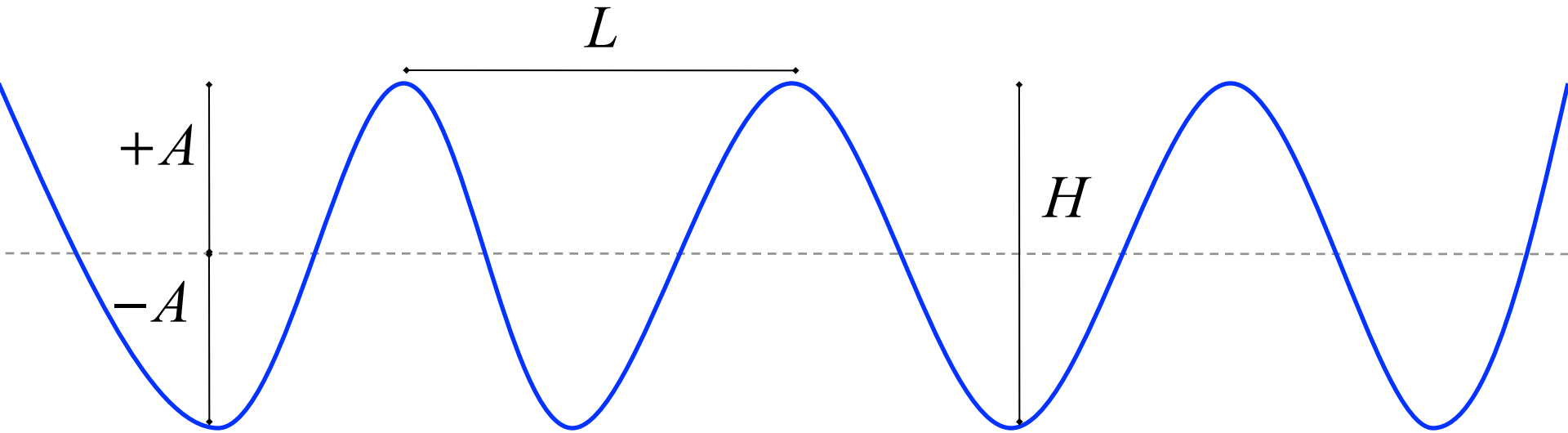
Wave number

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

Frequency

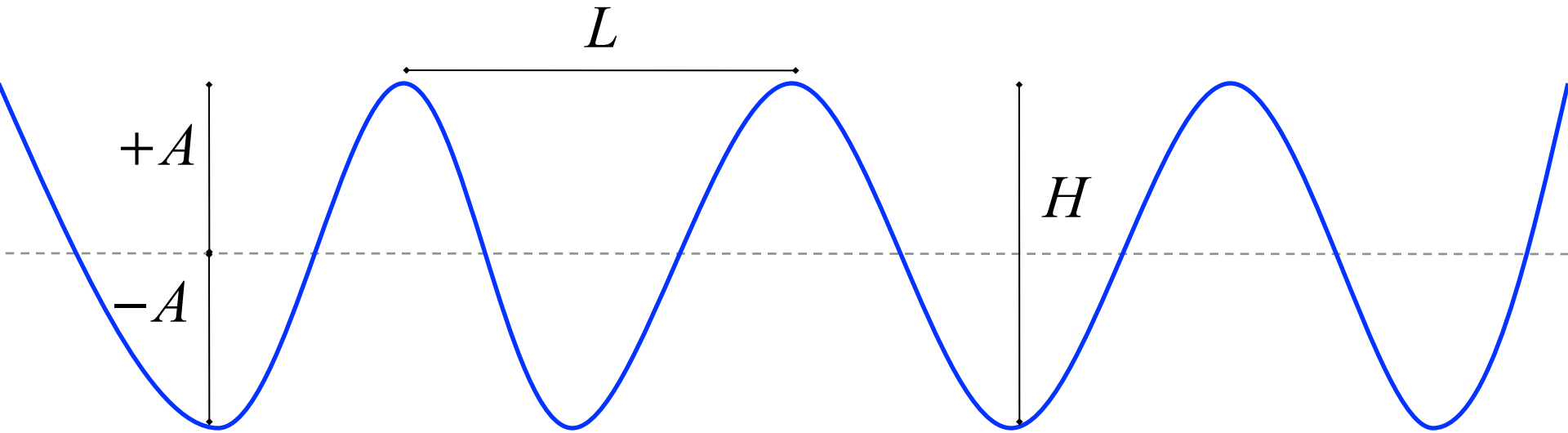
$$\omega = \frac{\text{number of peaks}}{\text{time}}$$

Ocean Surface Wave



Other definitions:

Ocean Surface Wave

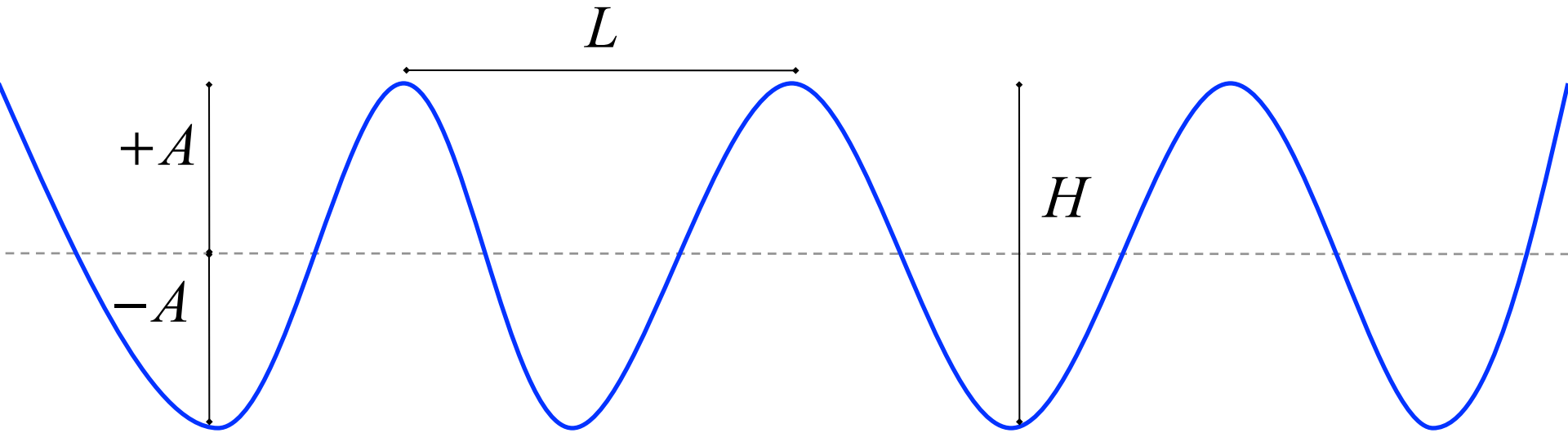


Other definitions:

The energy of the wave

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

Ocean Surface Wave



Other definitions:

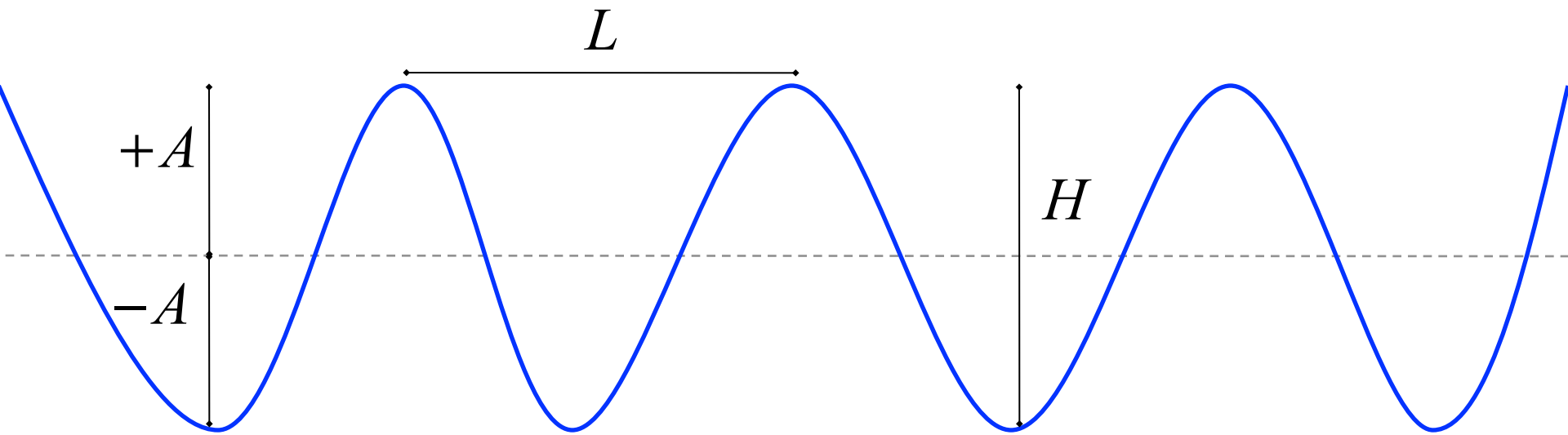
The energy of the wave

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

Progressive Wave

if moves energy through the water

Ocean Surface Wave



Other definitions:

The energy of the wave

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

Progressive Wave

if moves energy through the water

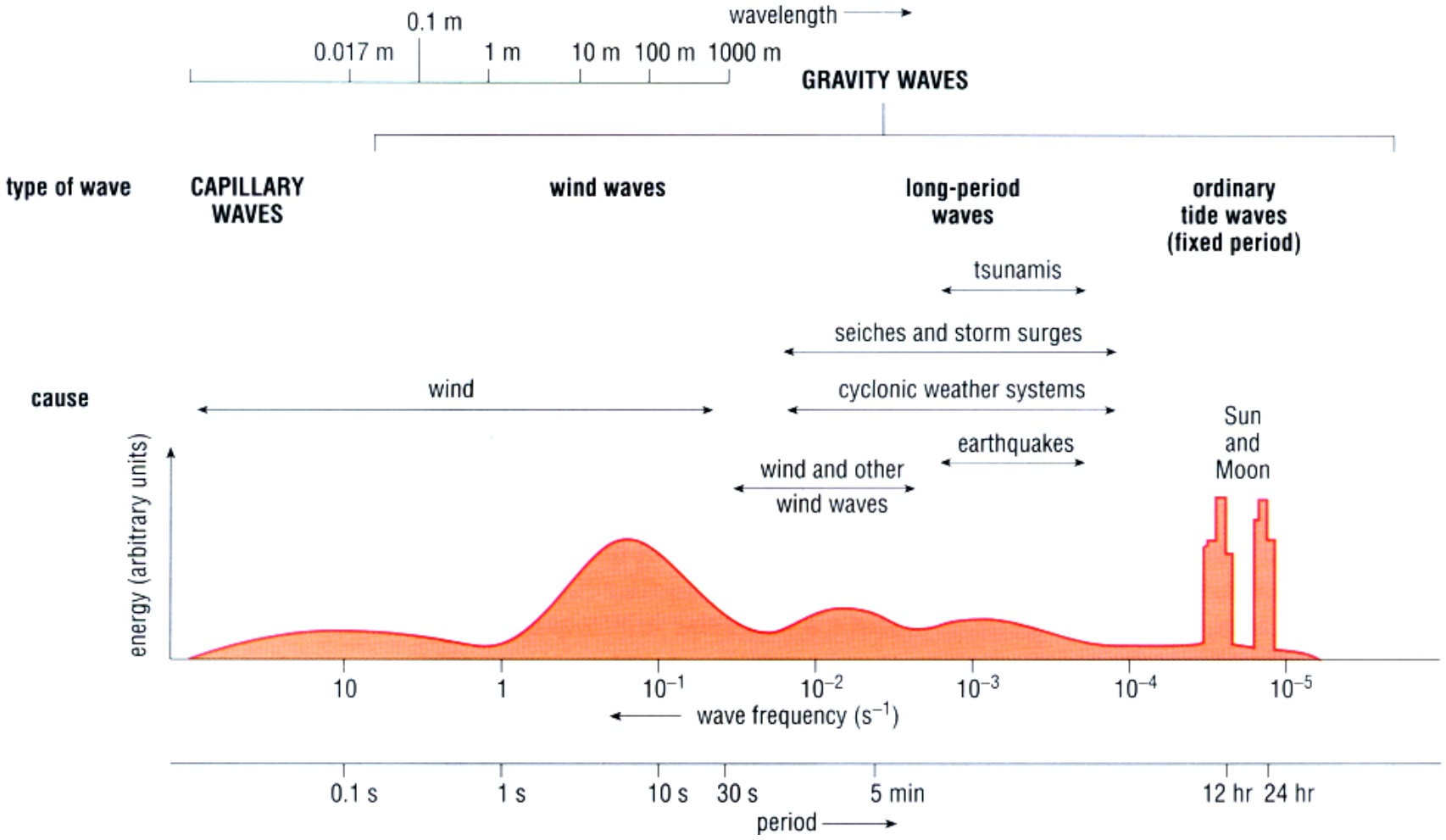
Ocean Surface Wave

exist because of 2 restoring forces

gravity

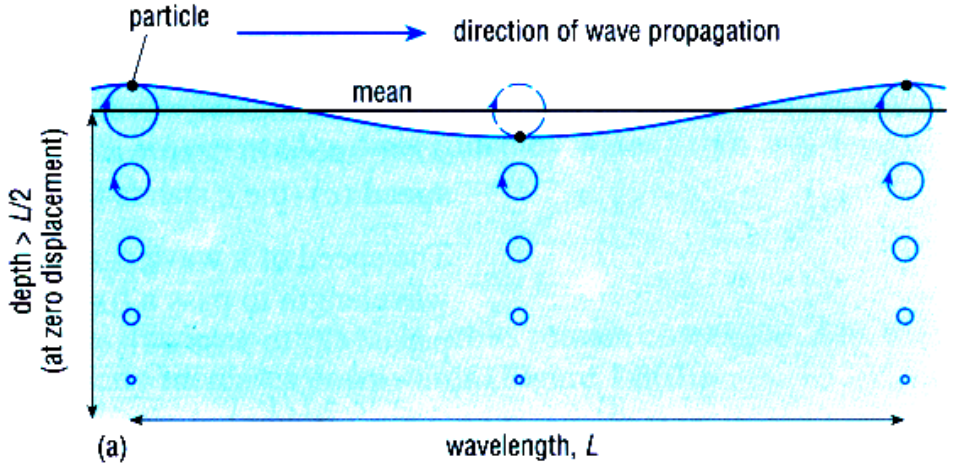
surface tension

Some Type of Waves in the Ocean

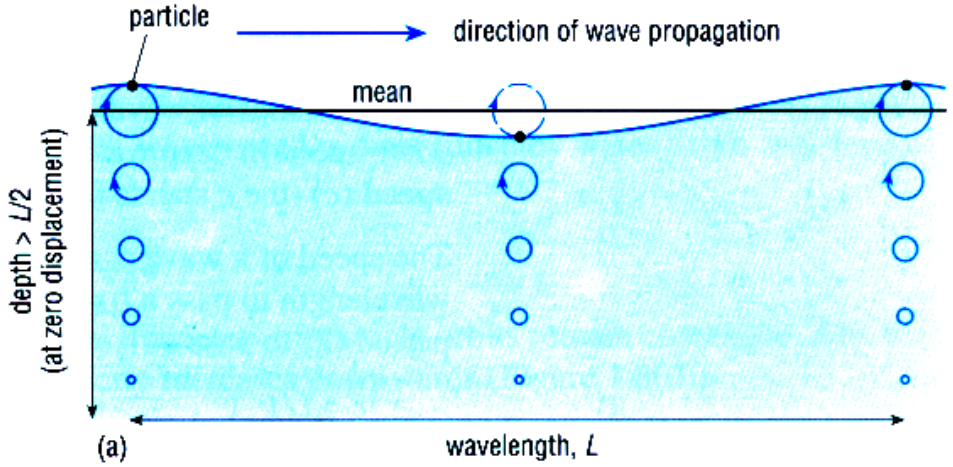


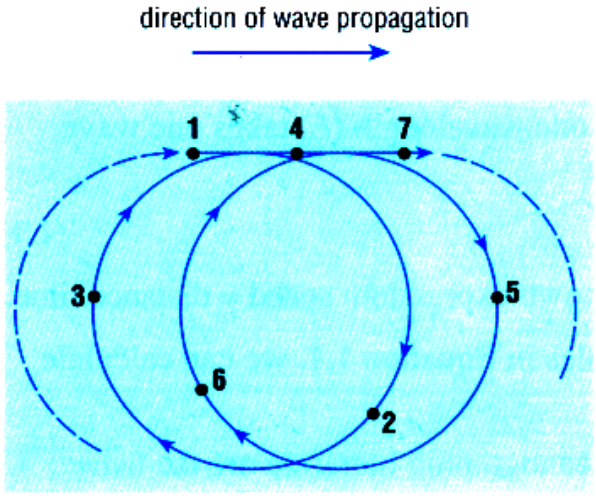
Waves travel through the material (water) without overall forward movement of particles

Waves travel through the material (water) without overall forward movement of particles



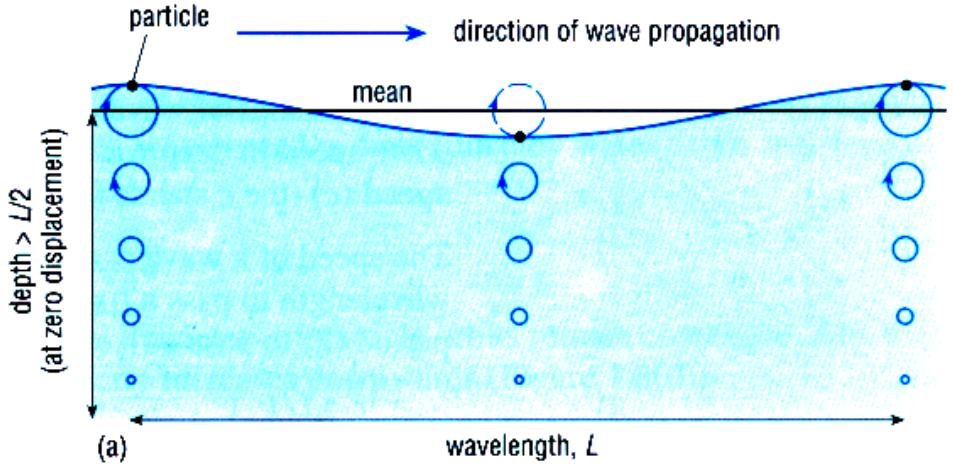
Waves travel through the material (water) without overall forward movement of particles



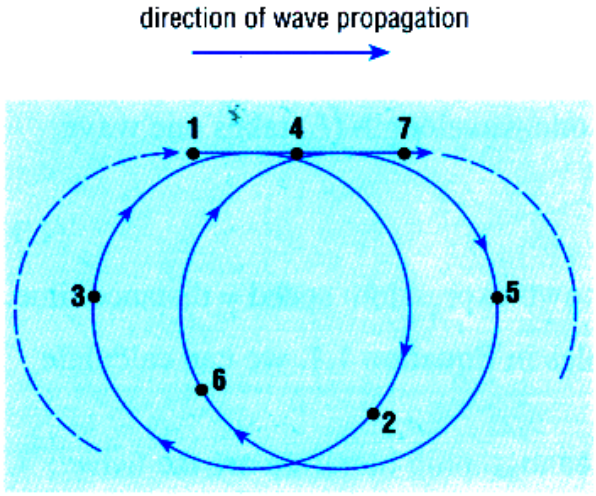


Waves travel through the material (water) without overall forward movement of particles

a) However particles move under the action of the wave

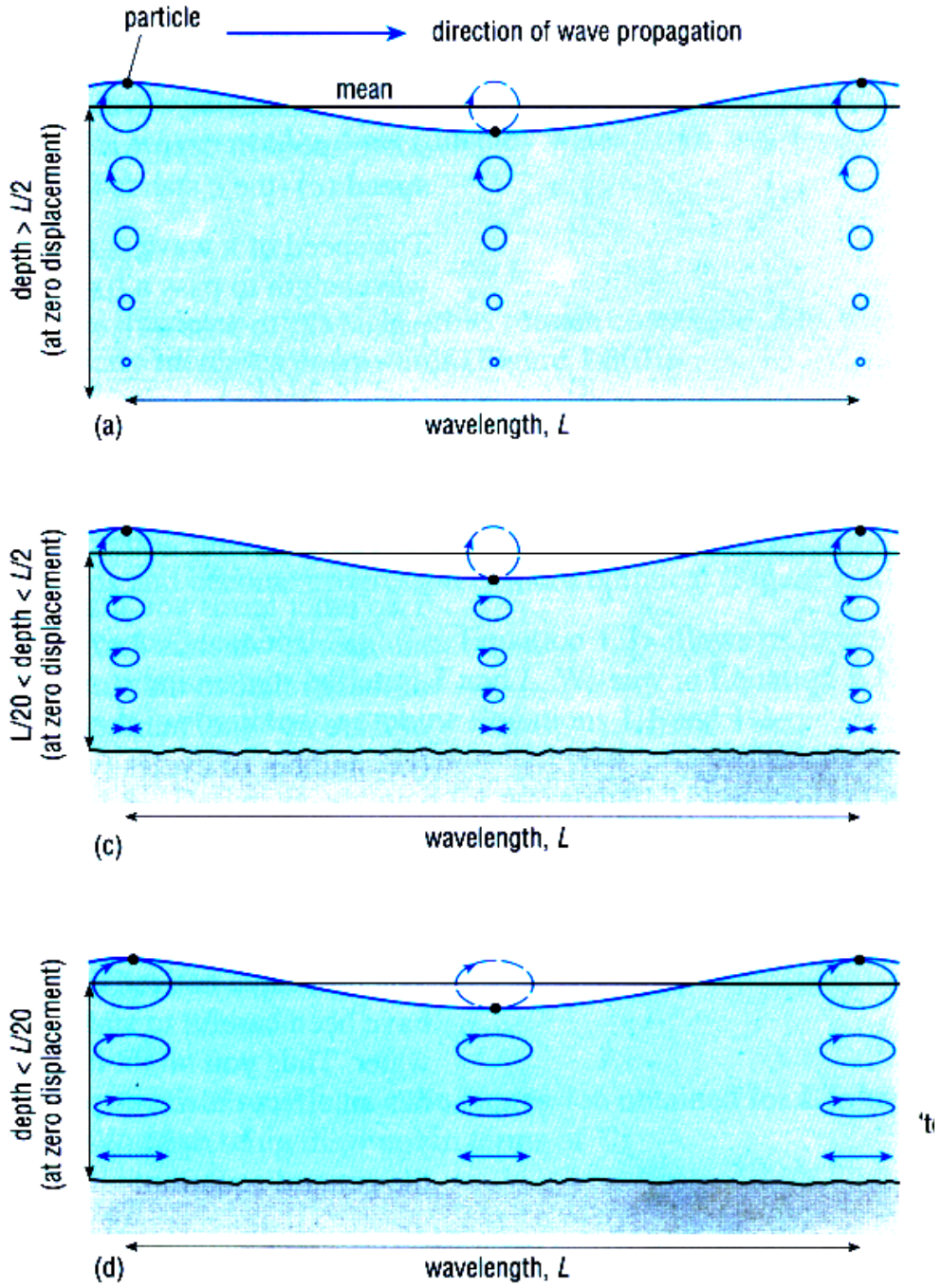


b) And there is a small forward drift of the particle **(the drift can be more or less strong depending on the type of the wave)**



The particle orbit are not always circles !

The particle orbit are not always circles !

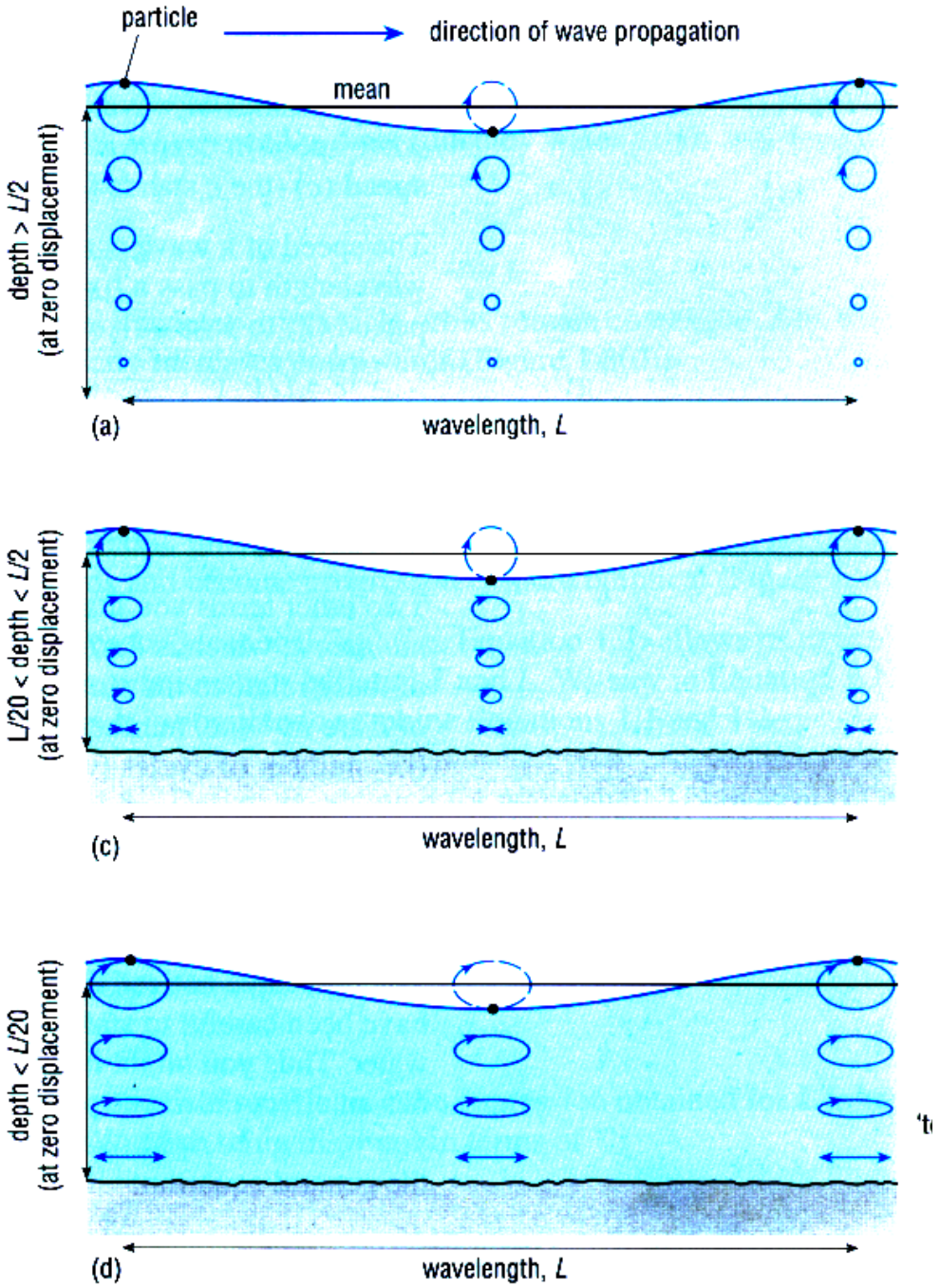


The particle orbit are not always circles !

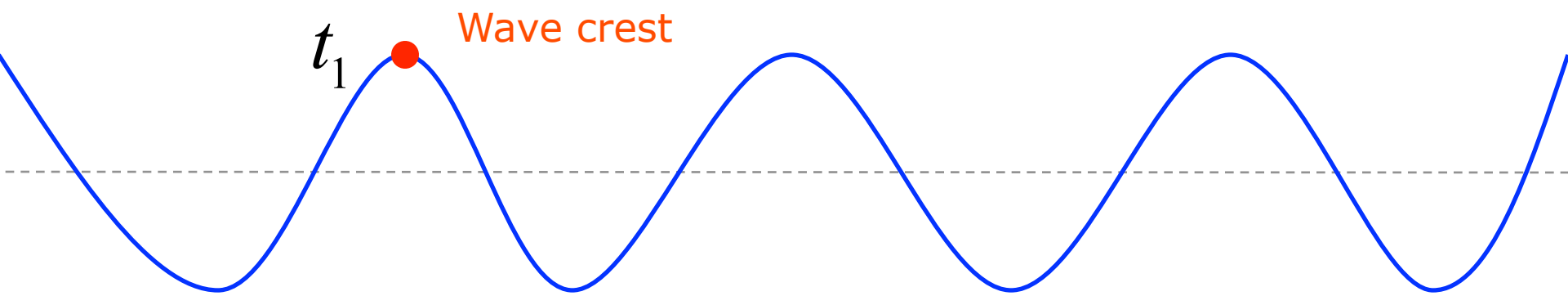
DEEP OCEAN

Intermediate depth

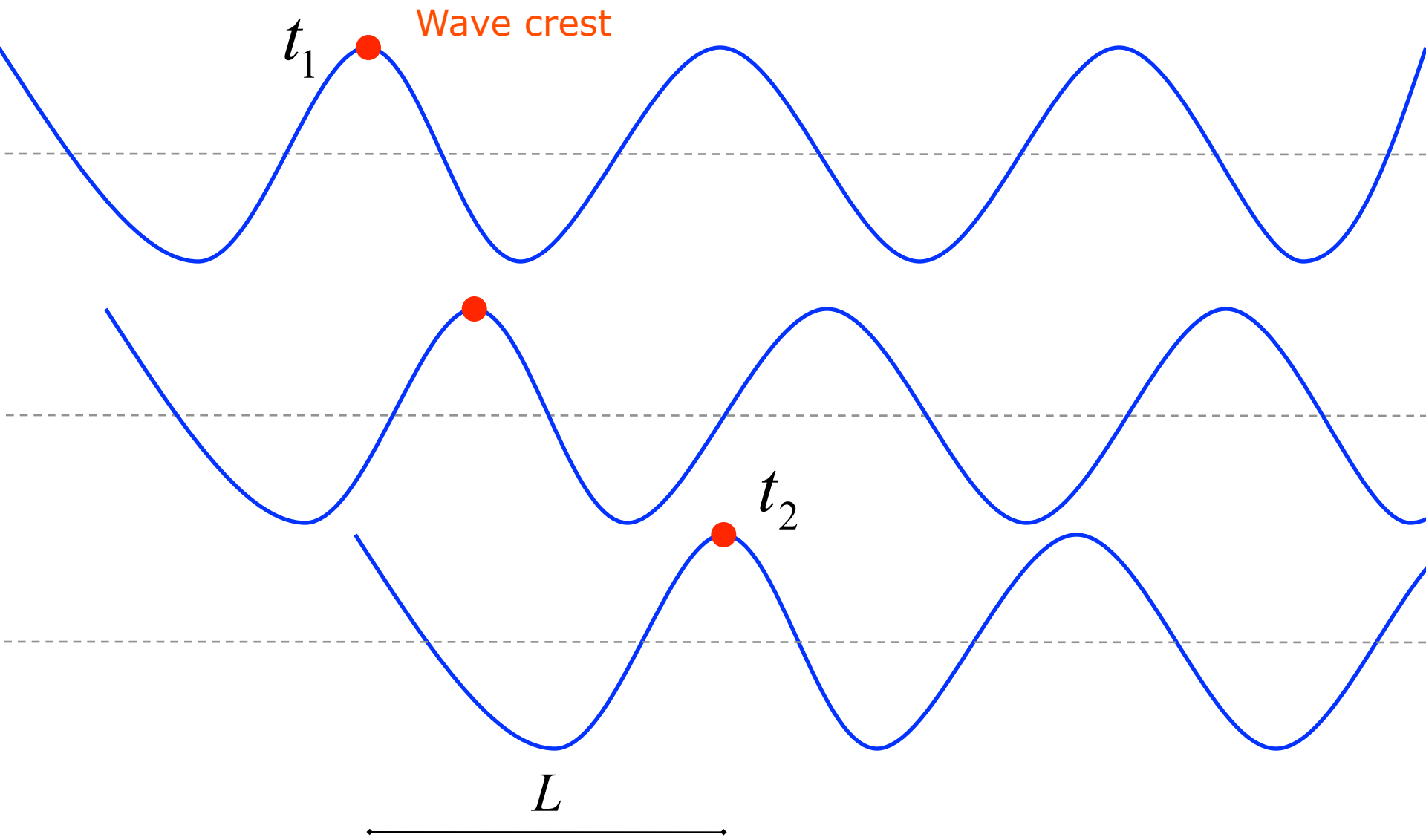
SHALLOW WATERS



Wave Speed

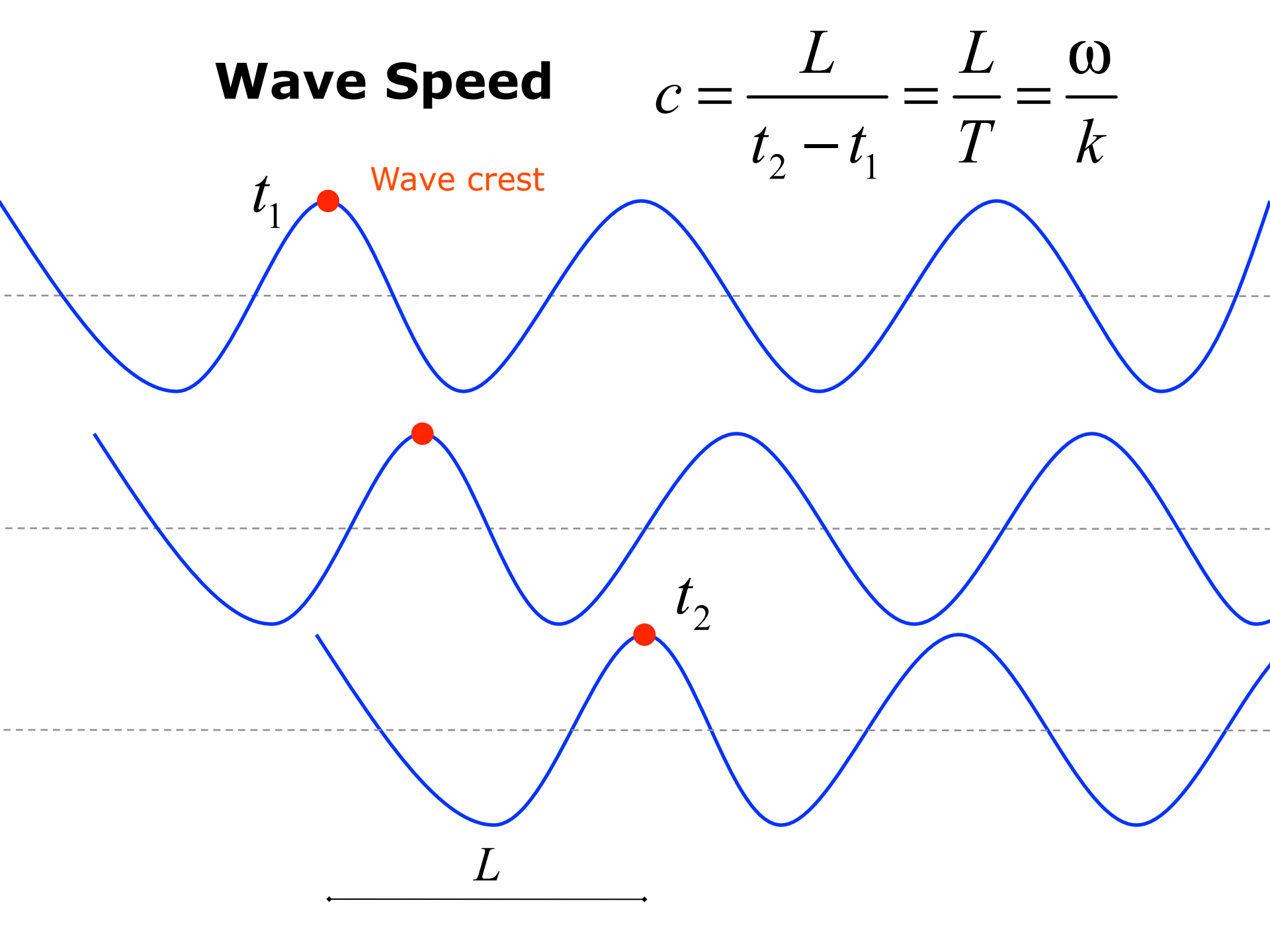


Wave Speed



Wave Speed

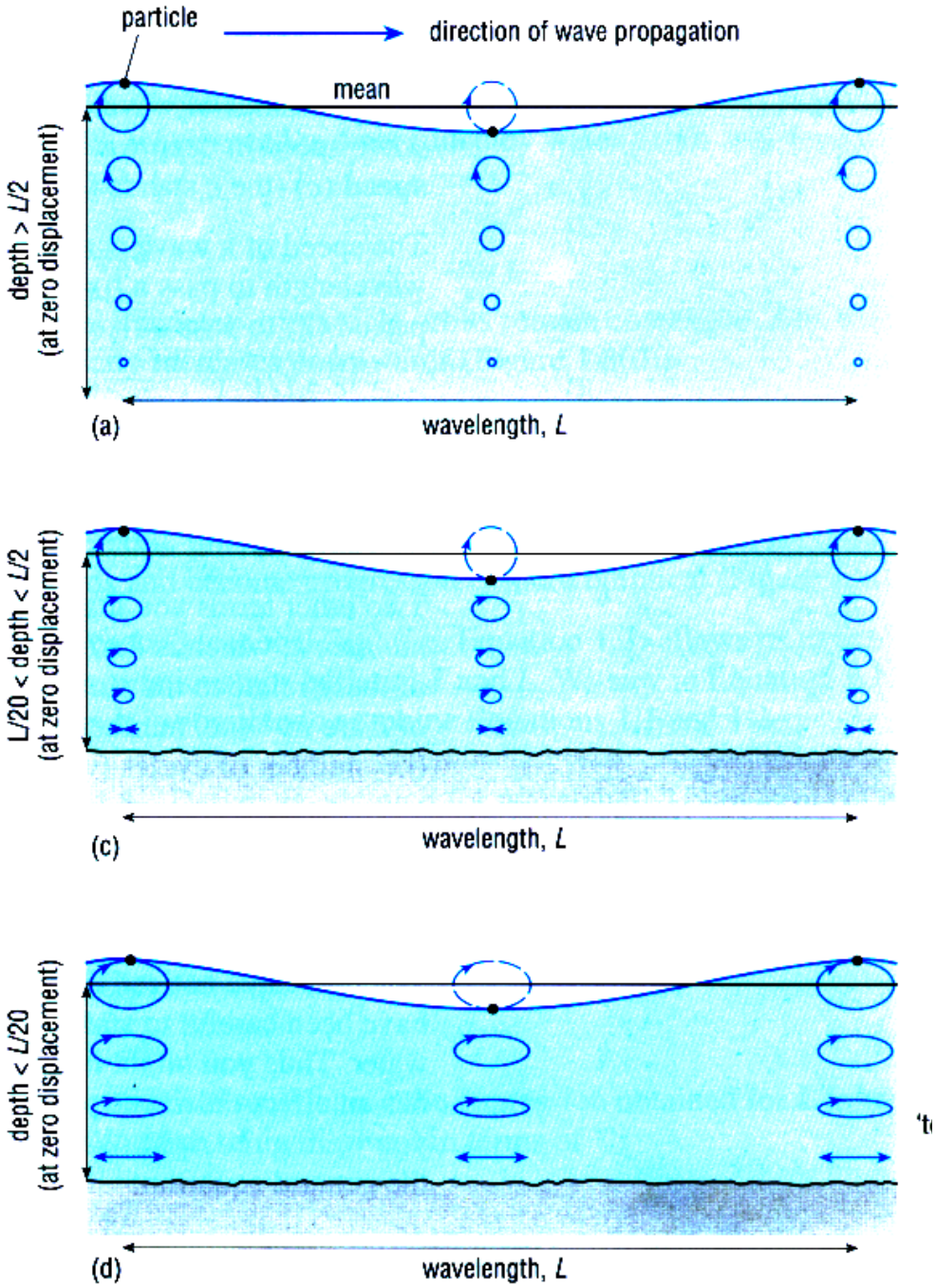
$$c = \frac{L}{t_2 - t_1} = \frac{L}{T} = \frac{\omega}{k}$$



$\frac{d}{L} >> 1$ **DEEP OCEAN**

Intermediate depth

$\frac{d}{L} << 1$ **SHALLOW WATERS**



Two limits in wave speed

$\frac{d}{L} >> 1$ **DEEP OCEAN**

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

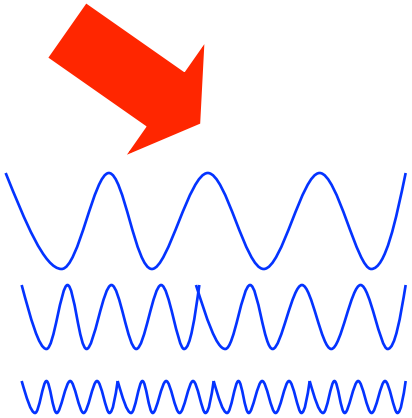
Depends on wavelength

$\frac{d}{L} << 1$ **SHALLOW WATERS**

$$c = \sqrt{gd}$$

InDependent of wavelength

Big STORM

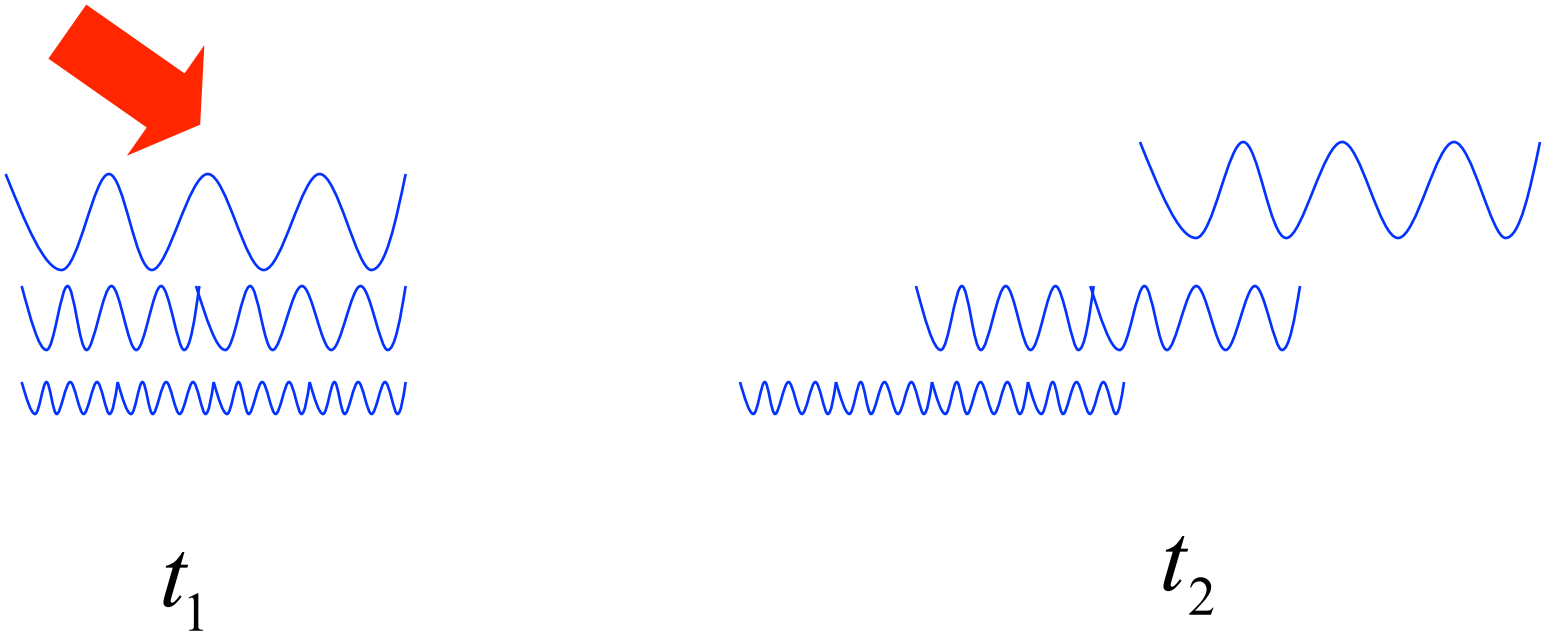


t_1

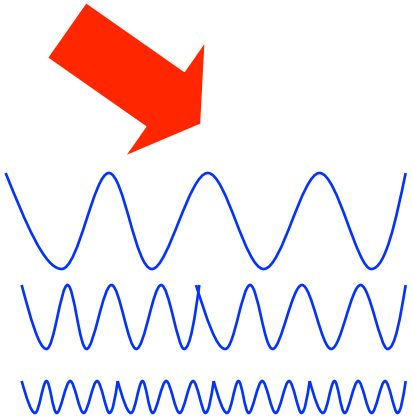
OPEN OCEAN ⟶ **COAST** ⟶

distance from STORM

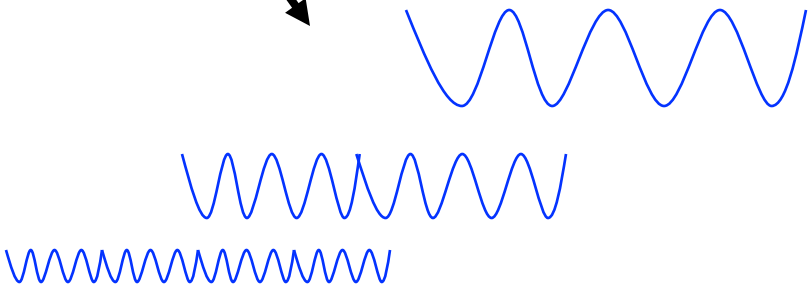
Big STORM



Big STORM



These waves are said to be dispersive



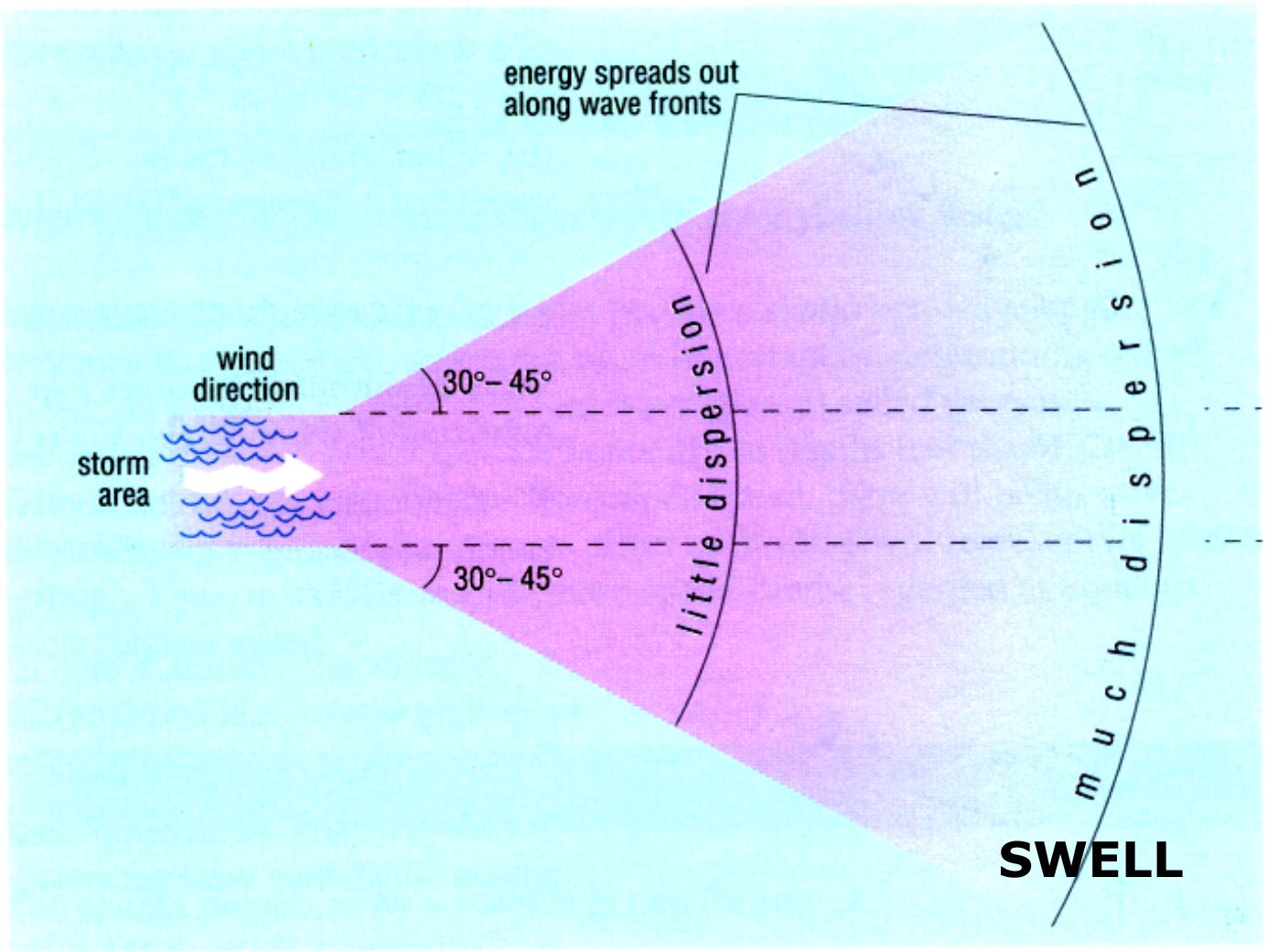
t_1

t_2

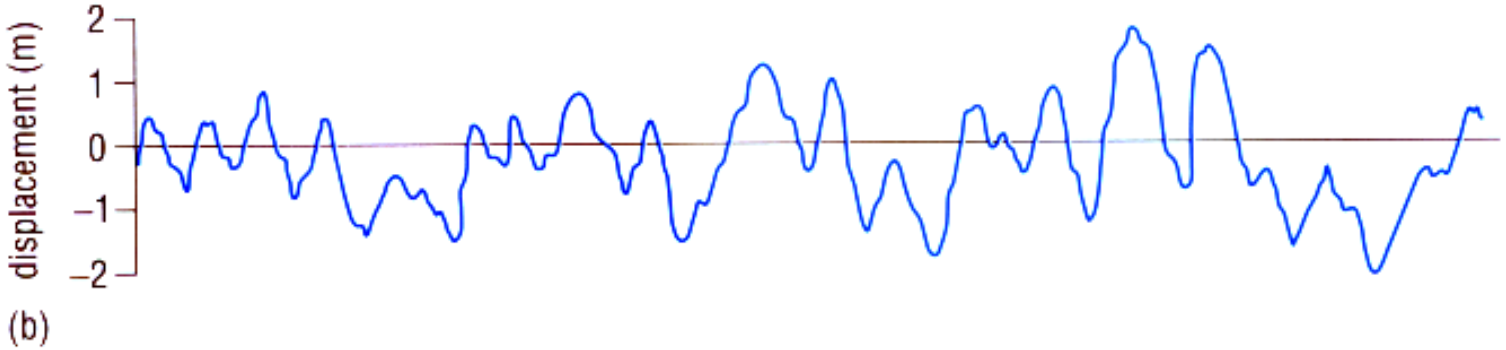
OPEN OCEAN → **COAST** →

distance from STORM

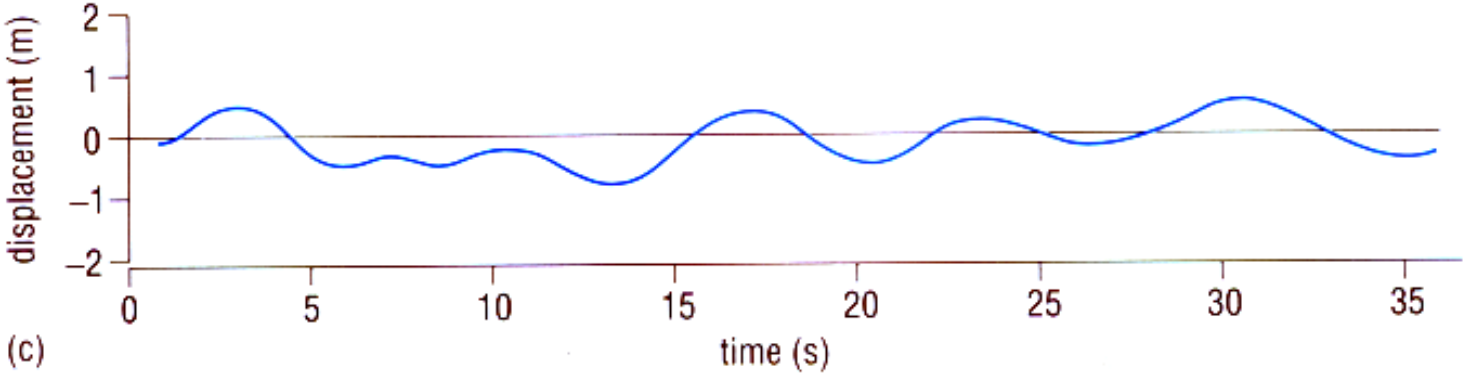
Effects of Wave Dispersion (in deep water)



(b)

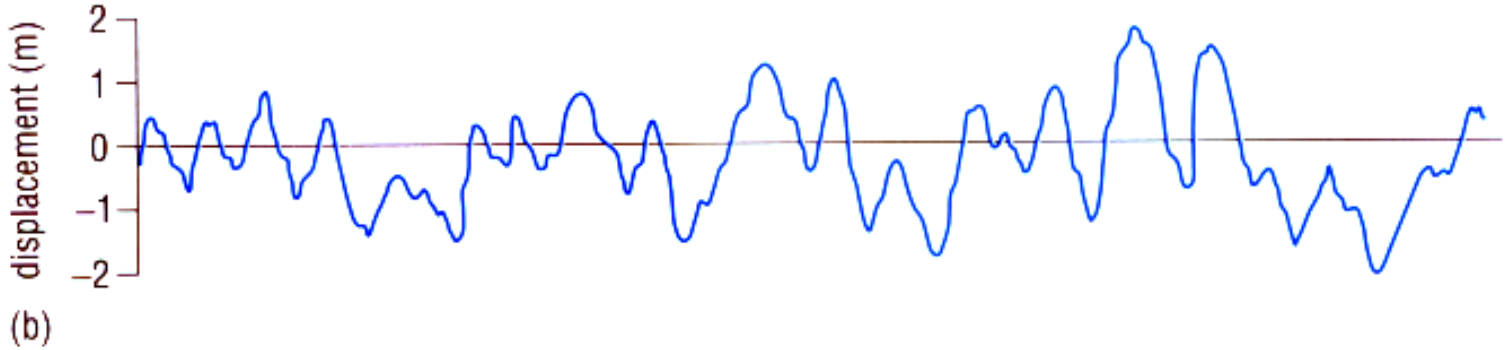

displacement (m)
2
1
0
−1
−2
(b)

(c)


displacement (m)
2
1
0
−1
−2
0
5
10
15
20
25
30
35
time (s)
(c)

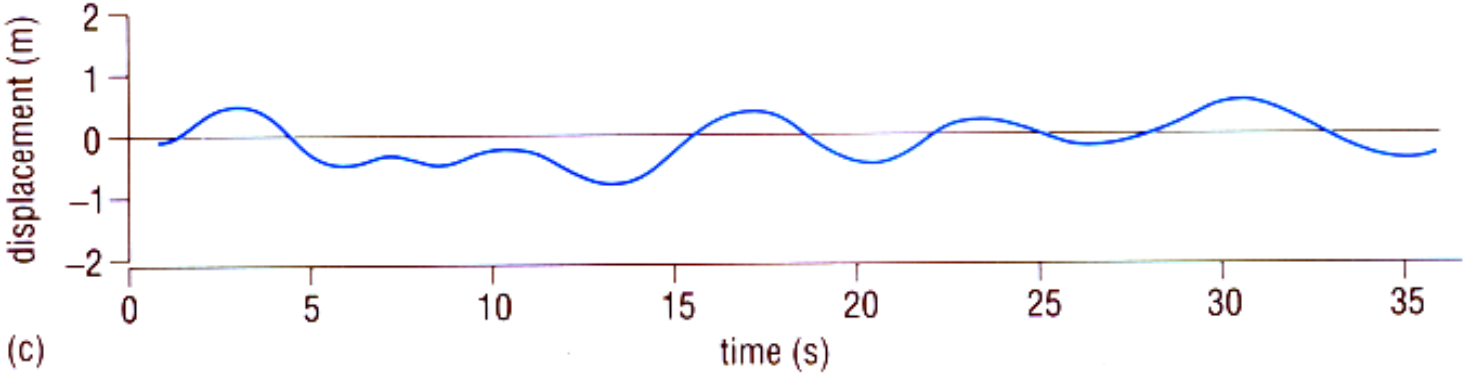
STORM

(b)

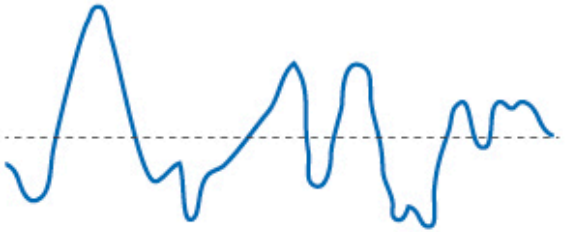


SWELL

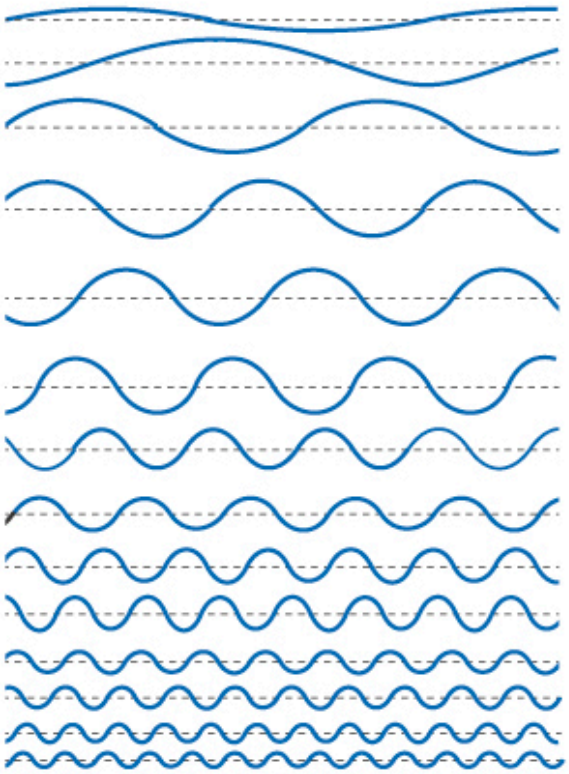
(c)



Analysis of Waves and their interference

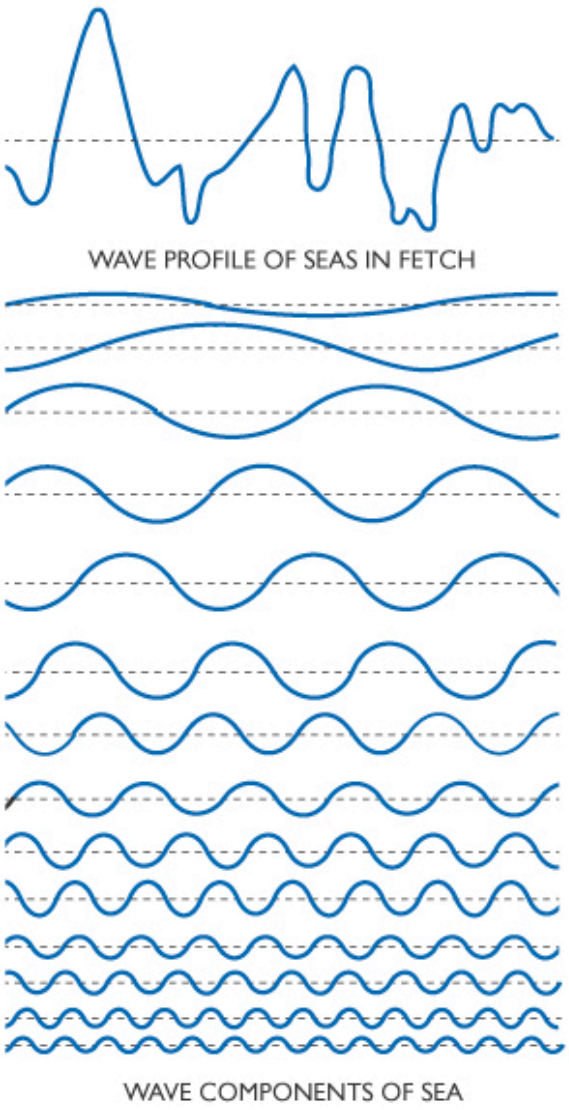


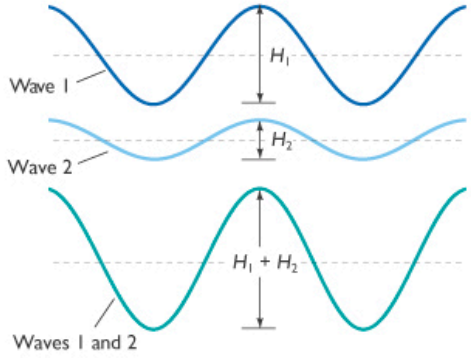
WAVE PROFILE OF SEAS IN FETCH



WAVE COMPONENTS OF SEA

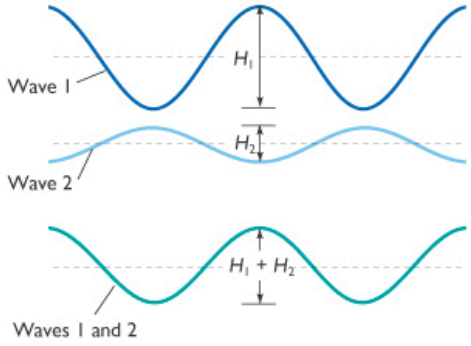
Analysis of Waves and their interference





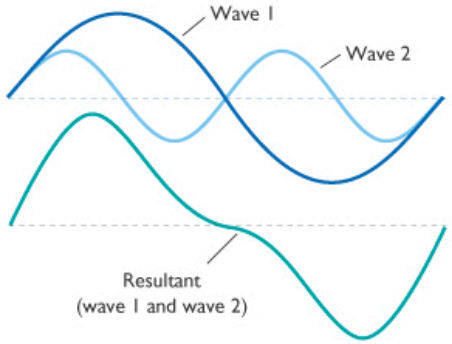
(b) CONSTRUCTIVE WAVE INTERFERENCE

Constructive



(c) DESTRUCTIVE WAVE INTERFERENCE

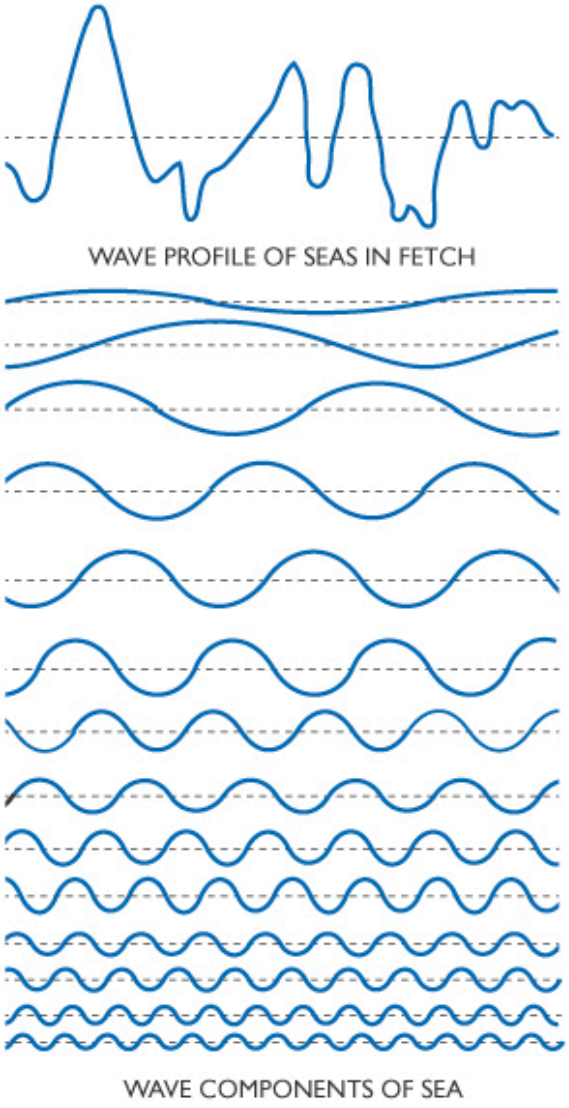
Destructive



(d) COMPLEX WAVE INTERFERENCE

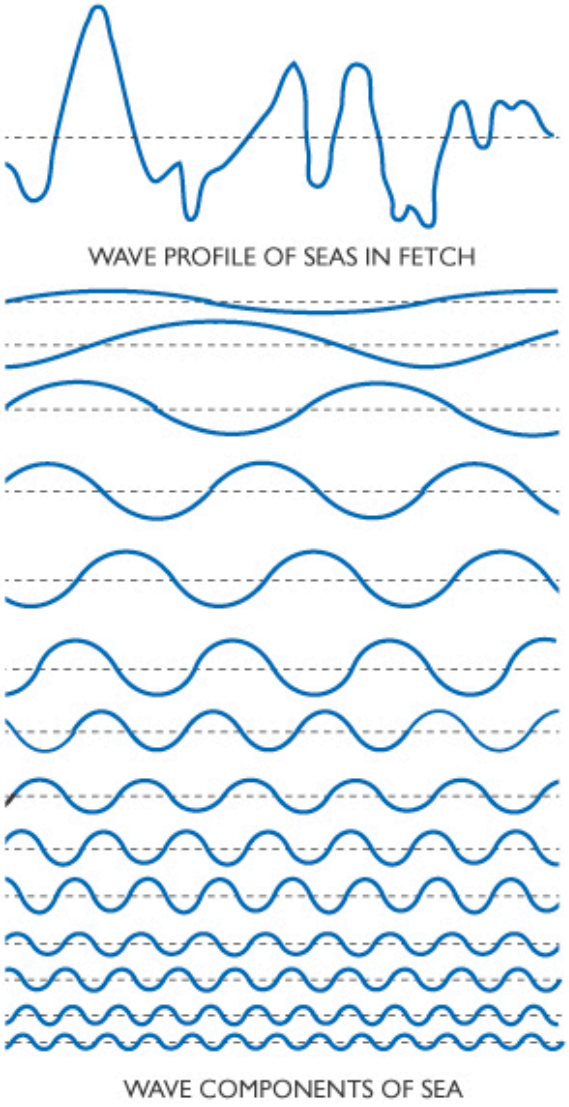
Complex

Analysis of Waves

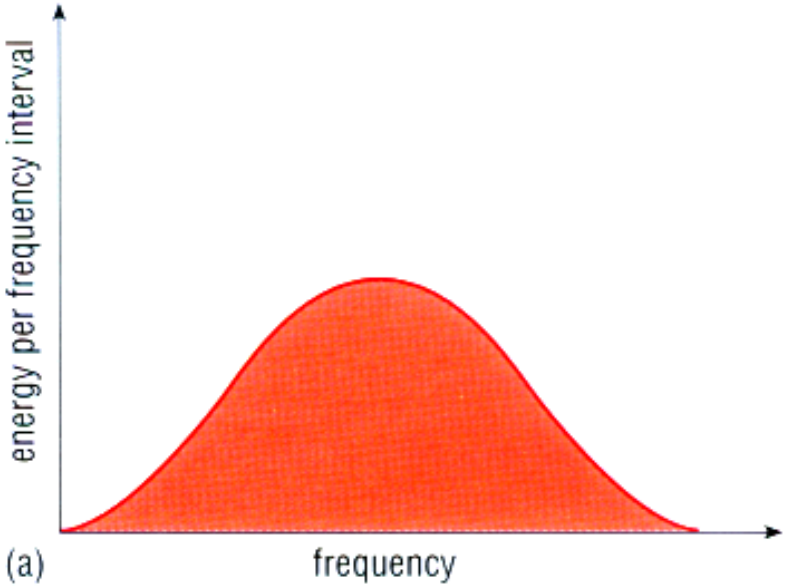


Physical Space

Analysis of Waves



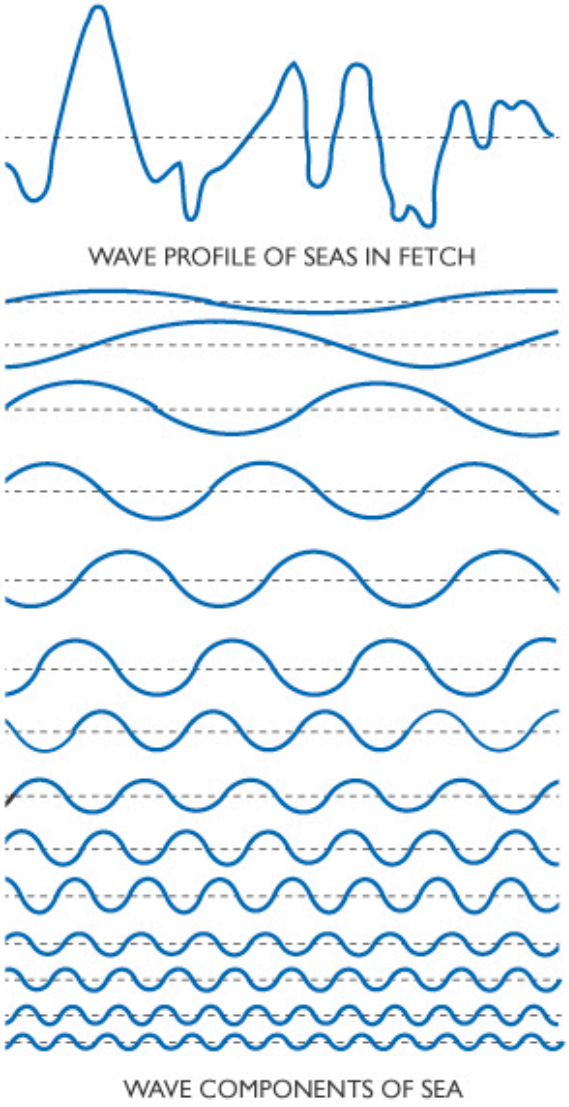
Spectra of Wave Frequency



Physical Space

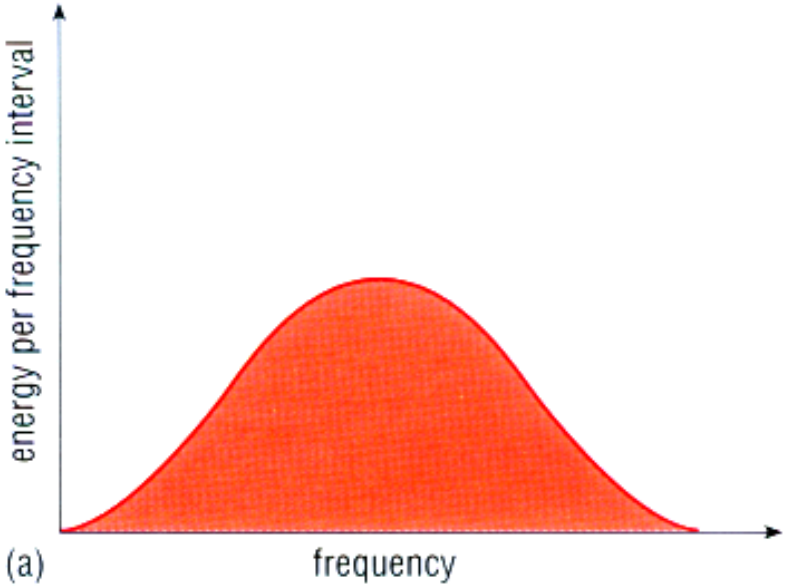
Frequency Space

Analysis of Waves



Physical Space

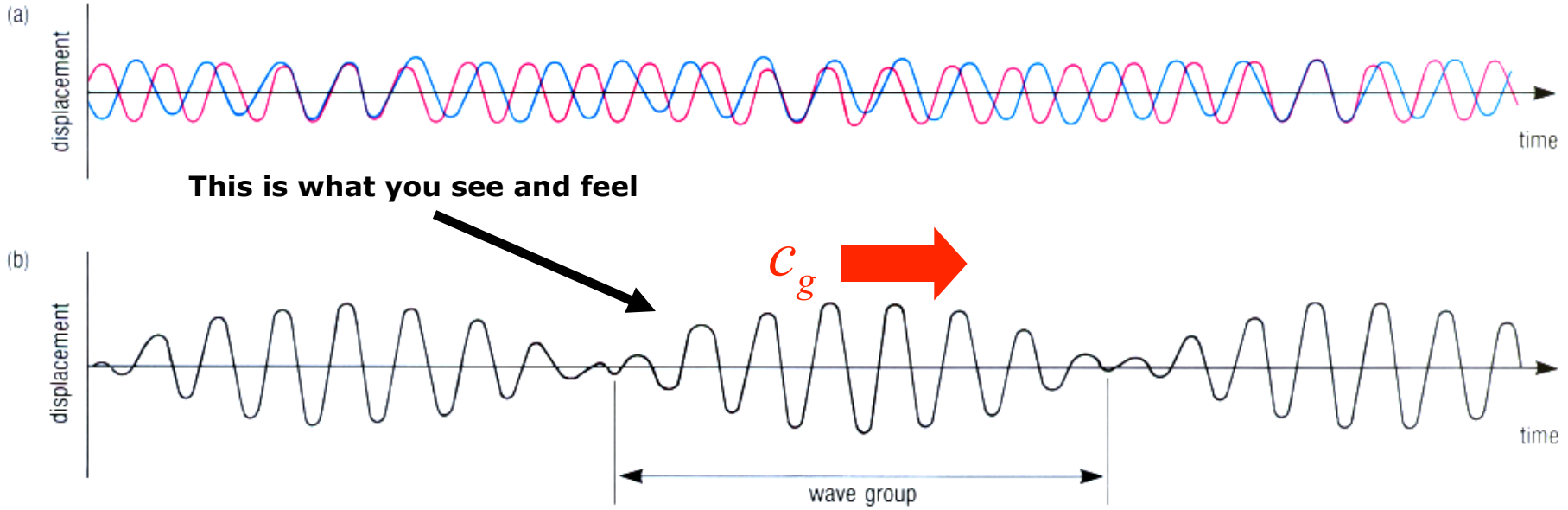
Spectra of Wave Frequency



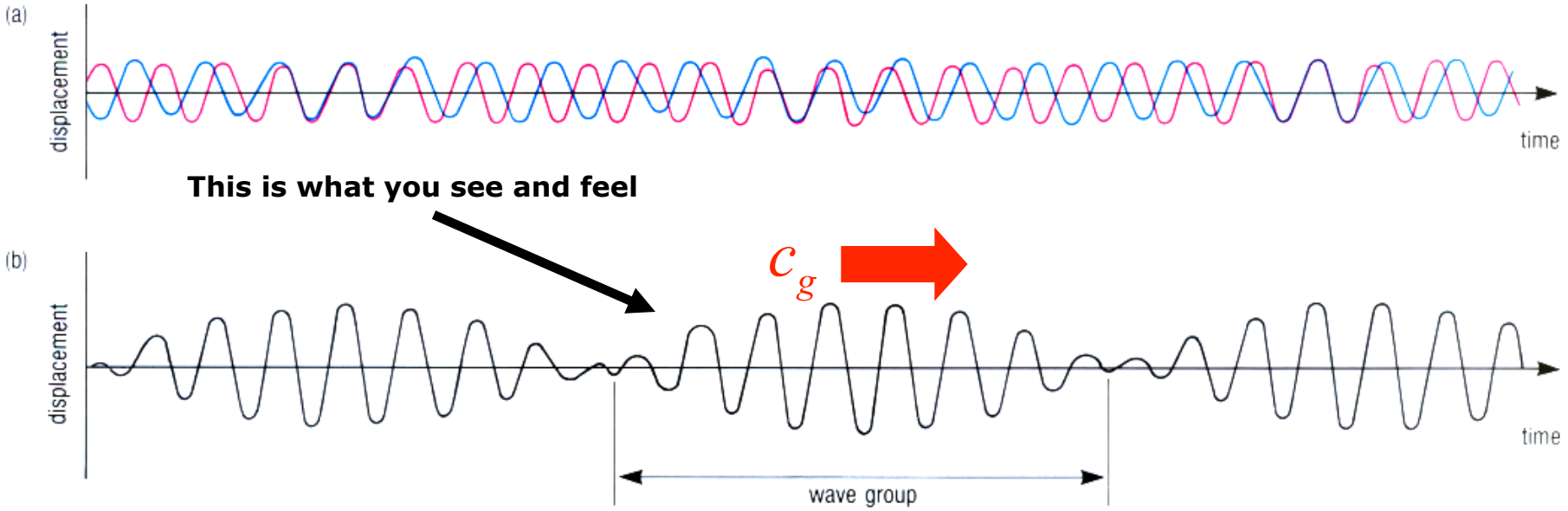
$$\omega = \frac{c}{k}$$

Frequency Space

Wave Group and Group Speed



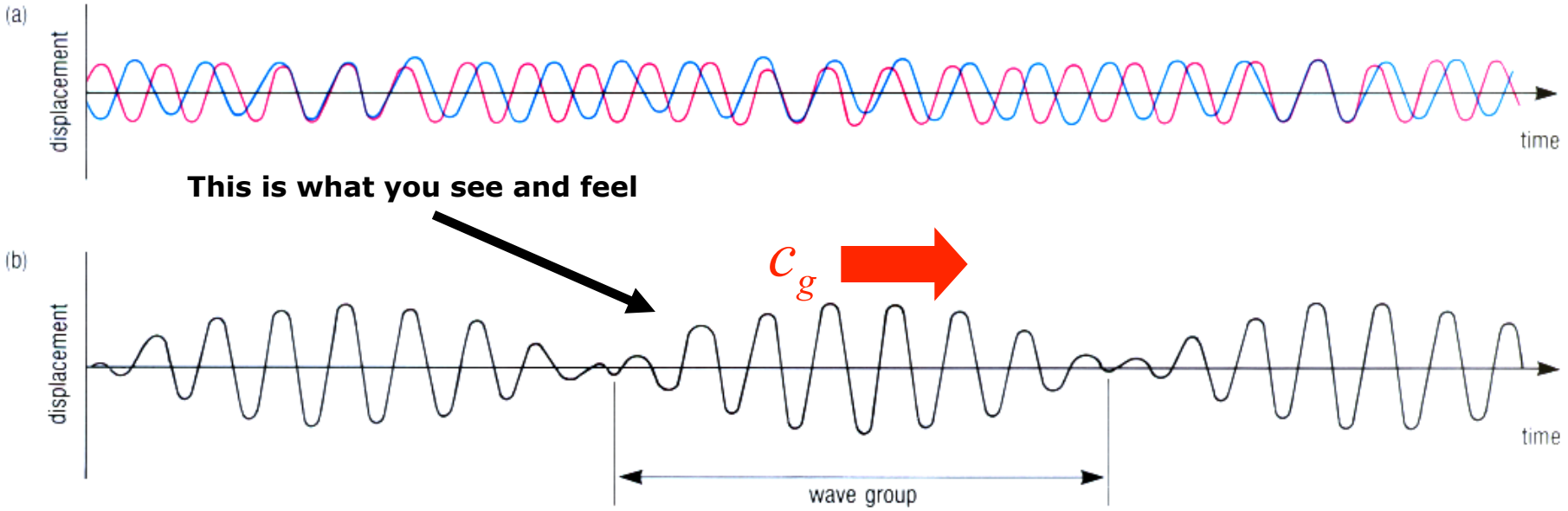
Wave Group and Group Speed



A

The energy of the wave field travels at the group speed velocity

Wave Group and Group Speed



A

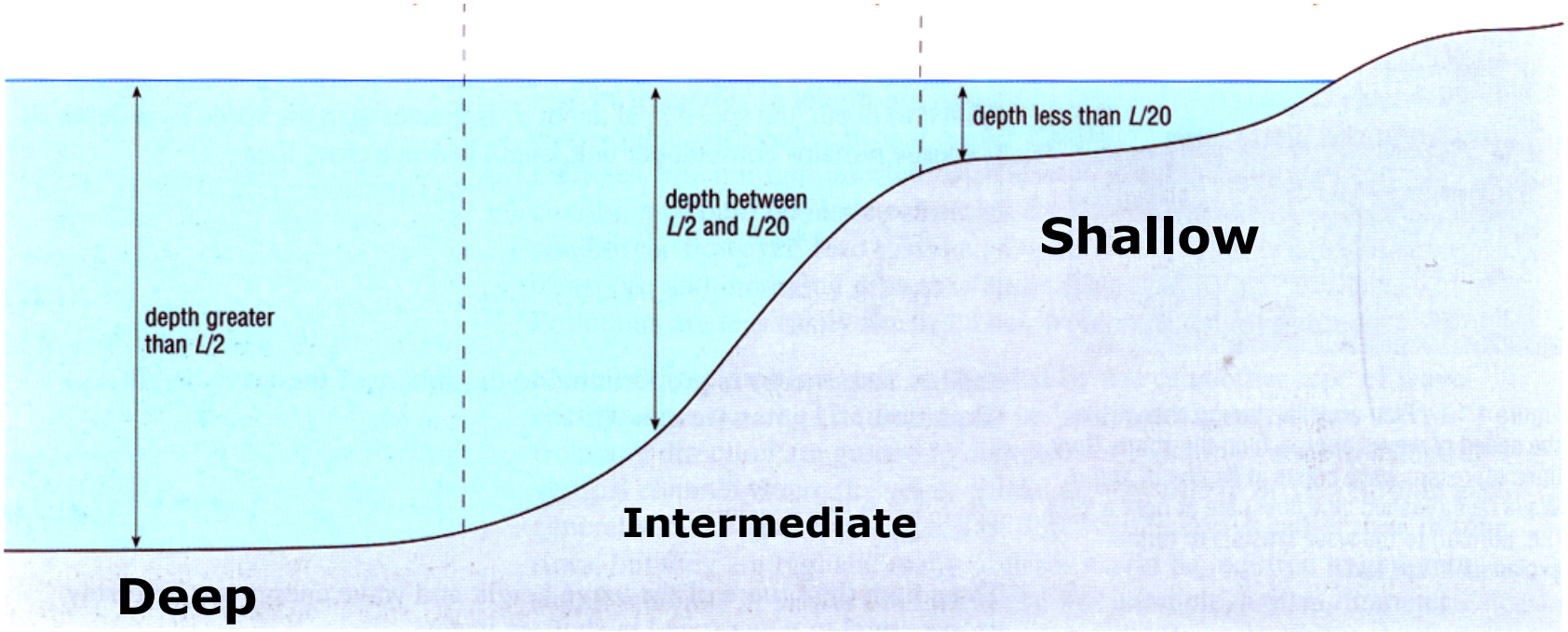
The energy of the wave field travels at the group speed velocity

B

The Wave Power is the rate at which energy is provided. Product of Wave Energy x Group Velocity

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

Waves approaching shore

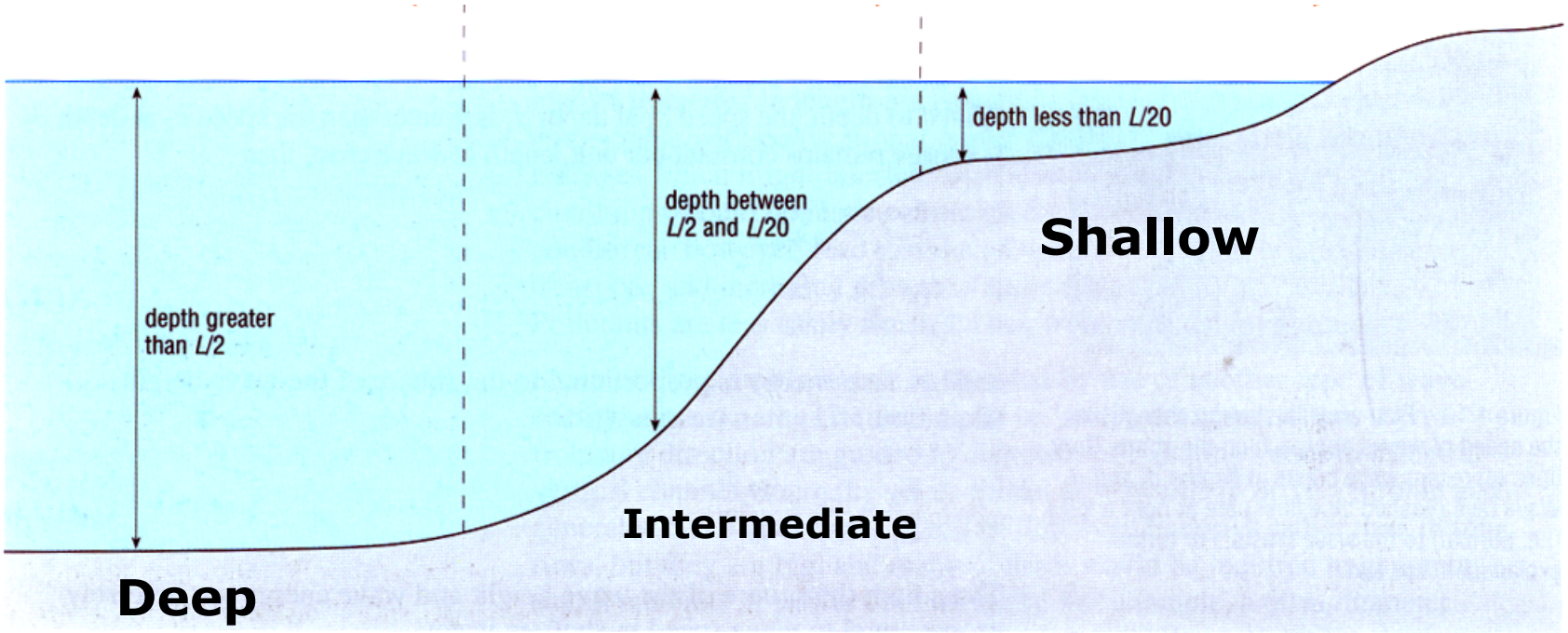


Waves approaching shore

$c_1 > c_2 > c_3$

$c_{g1} > c_{g2} > c_{g3}$

progressive decrease in wave speed (c) and group speed (c_g)



Waves approaching shore

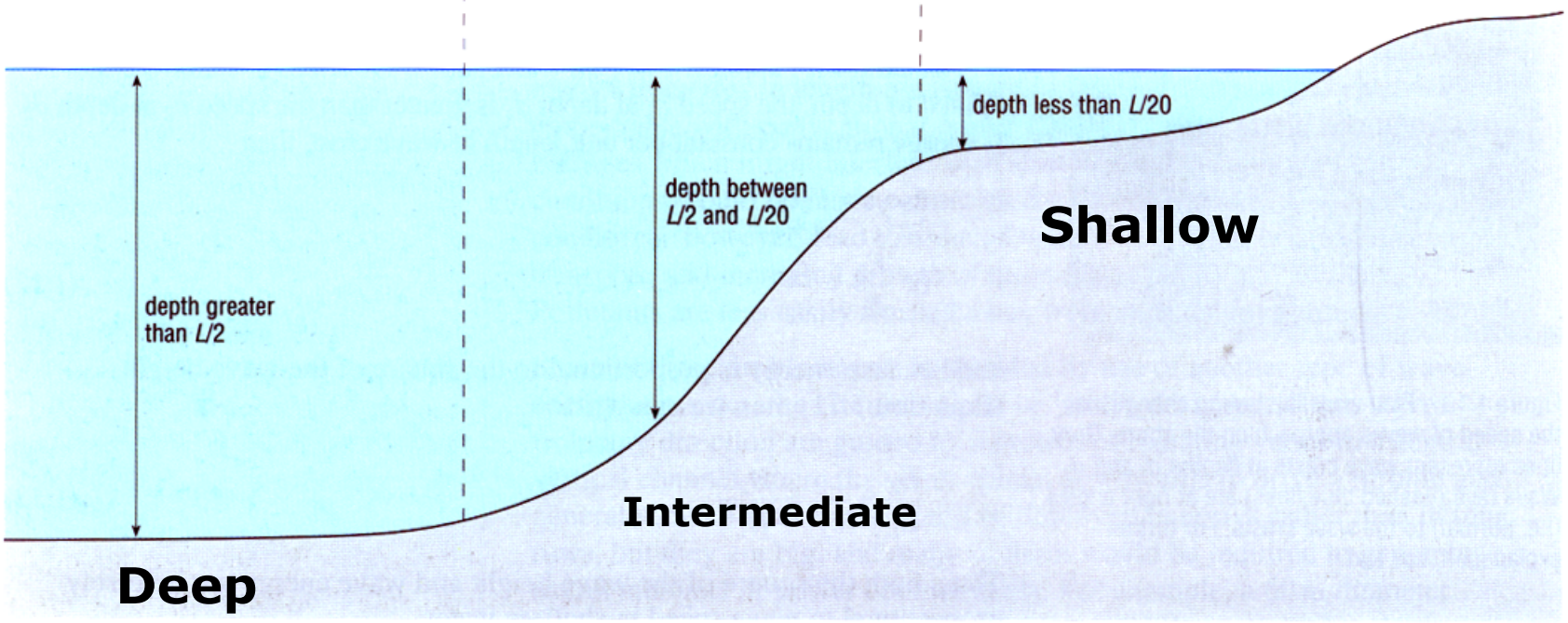
$c_1 > c_2 > c_3$

$c_{g1} > c_{g2} > c_{g3}$

progressive decrease in wave speed (c) and group speed (c_g)

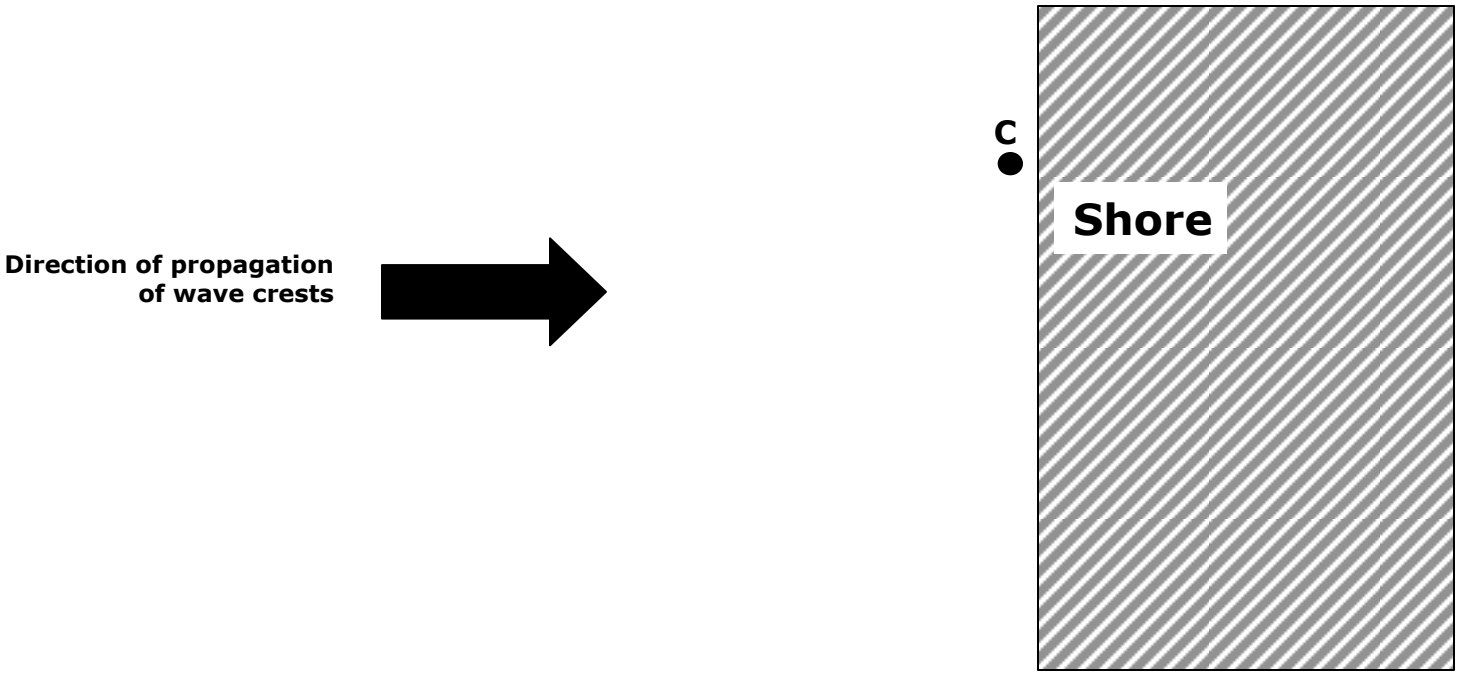
$$c_1 = \sqrt{\frac{gL}{2\pi}}$$

$$c_3 = \sqrt{gd}$$



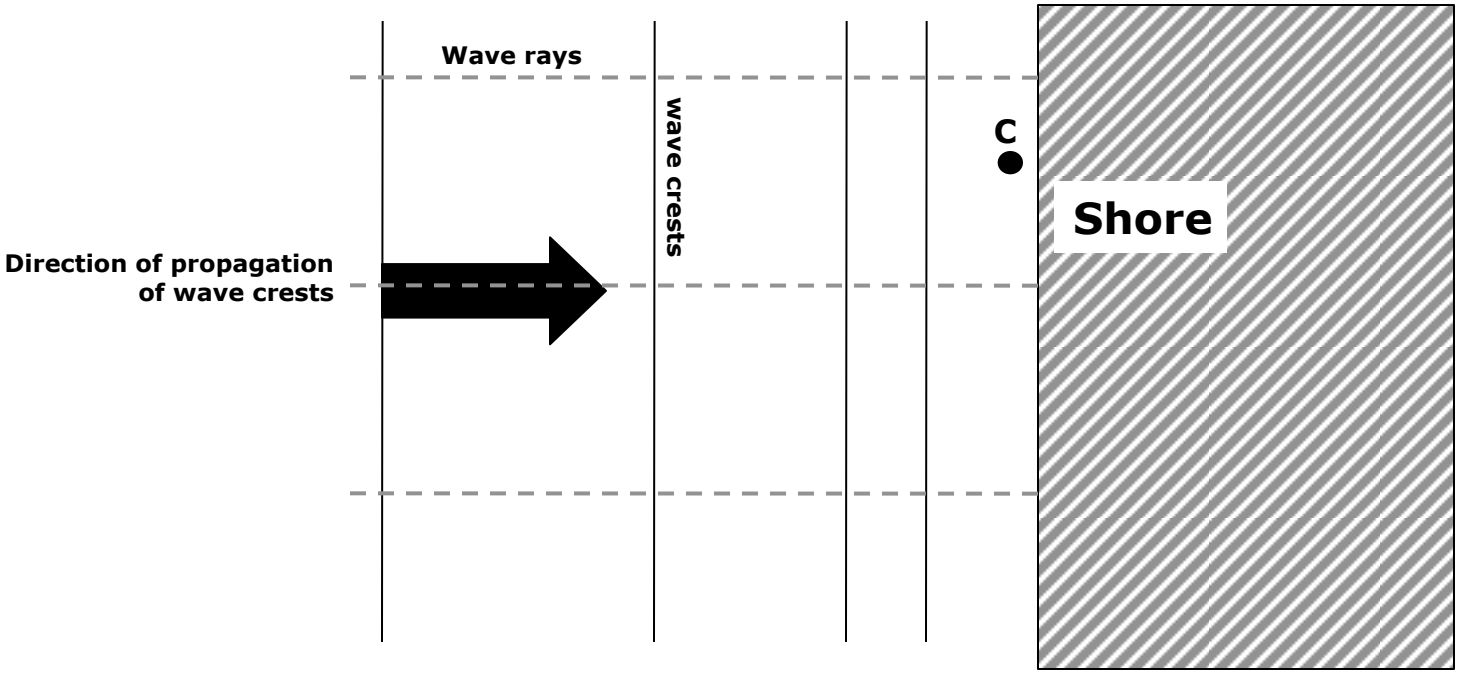
Waves approaching shore (a different view)

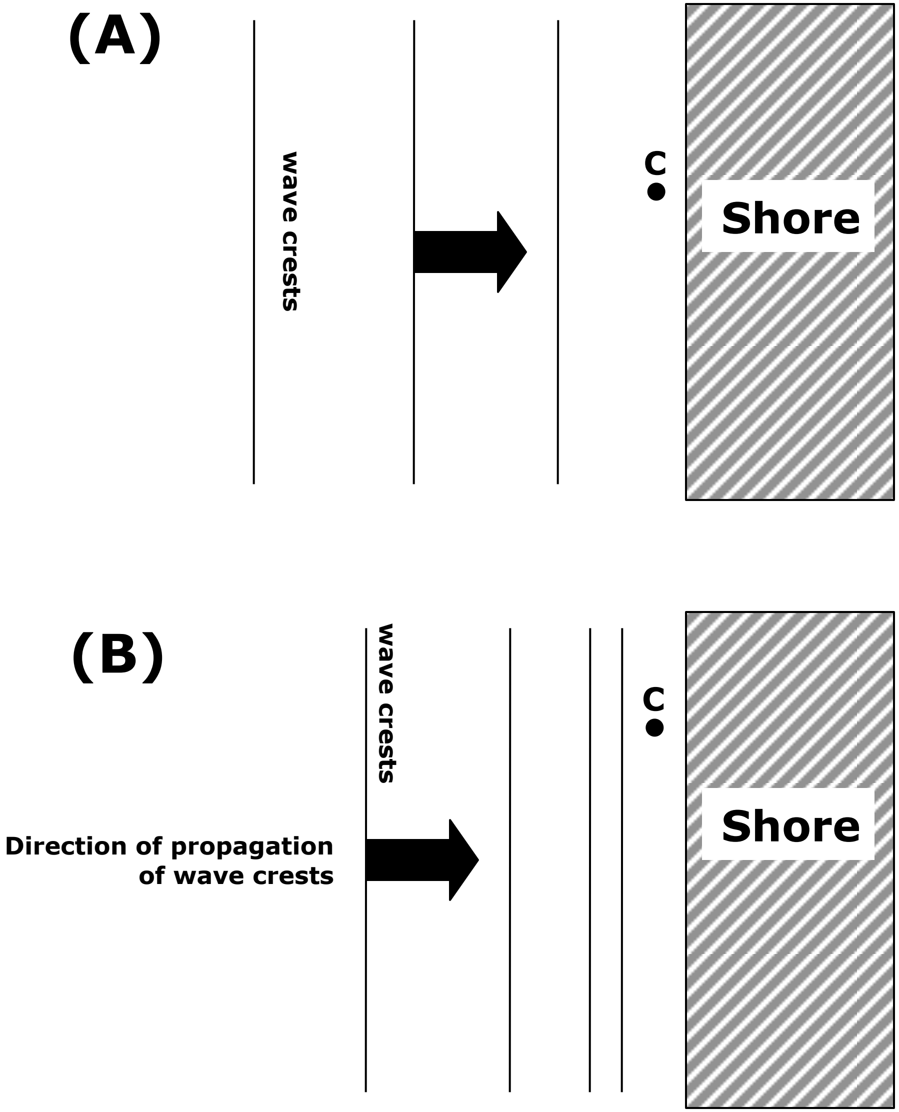
looking from above



Waves approaching shore (a different view)

looking from above



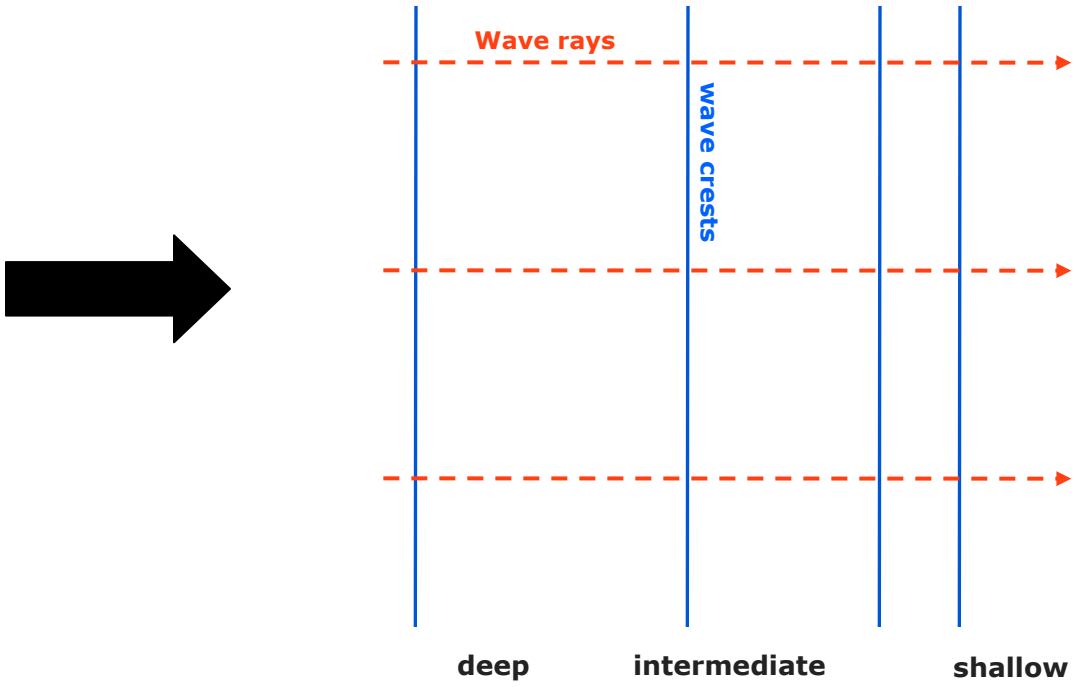


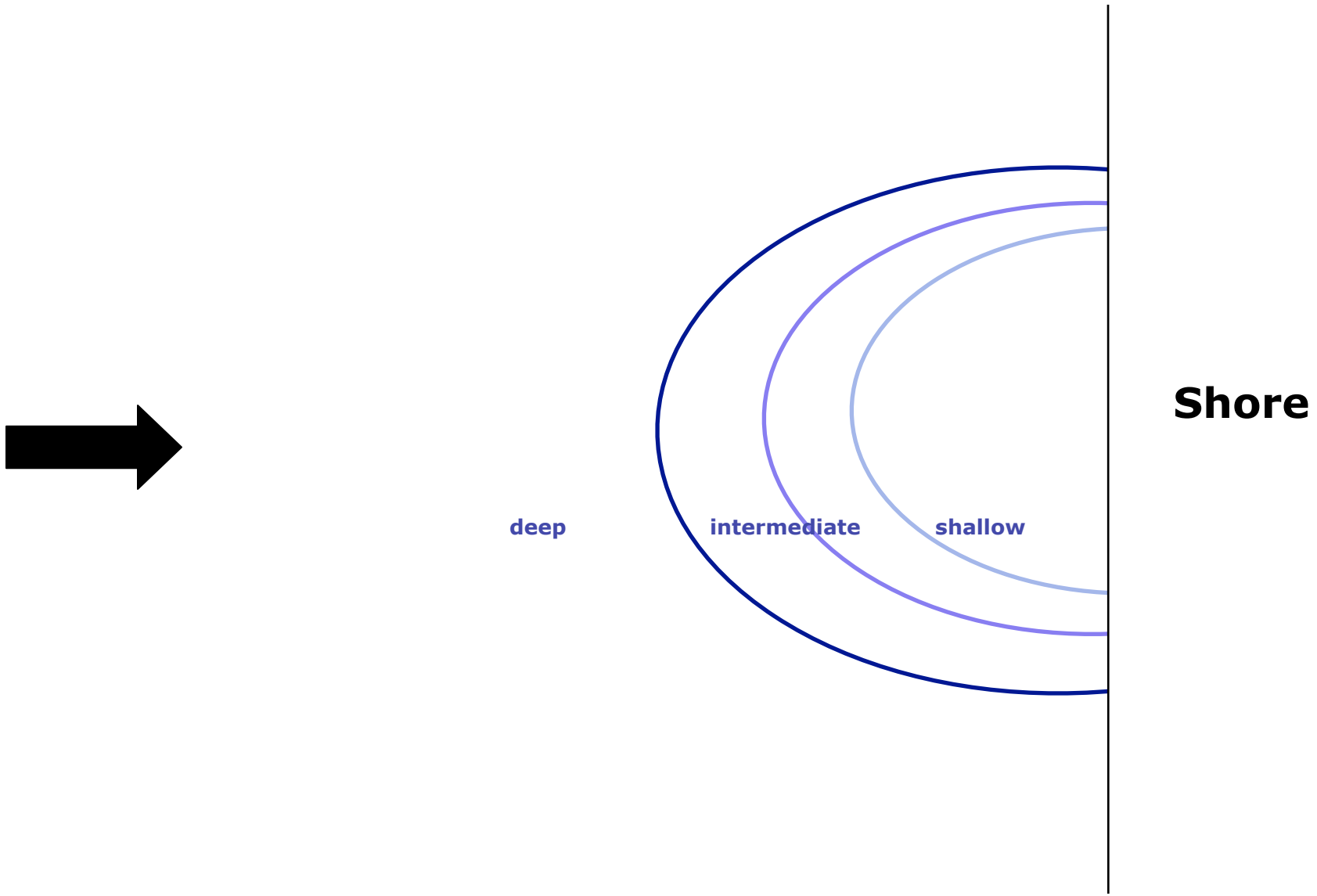
(A)
wave crests
C
Shore
(B)
wave crests
C
Shore
Direction of propagation
of wave crests

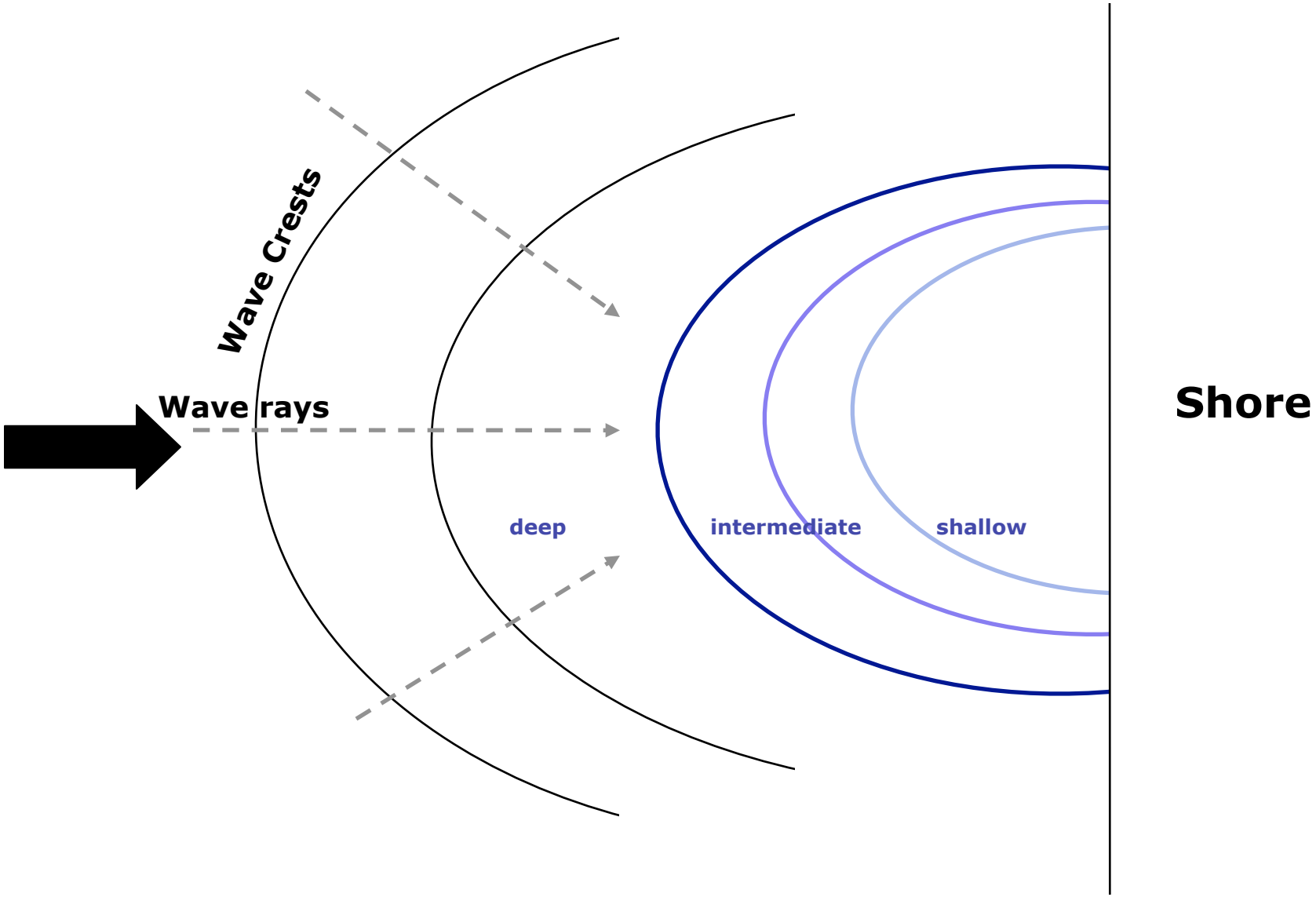
Review of definitions

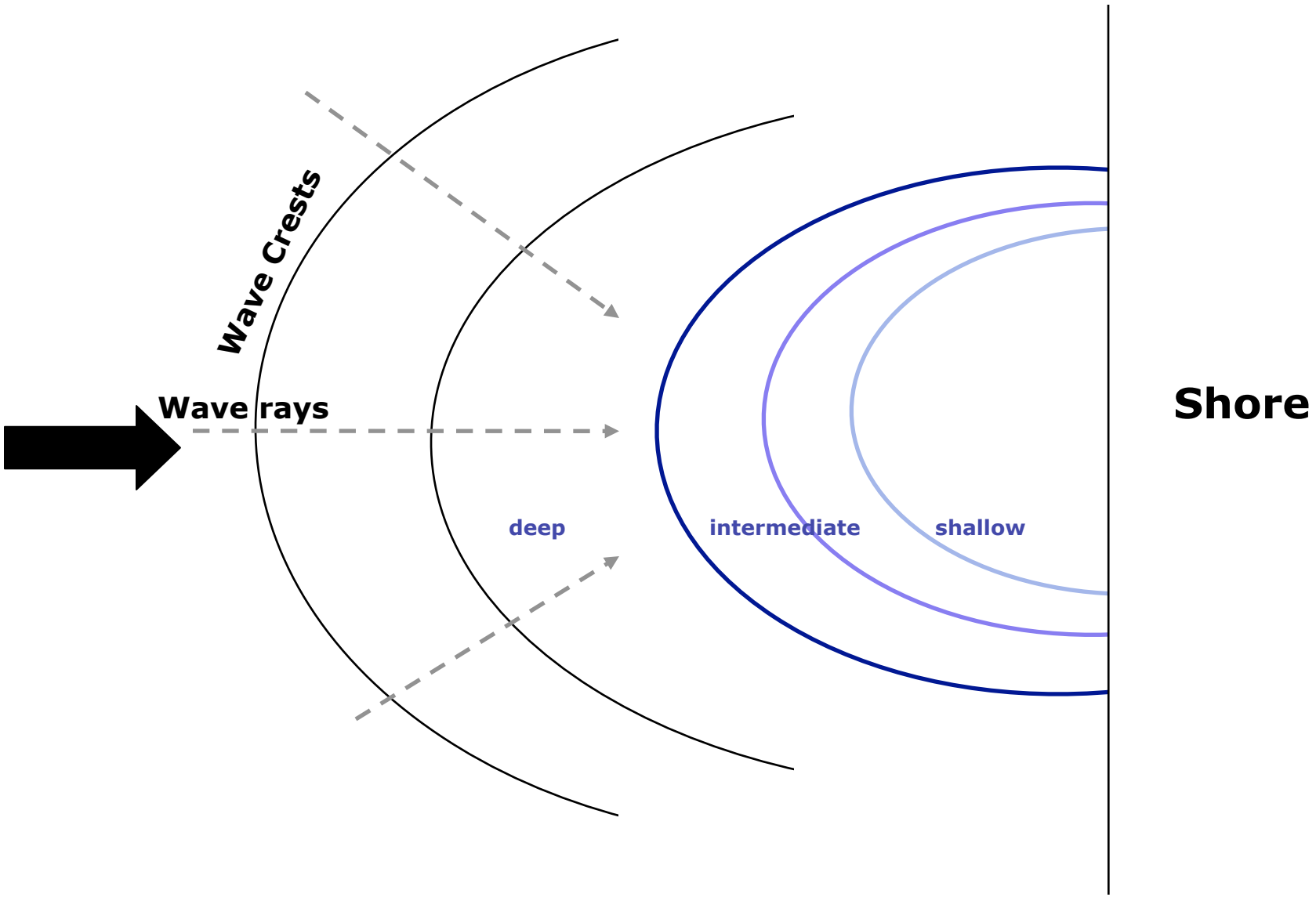
Wave crests are lines of equal height of the wave, they tend to align along lines of equal depths.

Wave rays indicate the direction of propagation of the wave energy and of wave crests.



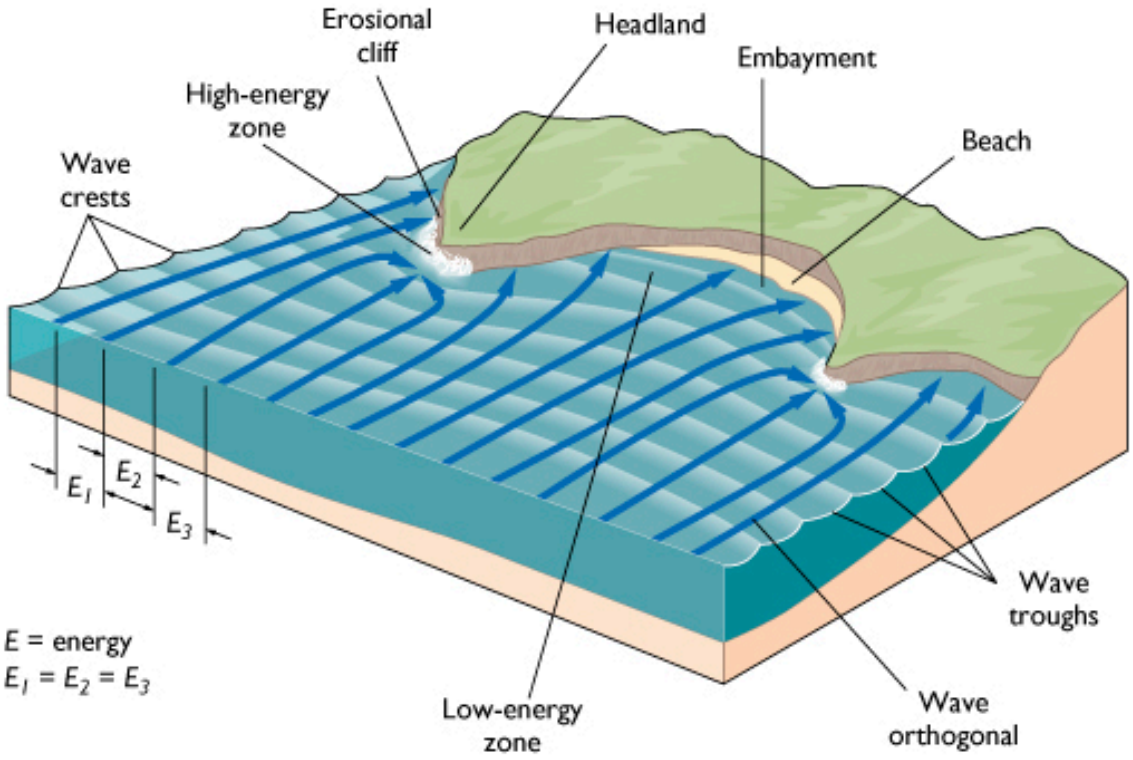

deep
intermediate
shallow
Shore


Wave Crests
Wave rays
deep
intermediate
shallow
Shore



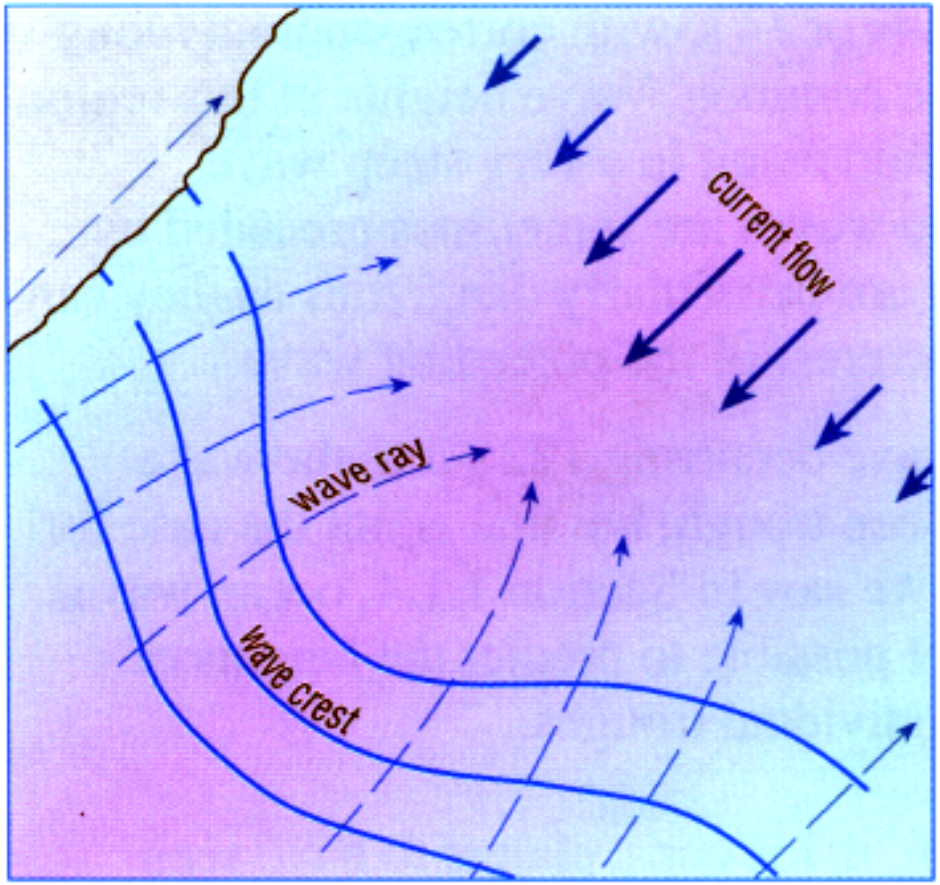
The focusing of wave rays will also increase wave heights

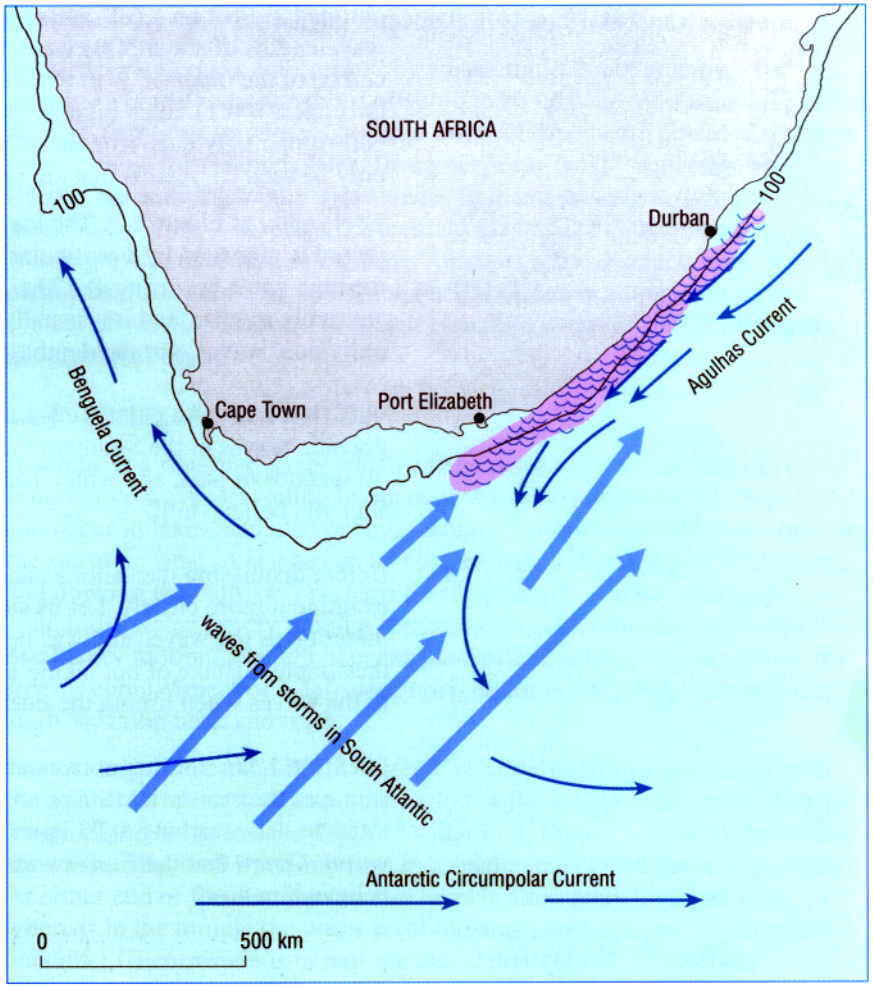
Wave refraction.

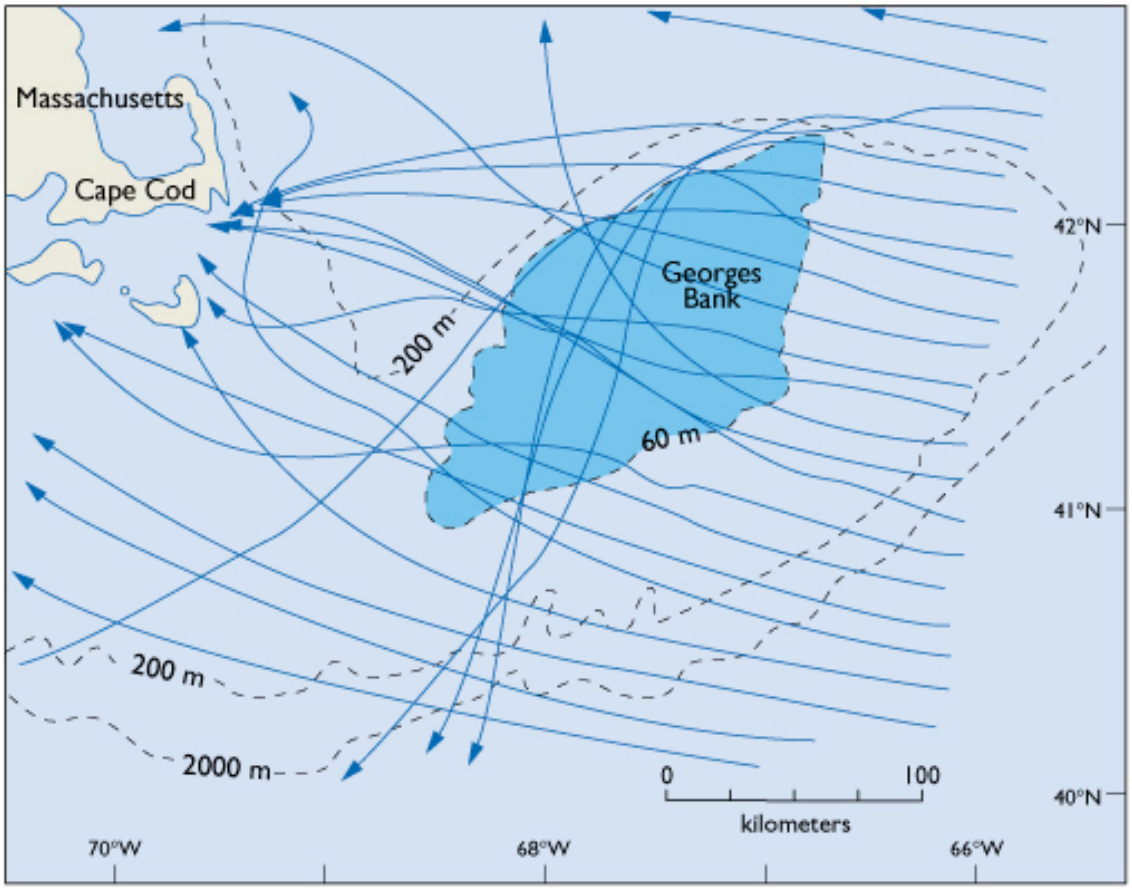


(a) WAVE REFRACTION

Waves and Currents

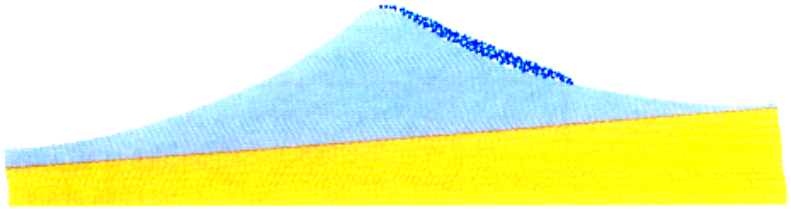



SOUTH AFRICA
100
100
Durban
Port Elizabeth
Cape Town
Agulhas Current
Benguela Current
waves from storms in South Atlantic
Antarctic Circumpolar Current
0
500 km

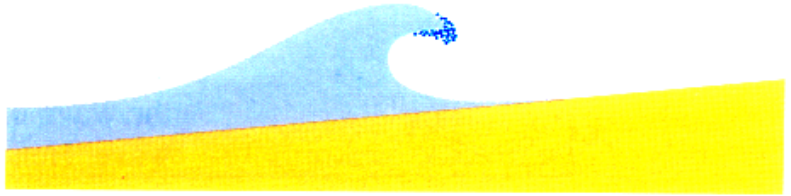


(b) WAVE REFRACTION OFF CAPE COD

Effect of steepness on approaching waves

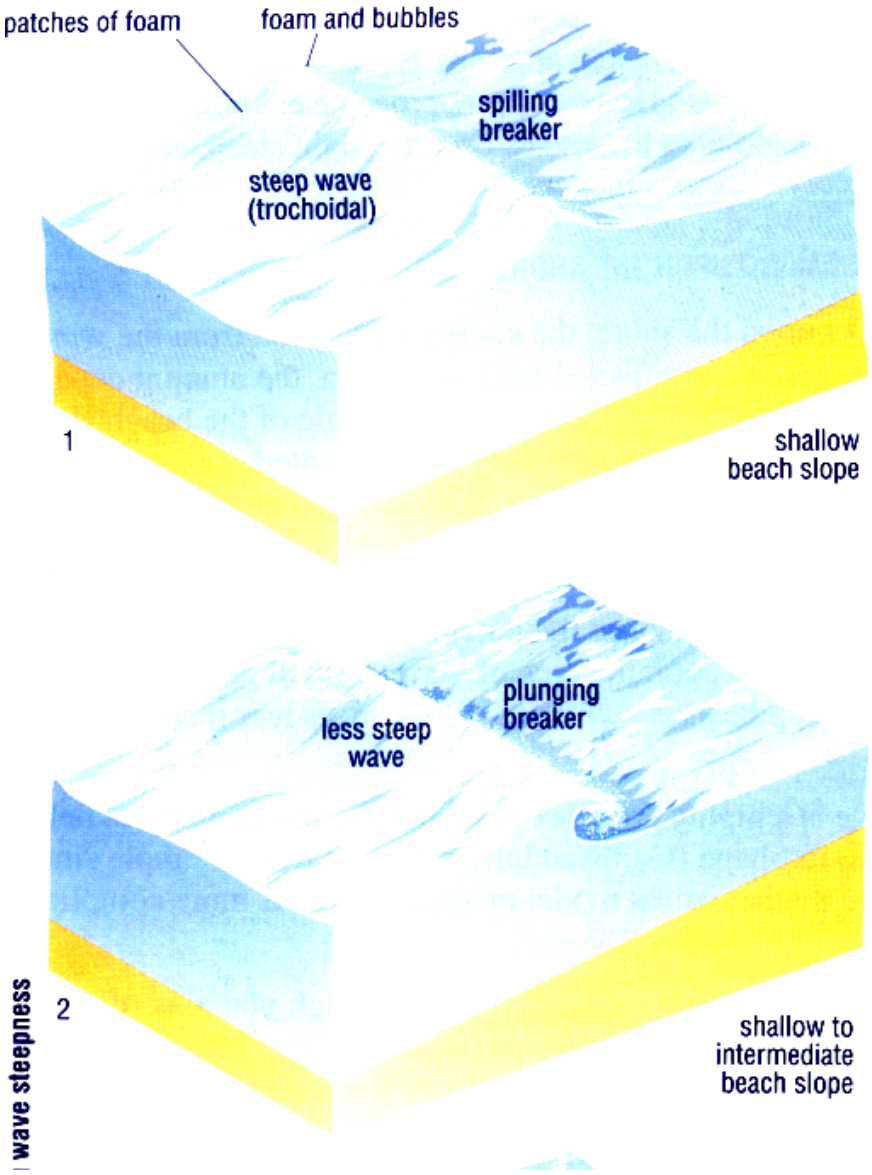


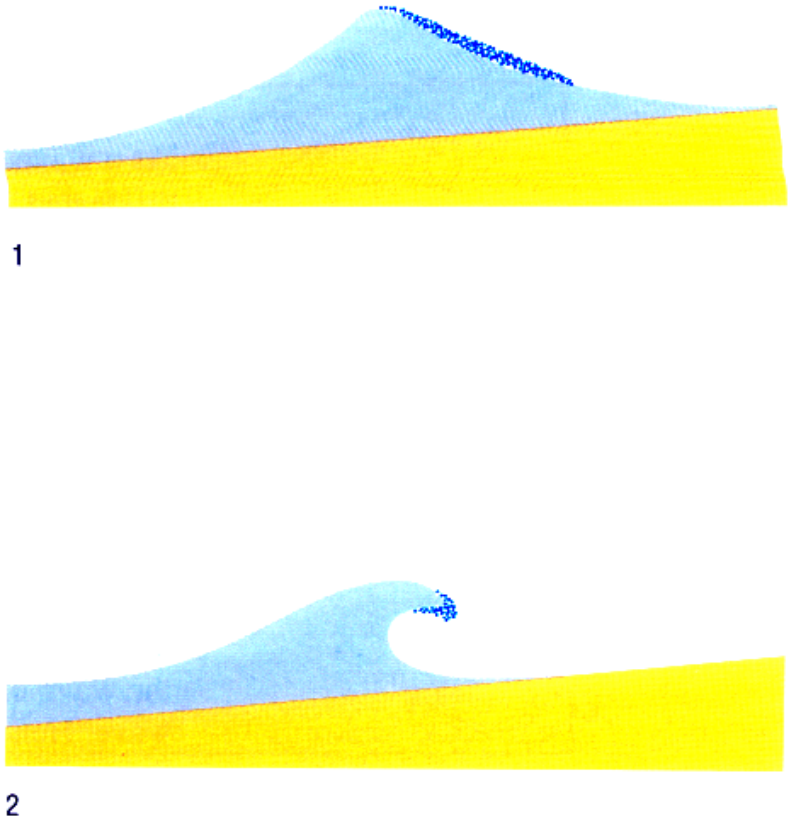
1



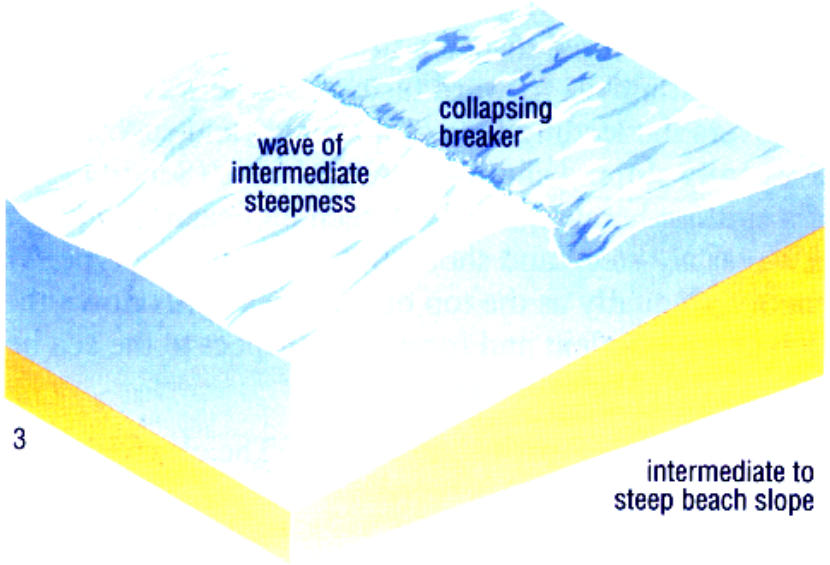
2

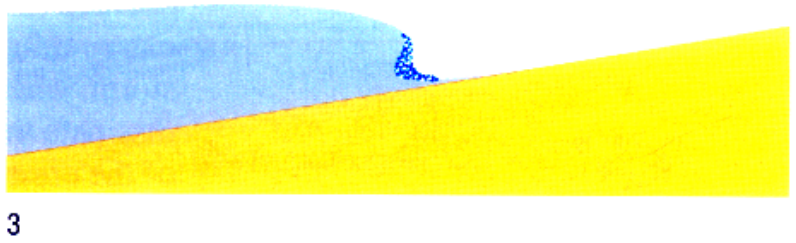
Effect of steepness on approaching waves

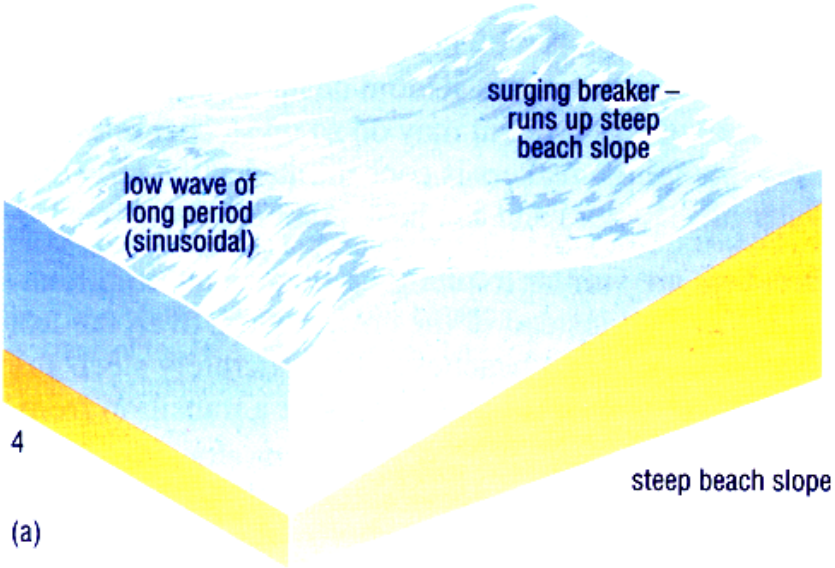


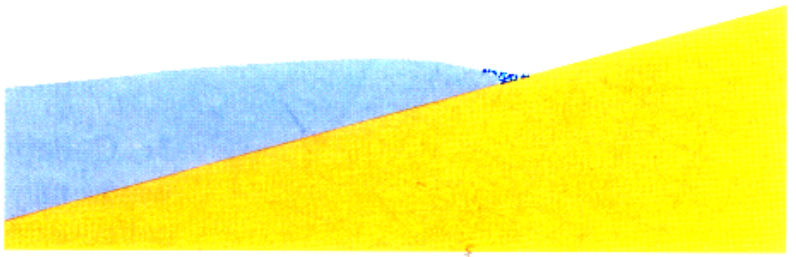


Effect of steepness on approaching waves
(more steep!)



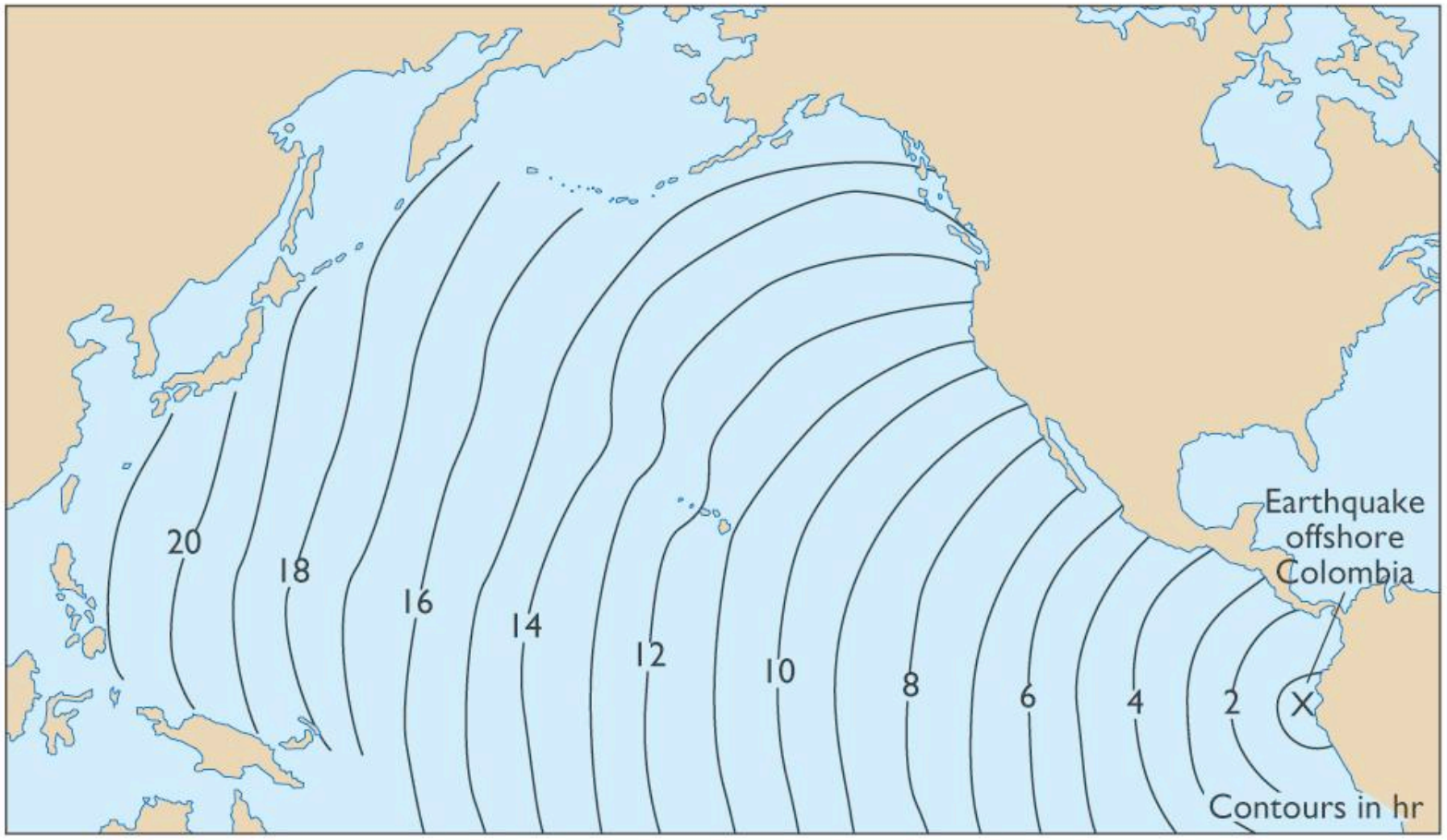






TSUNAMI

This diagram shows the position of the leading wave of a tsunami generated by a 1979 earthquake off-shore Colombia, South America.



(b) REFRACTION PATTERN OF 1979 TSUNAMI