WATER FOR LIFE

Module 2 The Oceans

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WATER FOR LIFE

Module 2 The Oceans

The vast majority of water at the Earth's surface is water found in the oceans. In this module we will look at seawater and the oceans. Specifically, we will examine the following:

- Physical properties of seawater
- Differences between ocean surface and deep ocean
- Currents and thermohaline circulation
- Waves
- Tides
- Transmission of light in seawater

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WATER FOR LIFE

SEAWATER

Almost all the water at the Earth's surface is seawater!

**Oceans cover 70% of the Earth's surface,
but contain 96.5% of all the water on our planet.**

WHY IS SEAWATER SALTY?

WHAT EXACTLY IS IN SEAWATER?

IS SALT CONTENT OF SEAWATER DIFFERENT IN DIFFERENT PARTS OF THE OCEAN?

HOW DO WE MEASURE SALINITY?

SEAWATER

WHY IS SEAWATER SALTY?

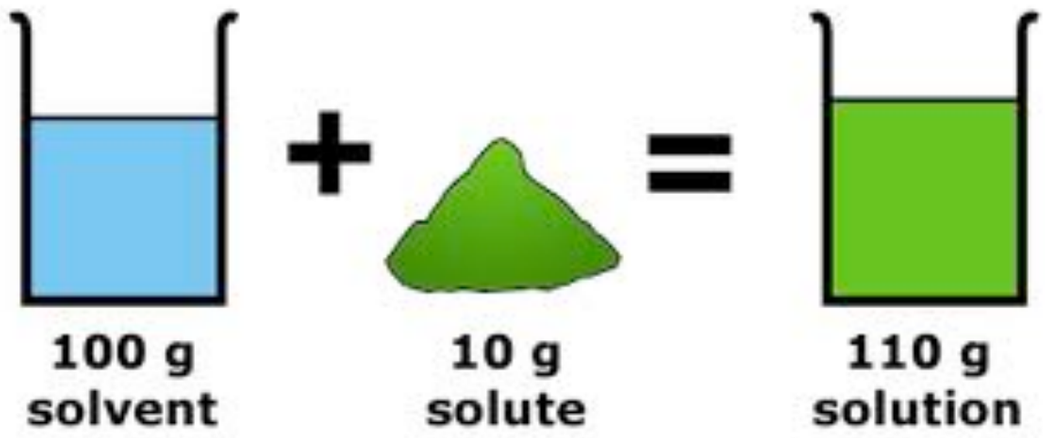
Water is a powerful **solvent**.
It can dissolve more substances than almost any other liquid!

When water comes into contact with a substance held together by opposite electrical charges, it break apart that compound. It will dissolve it. No wonder than that **most water in the world is not pure, but contains other compounds in solution**.

Water (or dissolving liquid) is a **solvent**.
Dissolved material (solid or gas) is a **solute**.
The combination is a **solution**.

Solution is homogeneous throughout and has properties different from original solvent. It is not the same as a *mixture*.

The simplest way to understand this is to simply taste the seawater -- it is salty because of the many solutes inside it.



SEAWATER

WHY IS IT SALTY?

POINT TO CONSIDER:

How much salt is there in the ocean?

By weight, seawater is about 96.5% water and 3.5% dissolved substances, most of which are salts of various kinds.

The world ocean contains some 5,000 trillion kilograms of salts. If the ocean water evaporated completely, its residue of precipitated salts could cover the entire planet with an even layer 45 m thick.

SEAWATER

WHAT EXACTLY IS IN SEAWATER?

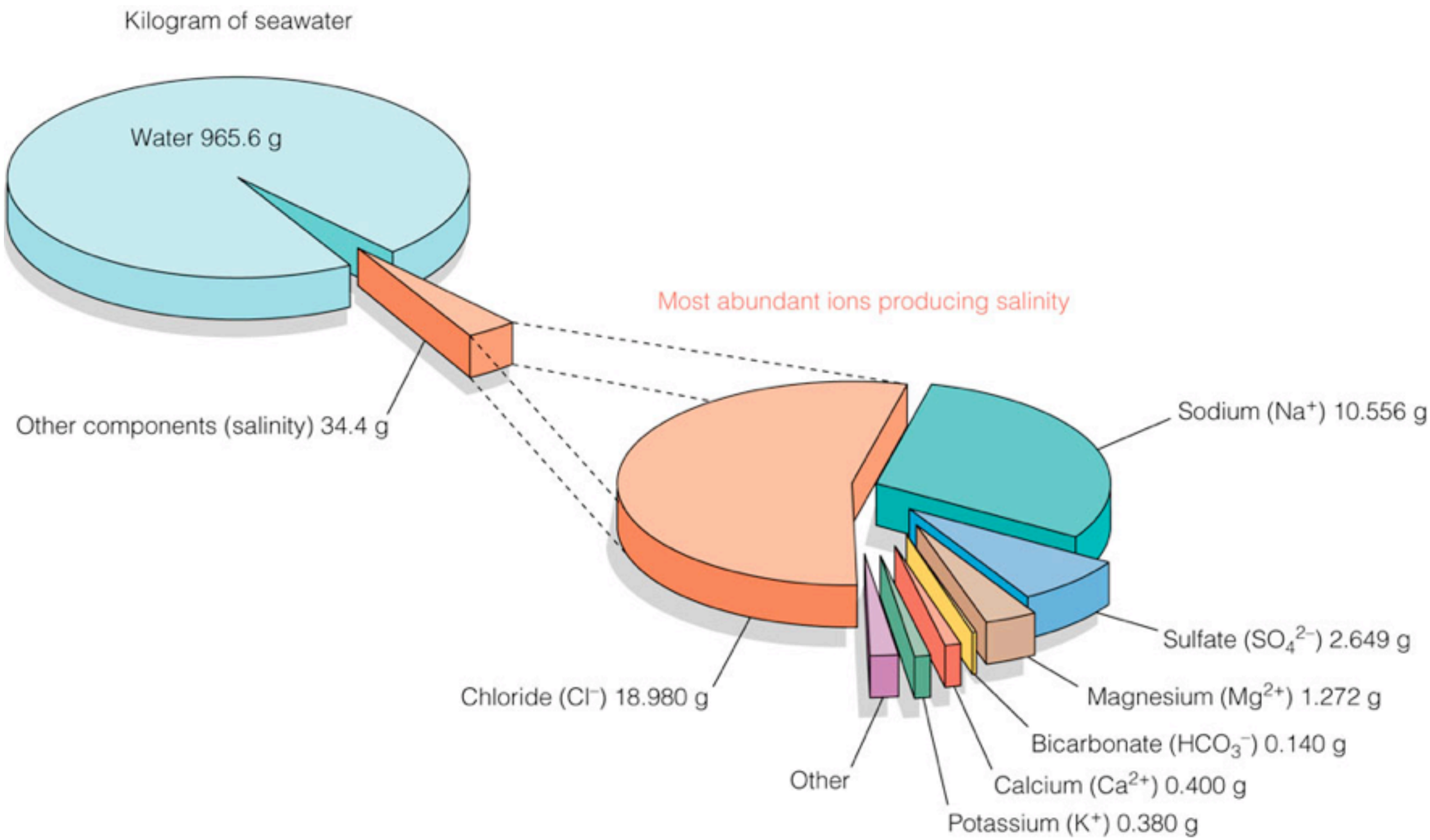
About 3.5% of seawater mass consists of dissolved solid substances. In marine sciences, we prefer to use ‰ (parts per thousand) instead of % (parts per hundred) because some important substances are found at low concentration. So seawater is about 35‰ dissolved solid substances.

Boiling away 1 kg (1000 grams) of water would leave a solid residue of about 35 grams. Almost all (99%) of this residual material would be made up of 7 constituents:

Cl^-	Chloride ion
Na^+	Sodium ion
SO_4^{2-}	Sulfate ion
Mg^{2+}	Magnesium ion
Ca^{2+}	Calcium ion
K^+	Potassium ion
HCO_3^-	Bicarbonate ion

SEAWATER

WHAT EXACTLY IS IN SEAWATER?



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If water evaporates, ions combine to make solid salts ($NaCl$, $MgSO_4$, $MgCl_2$, Na_2SO_4...)

SEAWATER

WHAT ELSE IS THERE?

99% of residual material from seawater is made of 7 major constituents. There are also **minor constituents** whose concentration in seawater is measured in parts per million.

Br	Bromine
Sr	Strontium
B	Boron
Si	Silicon
F	Fluorine

The remaining elements include nearly every chemical element present on the planet, but in extremely low concentrations. Their concentrations in seawater are measured in parts per billion. They are know as **trace elements**.

N	Nitrogen (non-gas)
Li	Lithium
I	Iodine
P	Phosphorus
Zn	Zinc
Fe	Iron (6 ppb)
Al	Aluminum
Mn	Manganese
Pb	Lead (0.04 ppb)
Hg	Mercury
Au	Gold (0.004 ppb) (4 ppt)

WHAT ELSE IS THERE?

ACTIVITY:

How much gold is there in the ocean?

Seawater contains almost every chemical element dissolved in it. Some are found in very small quantities, which we call trace quantities. But the ocean is huge -- there is so much water in it that even the content of trace elements is very significant. For example, consider how much gold is there in the ocean? The concentration of gold is 5 parts per trillion -- 0.00000000005 parts of gold per part of water. If we take a km^3 of water, how much gold is in it?

Seawater

Is salt content of seawater different in different parts of the ocean?

Fresh water has salinity of less than 0.5% by mass. Seawater has about 3.5% on the average, but it is different in different parts of the world. Ocean water has different salinity in different parts of the world.

There may be 31 grams of salts in a liter of water from the Arctic, but there may be 38 grams of salt in a liter of water from the Mediterranean.

HOW DO WE MEASURE SALINITY?

ACTIVITY:

Using a salinometer to check salinity of ocean, lagoon, and mangrove water.

SEAWATER

HOW IS SEAWATER REALLY DIFFERENT FROM FRESH WATER?

Most of the dissolved solids in seawater are inorganic salts that have been separated into ions. They interact with each other and with water molecules. This causes **some physical properties of saltwater to be different from pure water**.

Salinity modifies the physical properties of water. Many properties of solutions depend on the number of molecules of solute and change as the number of solute molecules changes (i.e., salinity changes).

HEAT CAPACITY of water decreases with increasing salinity. This is because salts have much lower heat capacity than water. Less heat is necessary to raise the temperature of seawater by 1°C than it is for fresh water.

FREEZING POINT of water is lowered with increasing salinity. Saltwater freezes at a lower temperature (around -2°C) than fresh water (0°C). Sea ice forms at lower temperatures than ice in freshwater lakes. Salts act as a kind of **antifreeze** -- ions interfere with bonding of H and O atoms into ice structure.

EVAPORATION RATE of water is slower with increasing salinity. Dissolved salts attract water molecules and cause them to evaporate slower. Seawater evaporates slower than fresh water.

SEAWATER

ARE THERE GASES DISSOLVED IN SEAWATER?

We've talked about salts and other solids dissolved in seawater. There are also **gasses** dissolved in seawater. Marine plants and animals would not be able to survive without them. No marine animal can get the needed oxygen from water molecules.

Life depends on *dissolved* oxygen and CO_2 in water.
Animals need oxygen and plants need CO_2.

Major gasses found in seawater are atmospheric gasses, they readily dissolve.

	atmosphere	*ocean*
N	78%	48%
O	21%	36%
CO_2	0.04%	15%

Their proportions in solution in seawater are different from proportions in the atmosphere.

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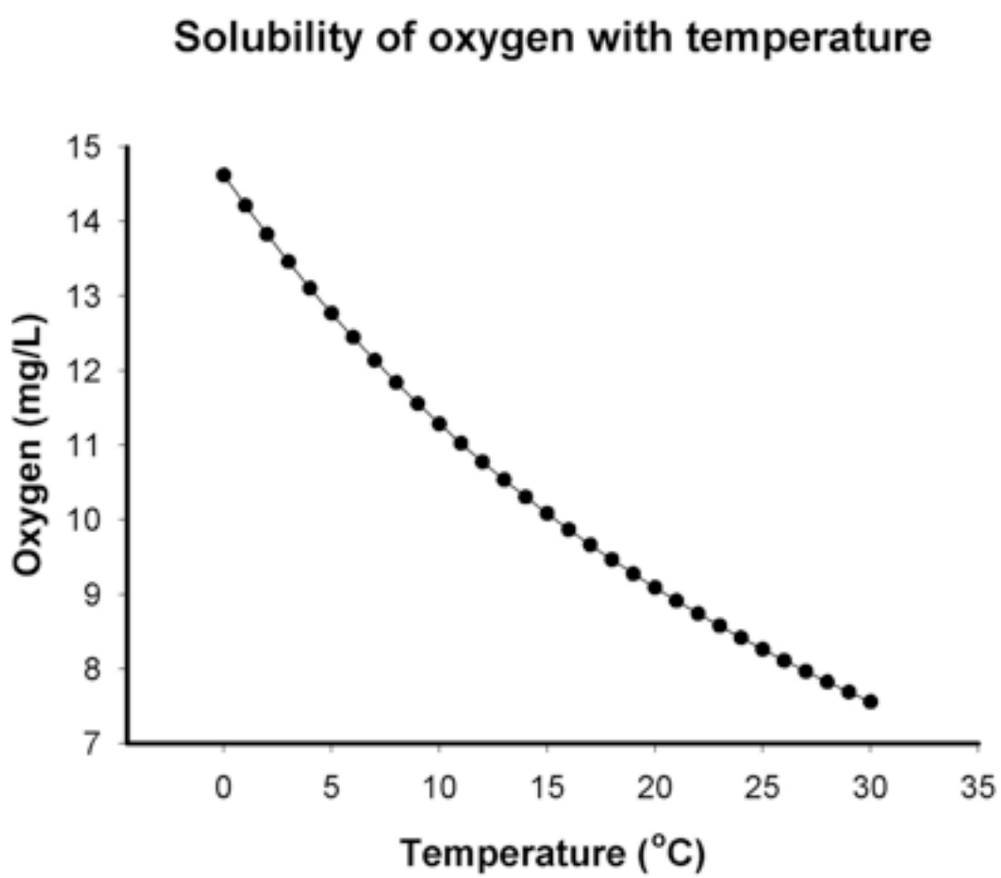
SEAWATER

IS GAS CONTENT OF SEAWATER DIFFERENT IN DIFFERENT PARTS OF THE OCEAN?

Seawater does not have the same amount of different gasses everywhere. This is because temperature of water controls the amount of gas water can hold. Warm water can contain less gas than cold water.



Solubility of gasses in water decreases with increase in temperature.

More gas is present in a solution with a lower temperature compared to a solution with a higher temperature.

Seawater in tropical areas, especially in shallow coral reefs, contains less oxygen (and other dissolved gases) than seawater in cold seas.

SEAWATER

IS GAS CONTENT OF SEAWATER DIFFERENT IN DIFFERENT PARTS OF THE OCEAN?

ACTIVITY:

Why does a carbonated drink go flat?

Increase in temperature negatively affects gas solubility. Warm water can contain less gas than cold water. You can always remember this relationship if you think about what happens to a glass of carbonated drink as it stands around for a while at room temperature. The taste gets "flat" because carbon dioxide has escaped. It would have stayed longer inside a fridge. What if it's a closed bottle?

SEAWATER

IS GAS CONTENT OF SEAWATER DIFFERENT IN DIFFERENT PARTS OF THE OCEAN?

Even if the temperature of the whole ocean were the same, the seawater would still not have the same amount of different gasses everywhere. This is because the pressure of water also controls the amount of gas water can hold. Water under greater pressure can contain more gas than water under less pressure.

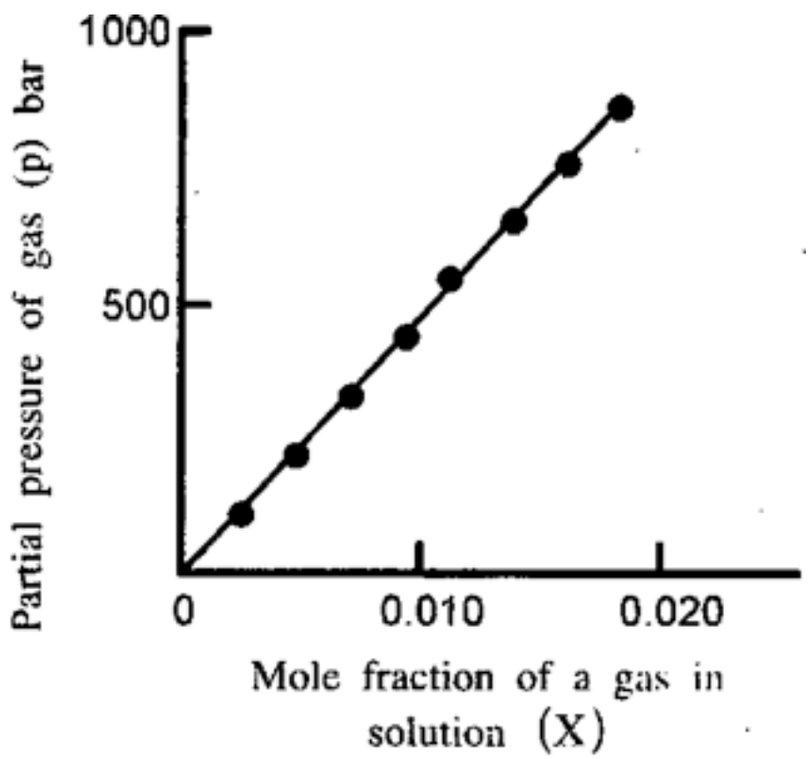


Fig. 3.1

Solubility of gasses in water increases with increase in pressure.

More gas is present in a solution under higher pressure compared to a solution with a lower pressure.

Water in the deep ocean, where the pressure is great, can contain more dissolved gas than water at the ocean surface.

SEAWATER

IS GAS CONTENT OF SEAWATER DIFFERENT IN DIFFERENT PARTS OF THE OCEAN?

ACTIVITY:

Why does a carbonated drink fizz when a bottle is opened?

Increase in pressure positively affects gas solubility. Water under more pressure can contain more gas than water under less pressure. You can also remember this relationship by using a carbonated drink example. When pressure is released (bottle opened), gas comes out of solution (bubbles out).

WATER FOR LIFE

Sea surface vs. the deep ocean

There are differences between different areas of the ocean surface around the globe. Even more importantly, there are major differences between the ocean near the surface and deep ocean. A beginning of an understanding of how the world ocean system functions must be rooted in an understanding of ocean depths.

Where is the ocean warmest?

Where is the ocean saltiest?

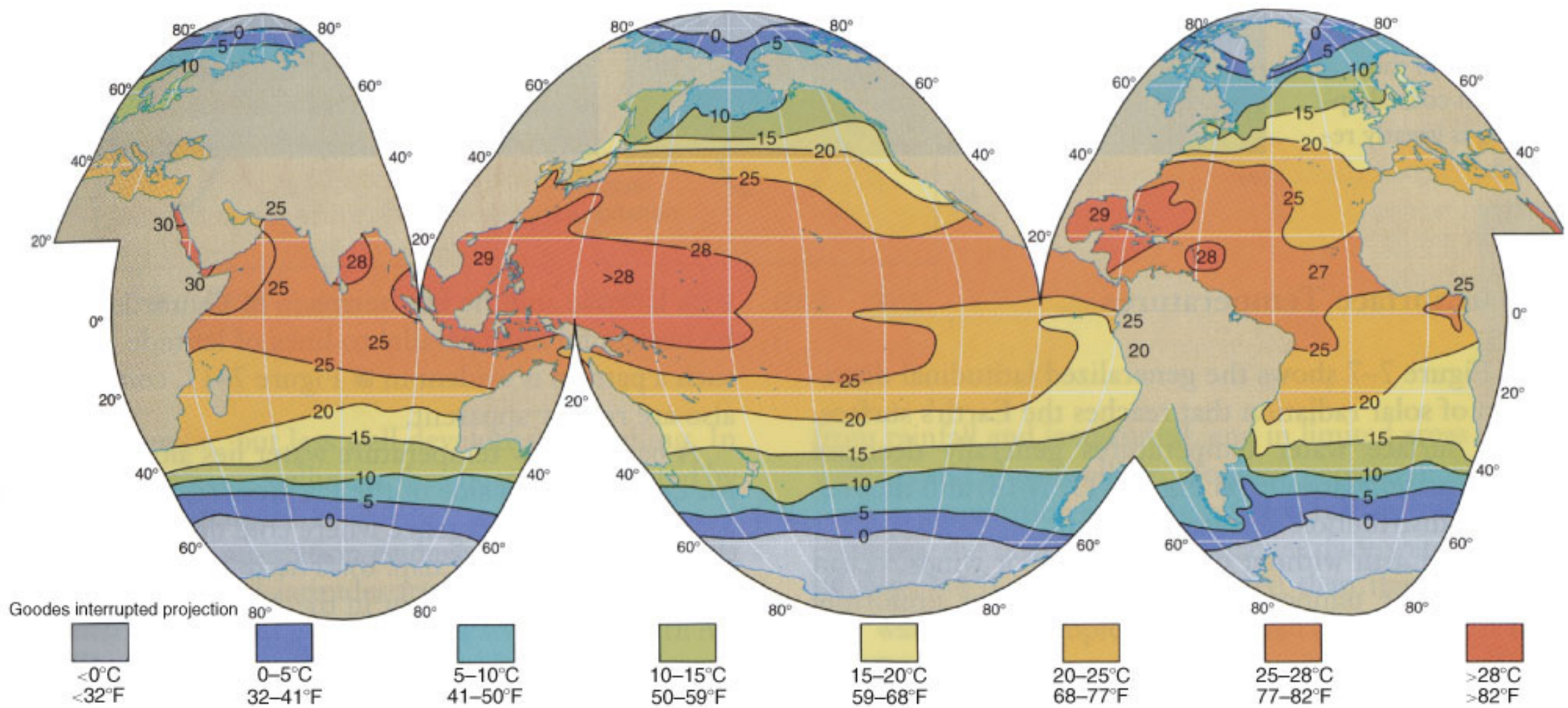
What is the temperature like in ocean depths?

What is the density like in ocean depths?

Sea surface vs. the deep ocean

Where is the ocean warmest?

Sea surface temperature (**SST**) is the highest in tropical and equatorial oceans where there is most input of heat energy from the sun. The temperature gets progressively cooler with latitude.



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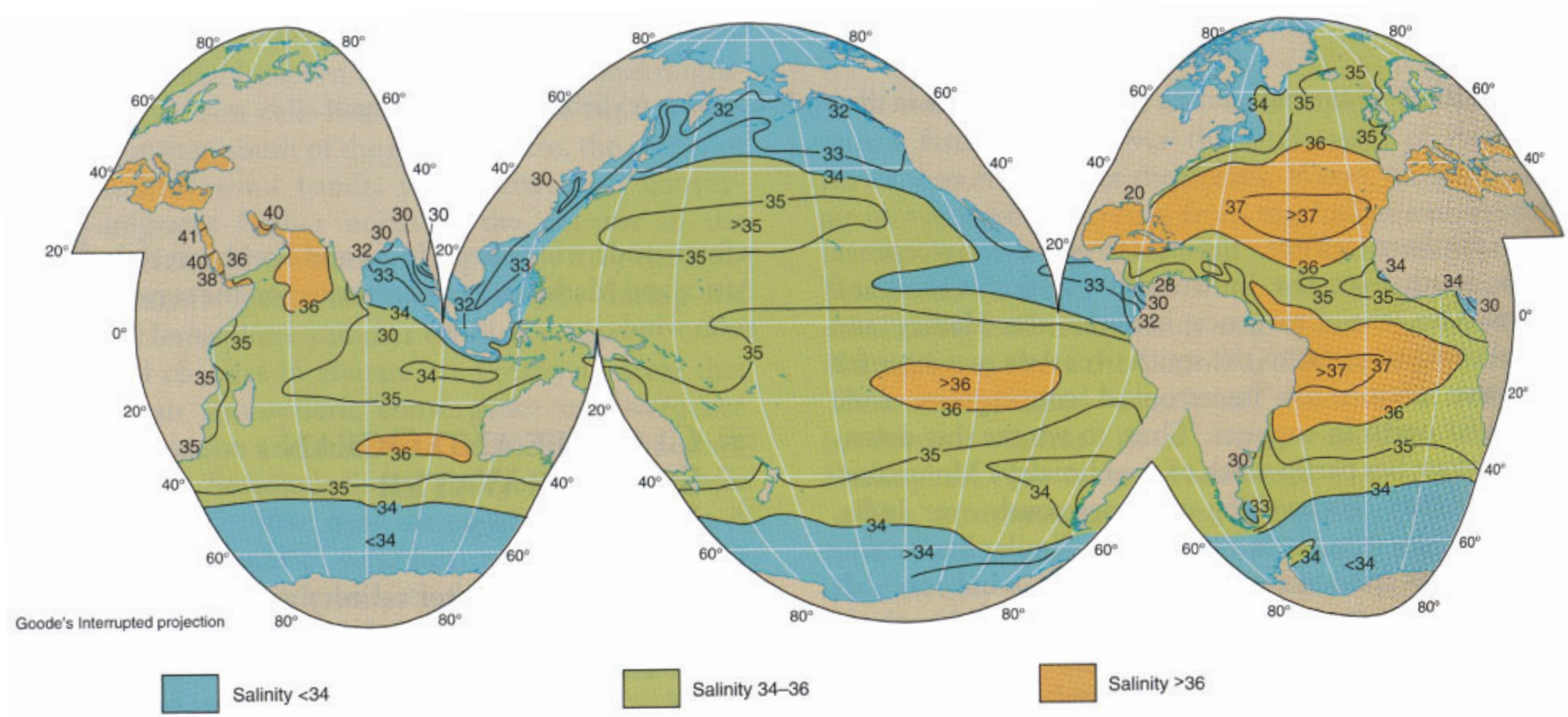
Sea-surface temperatures during Northern Hemisphere summer

Sea surface vs. the deep ocean

Where is the ocean saltiest?

Sea surface salinity (**SSS**) is the highest in tropical oceans where the evaporation rate is high (higher than precipitation rates). It is lower in polar regions, where lots of freshwater comes from melting ice. It is also lower near coasts where river runoff is high and lots of surface water enters the ocean.



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Sea surface vs. the deep ocean

What is it like in the ocean depths?

Regional variations in temperature and salinity (and therefore density) are confined to the ocean surface.

Beneath the uppermost 2,000 meters of water, there are practically no differences in temperature and salinity (and therefore, density).

The deep ocean below a tropical place is just as cold and salty and dense as below the Arctic region.

The Oceans

Sea surface vs. the deep ocean

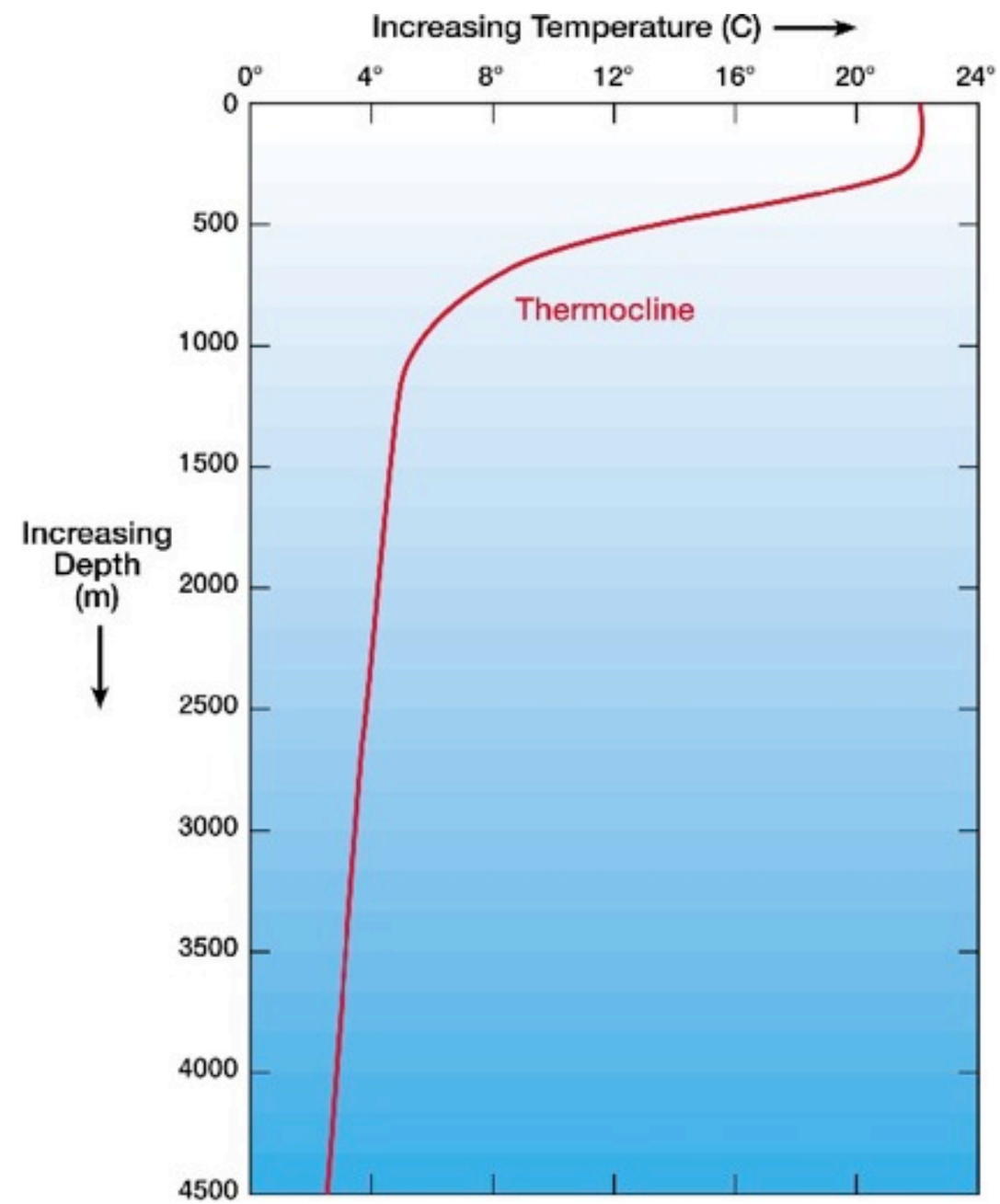
What is the temperature like in ocean depths?

Temperature changes with depth.

Near the surface, there is little decrease in temperature with depth because of water mixing by waves and surface currents.

Below that **mixed zone**, the temperature starts to decrease rapidly with depth. This zone is called **thermocline**. In the tropics, there is more solar heat and greater sunlight penetration due to greater angle of rays and less suspended matter in water -- so thermocline is more pronounced and deeper. (In cold regions, there is little solar heating so the thermocline is absent).

Below the thermocline, temperature is stable and close to uniform (between 3ºC and -1ºC). This is most of the ocean's volume, so that's why global ocean temperature average is <4ºC).



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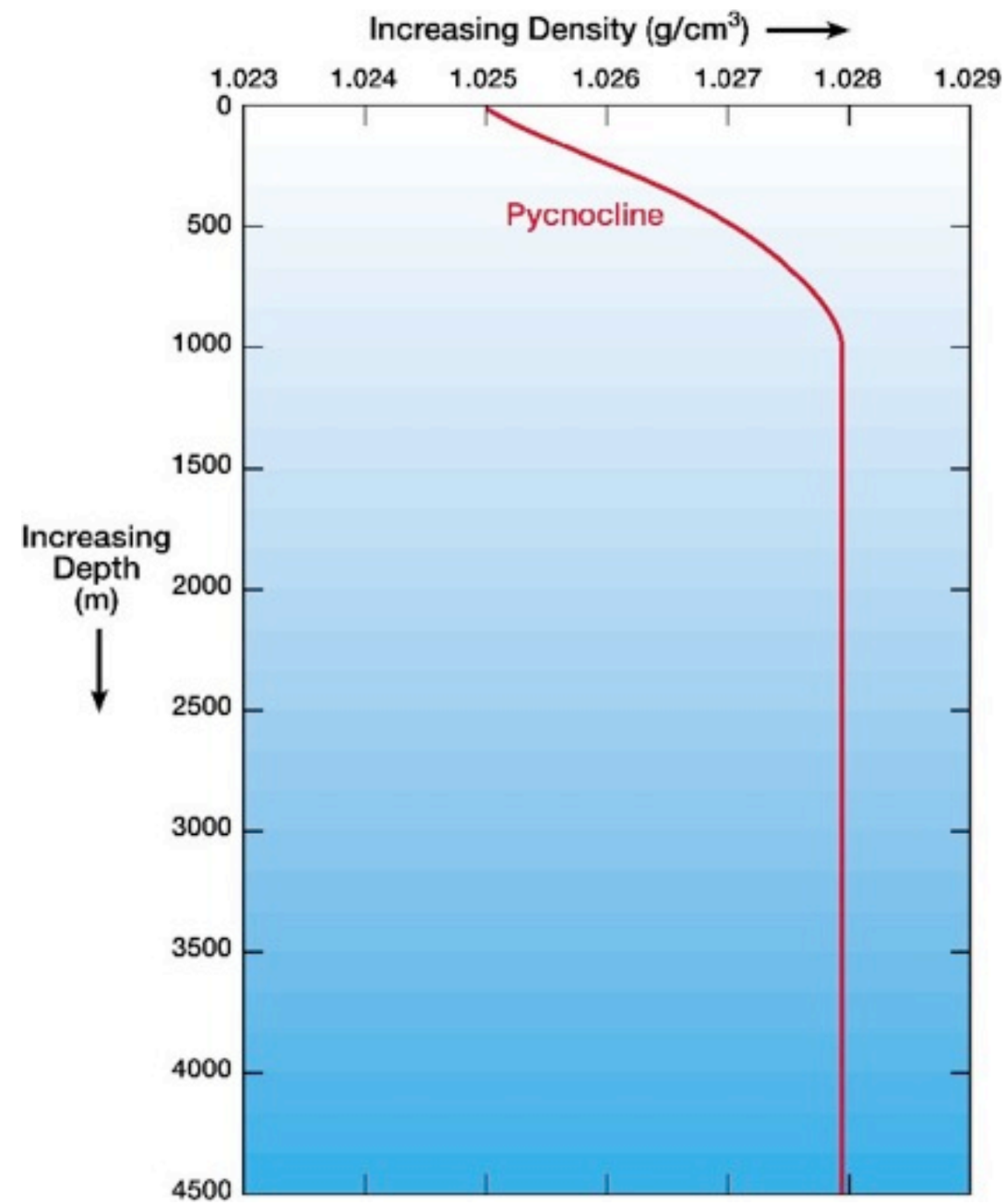
Sea surface vs. the deep ocean

What is the density like in ocean depths?

Density changes with depth.

Density of water increases as temperature decreases. That means that the warm water at the surface is less dense than cold water in the ocean depths. This is to be expected -- less dense things float on top of more dense things.

If the situation reverses and the water at the surface becomes more dense (e.g., due to increase in salinity) than the deep water, this surface water will sink to find an equilibrium.



2 The Oceans

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Sea surface vs. the deep ocean

What is the density like in ocean depths?

The ocean is density stratified <u>due to differences in density</u> (mostly due to different temperatures).

2% of ocean volume

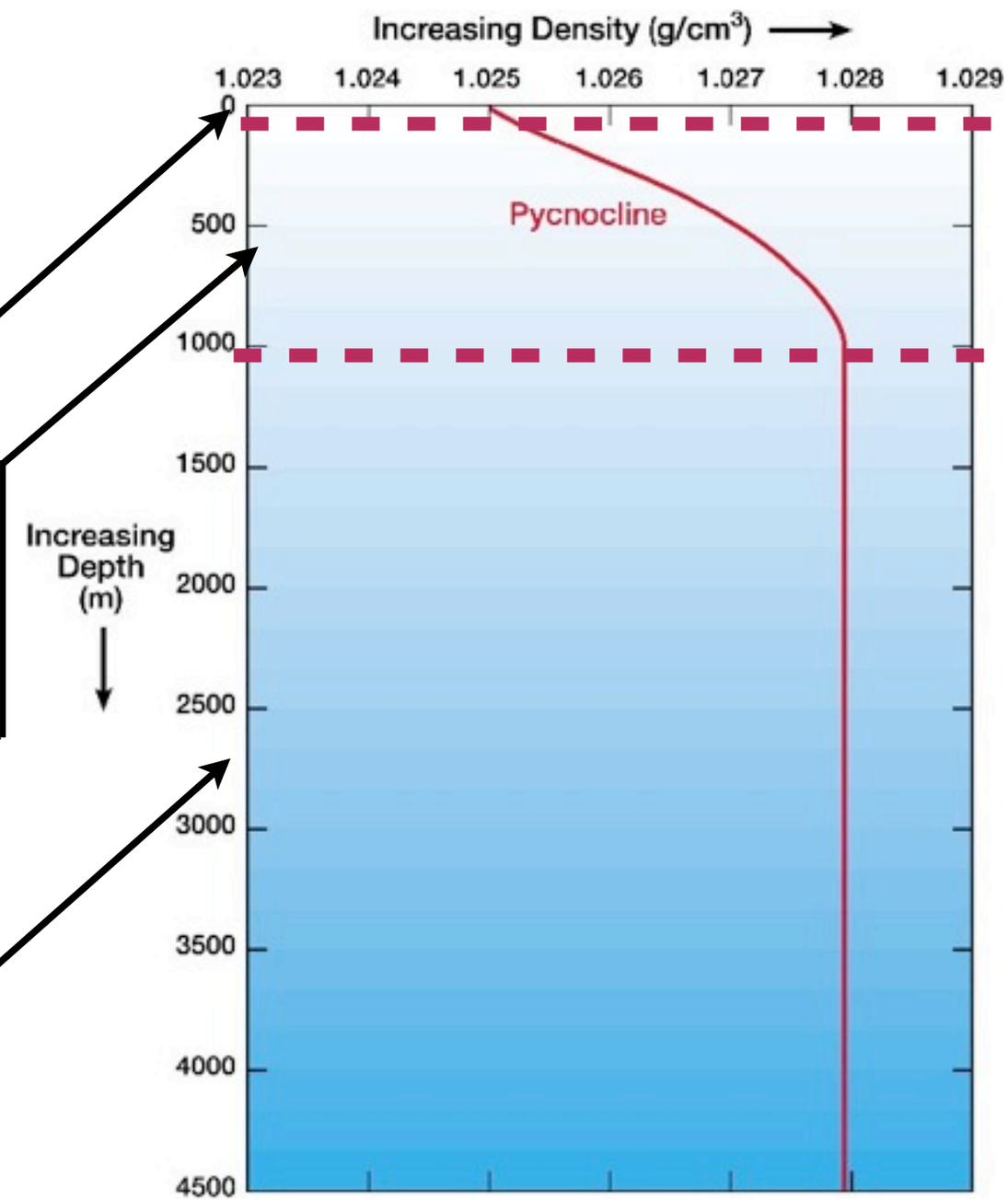
Surface zone (mixed layer): Temperature and salinity are relatively constant with depth because of mixing by waves and currents. This zone is in contact with atmosphere and receives sunlight. It is the least dense water of the ocean (density still increases with depth). Thickness varies locally from a few meters to few 100s m.

18%

Pycnocline: Depth where the density increases very fast with depth. It isolates surface water from denser deeper water.

80%

Deep zone: Below 1000m, there are very slight changes to water density with depth.



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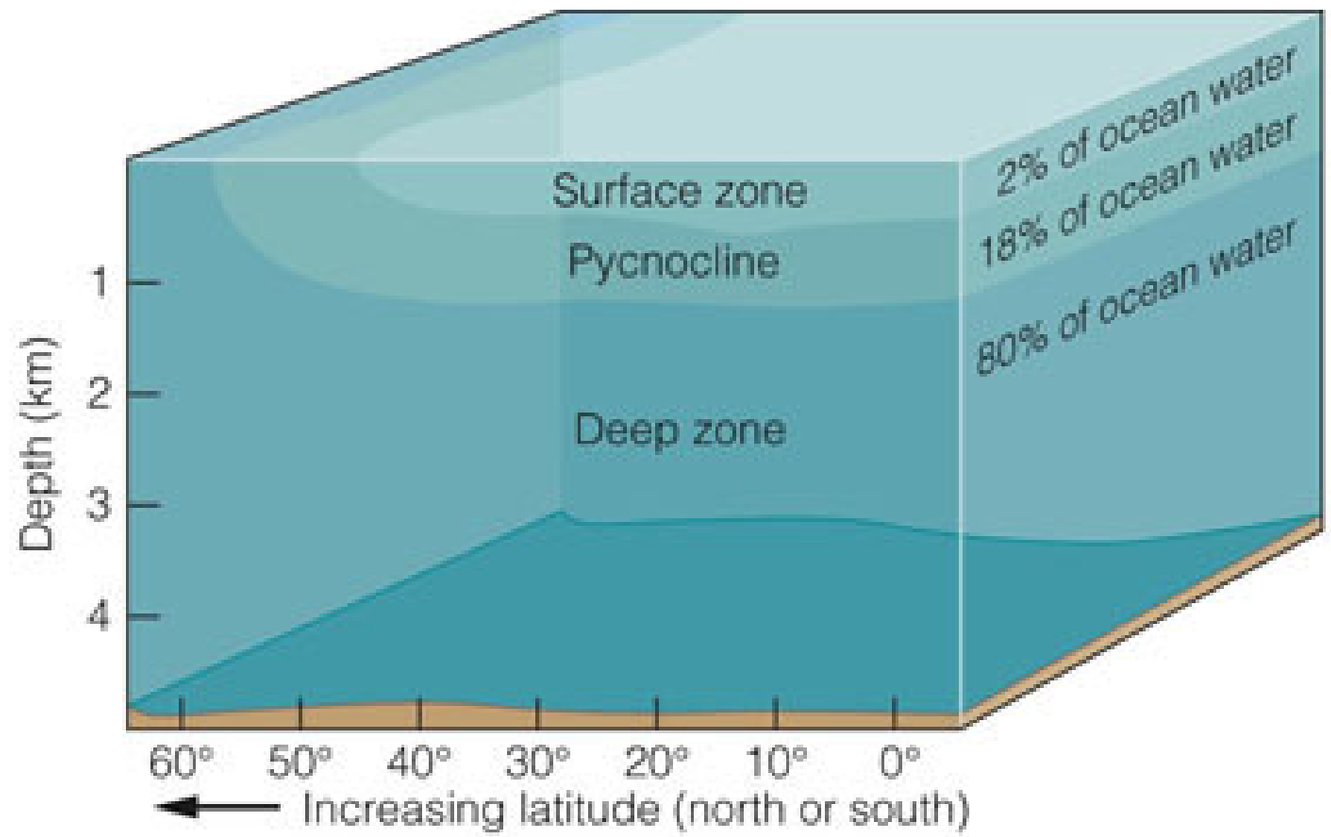
Sea surface vs. the deep ocean

What is the density like in ocean depths?

Surface zone (mixed later), pycnocline zone, and deep zone have characteristic temperature, salinity, and density, and therefore represent **distinct water masses**.



Layering by density effectively traps huge volumes of water below the pycnocline and isolates them from solar heating, surface circulation, and light. 80% of the ocean is thus not involved in surface circulation.

So does that mean that there is no vertical circulation? Once the water is deep does it ever come back up?

Sea surface vs. the deep ocean

What is the density like in ocean depths?

ACTIVITY:

Layering of water by density.

Exercise using waters of different salinities colored by different dyes. Waters are gently added to the same vessel one after another and stratification is observed.

WATER FOR LIFE

Ocean circulation

The ocean is in constant motion. That means that the vast water mass that comprises the oceans is always on the move. These movements of large water masses at the ocean surface and also below the ocean surface, throughout the ocean and including great depths, are called **currents**. They move warm and cold water from one place to another and are therefore very important in controlling the climate of our planet. They are also important for living things because they transport nutrients that marine organisms need.

What are surface currents?

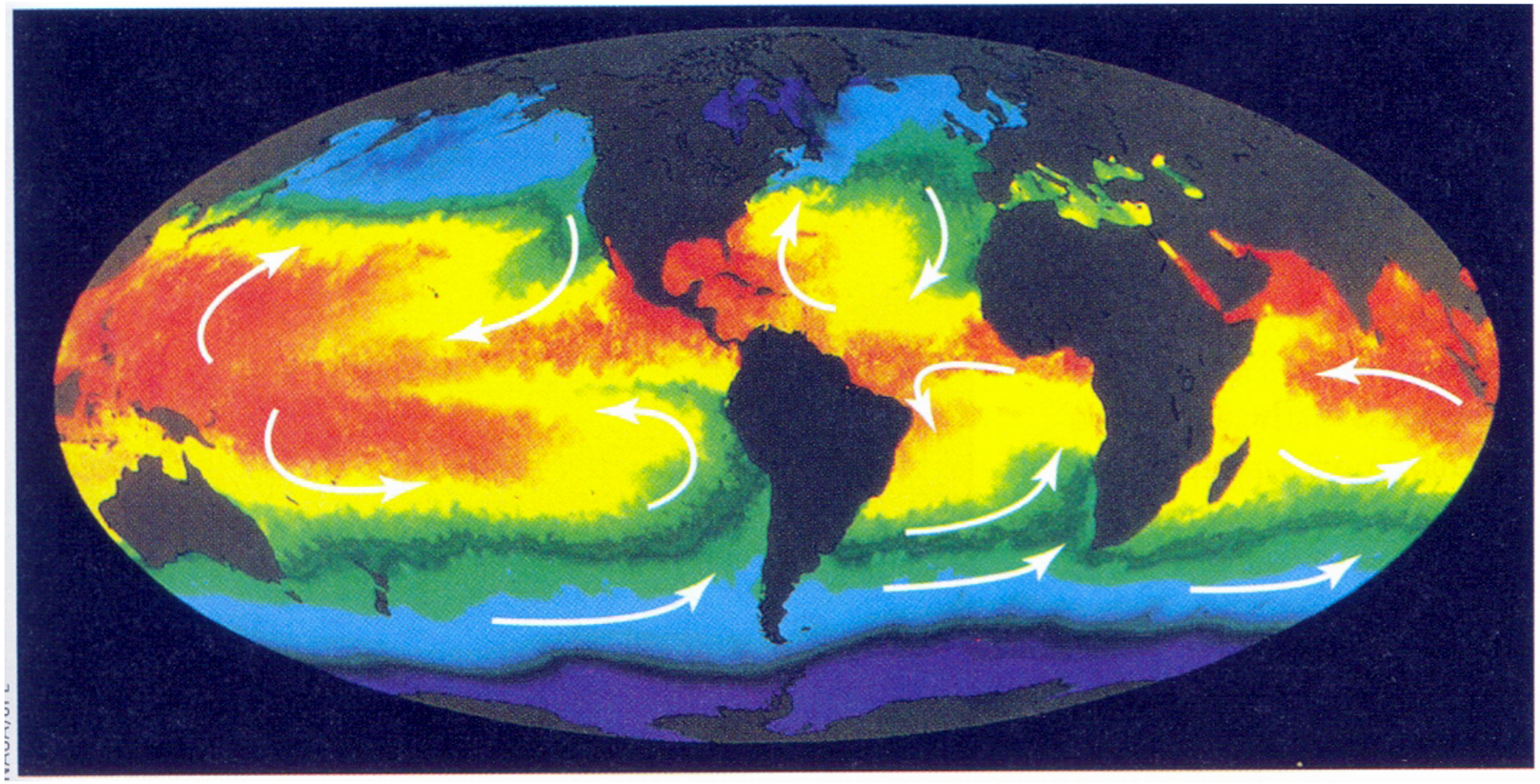
Are there deep ocean currents?

Ocean circulation

What are surface currents?

Sea currents are movements of large water masses between different parts of the ocean. At the ocean surface, the **currents are driven by wind**.

Just as there are characteristic winds blowing in different parts of the globe, so there are permanent surface currents. However, due to the rotation of the Earth, the currents are not straight, they veer to the side.



Surface currents as seen from the pattern of sea surface temperatures. Warm colors represent warm water, cold colors represent cold water. Note how currents move and twist clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.

Ocean circulation

Are there deep ocean currents?

Sea currents are not limited to the ocean surface. There are large scale currents in the deep ocean and they are **driven by differences in density**. Remember that the ocean is density stratified, so vertical movement of water masses can only happen where changes in density permit it.

In general, surface water is warmer (less dense) than deeper water. When surface water also has lower salinity, it makes it even less dense, so it easily floats. However, **if *surface water has higher salinity or lower temperature than deeper water*, its high density can *destabilize vertical stratification of water.***

Very dense water is produced at poles (cold and saline due to ice freezing) and dry, hot areas (saline water due to high evaporation). Such water sinks toward the bottom and displaced other, deeper water. In this way, the entire ocean water, not just the surface, circulates in a giant deep water circulation system. Because deep ocean currents are driven by density differences caused by temperature and salinity, they are known as **thermohaline circulation**.

*

In the tropical areas, there is a strong thermocline. Hot water on top, cold dense water below. This makes a very strong pycnocline and prevents vertical movement. The water column is stable despite salinity being relatively high due to high evaporation rates.

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Waves

Waves nearly constantly wash against our reefs and shores. Let's consider a few basic questions about them to understand them better.

Does water travel in a wave?

What causes waves?

How big do they get?

WATER FOR LIFE

Waves

Does water travel in a wave?

Waves are disturbances caused by the movement of energy from a source through some medium. The medium can be solid, liquid, or gas.

Which waves have we discussed or you already know? Seismic, light, sound, radio, etc.

As energy passes through a medium, particles of the medium move. Sometimes we can perceive this motion. **Ocean waves** *appear* as ridges of water traveling across sea surface.

The traveling waves seem like the water is moving with the wave, but this is not the case. **Only energy travels at the speed of the wave, water does not.**

The movement of water along a wave is an illusion.

WATER FOR LIFE

Waves

Does water travel in a wave?

ACTIVITY:

A wave of hands.

We will all line up and put our hands up and down in a sequence, one after another. This will simulate a wave and demonstrate how a wave travels but no horizontal movement occurs.

WATER FOR LIFE

Waves

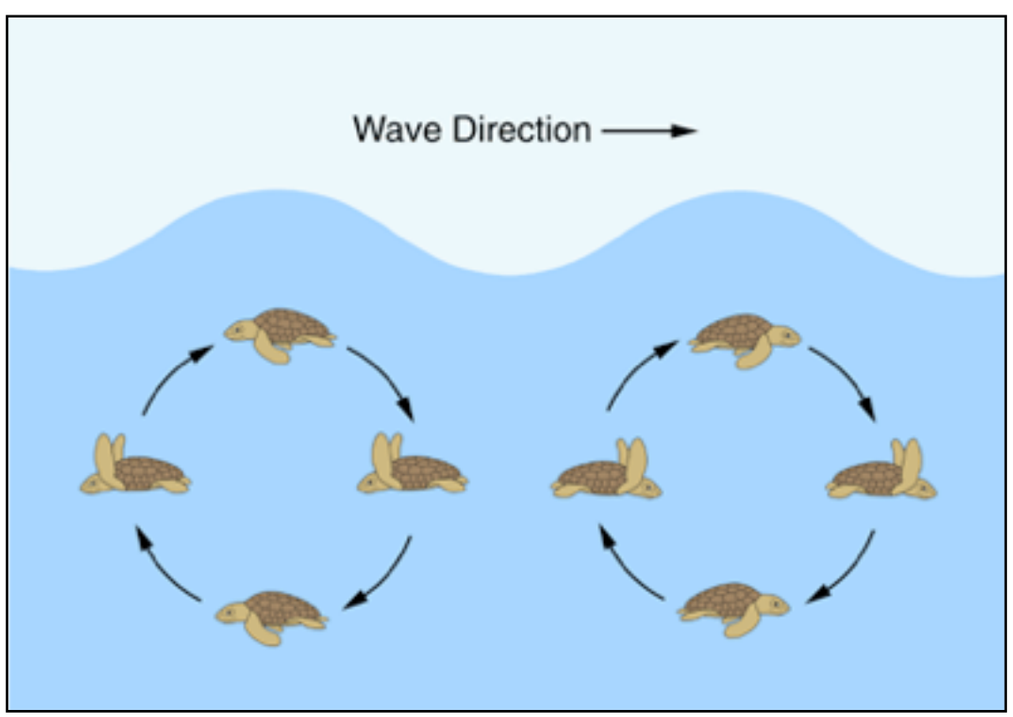
Does water travel

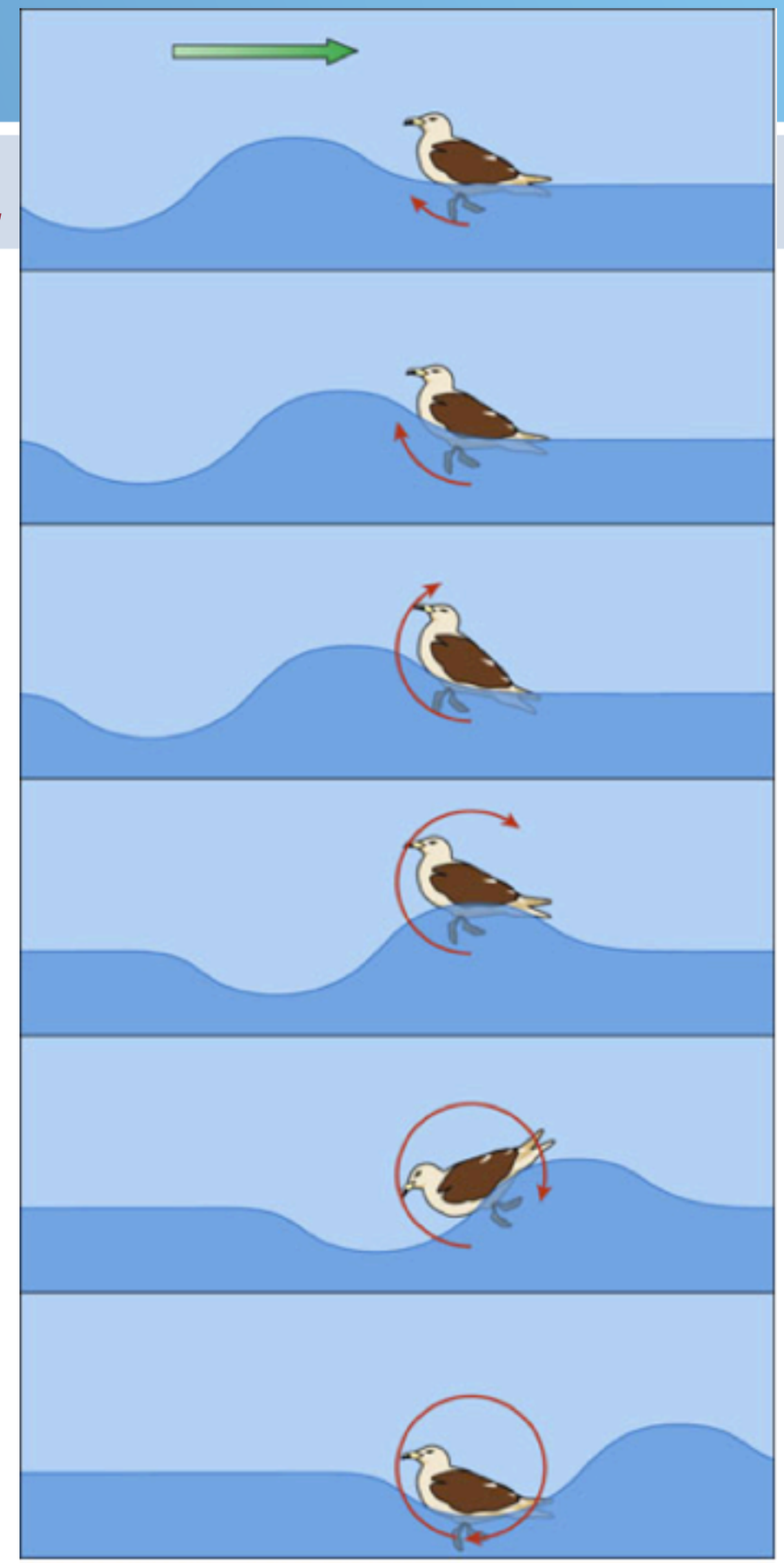
Energy is transmitted from one water particle to another. Energy - and not the water - travels along ocean surface.

<u>Water particles in a wave only undergo circular motion in closed orbital paths.</u>

Did you ever swim among waves?

How did the water move you? Horizontally along the wave or mostly up and down?





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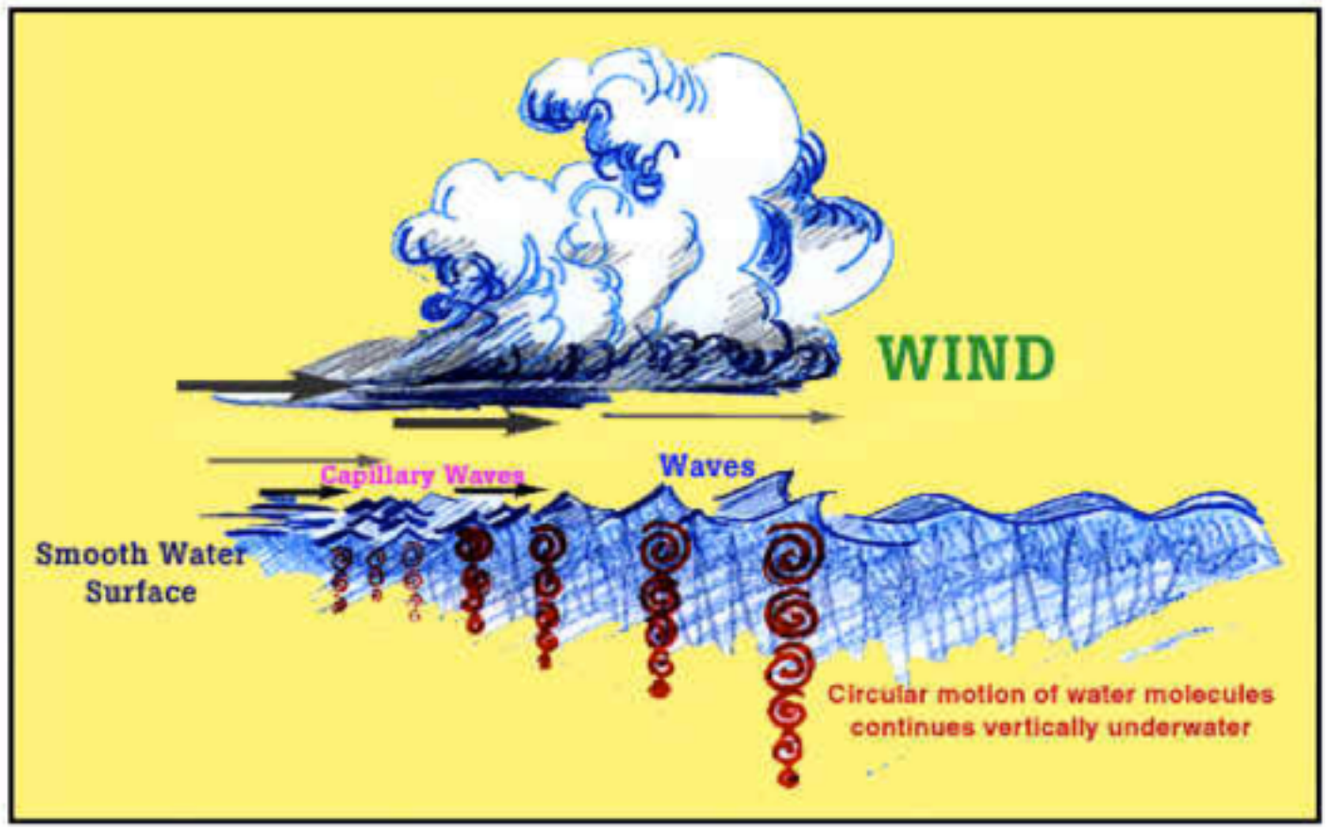
Waves

What causes waves?

The main cause of waves is the wind. They grow by <u>transfer of wind energy into water.</u> The force opposing this is gravity, which seeks to restore flatness.



Some special waves can be caused by other factors, notably underwater earthquakes which can trigger giant waves known as tsunami.

WATER FOR LIFE

Waves

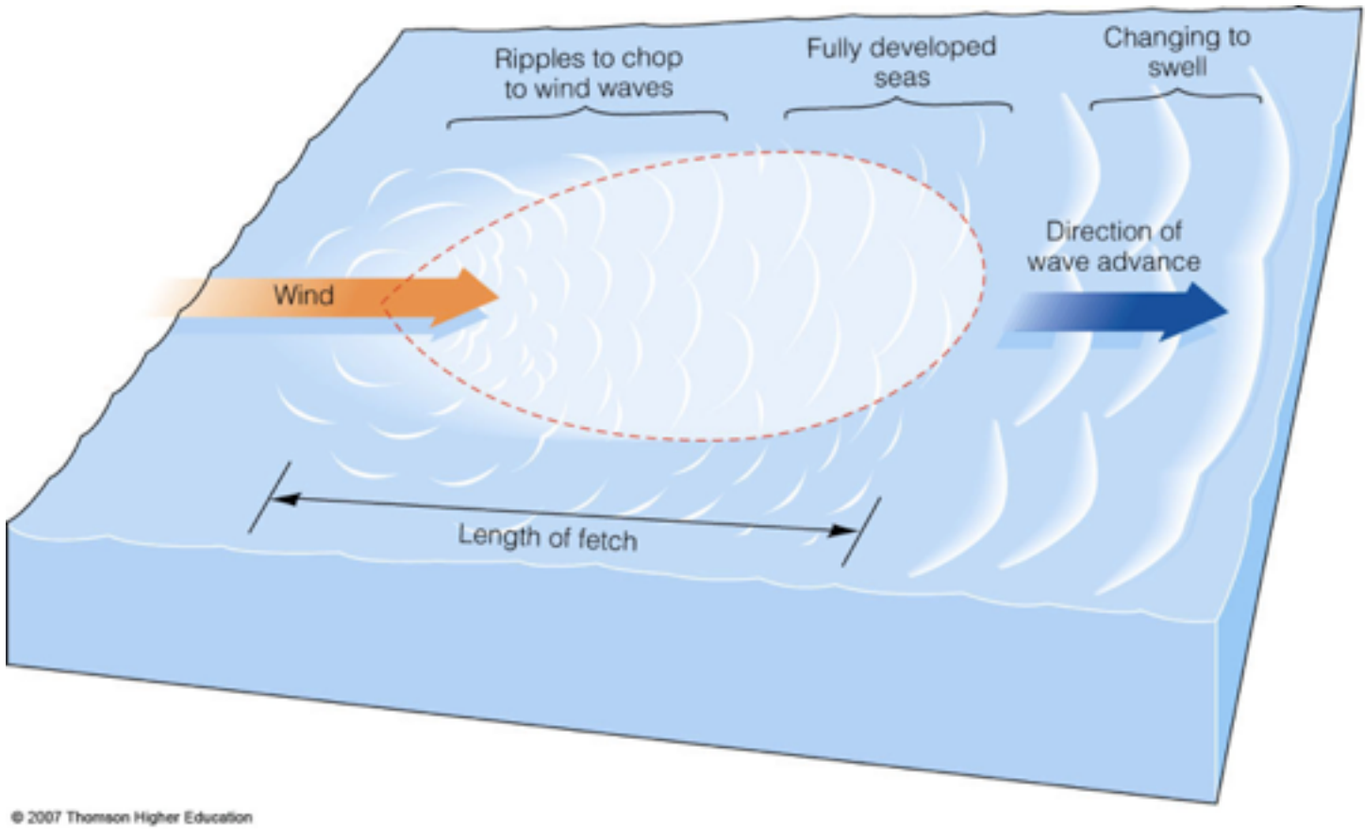
How large can waves get?

Wave height (and formation of wind waves in general) is controlled by three factors:

Wind speed -- must be faster than the speed of waves. Energy can be transferred from air to ocean only if wind is moving faster than wave crests.

Wind duration -- must be sufficiently long. Fast winds that blow very short time will not generate large waves.

Wind fetch -- distance over which wind blows without a major change in direction should be significant. The longer the wind fetch the bigger the waves.



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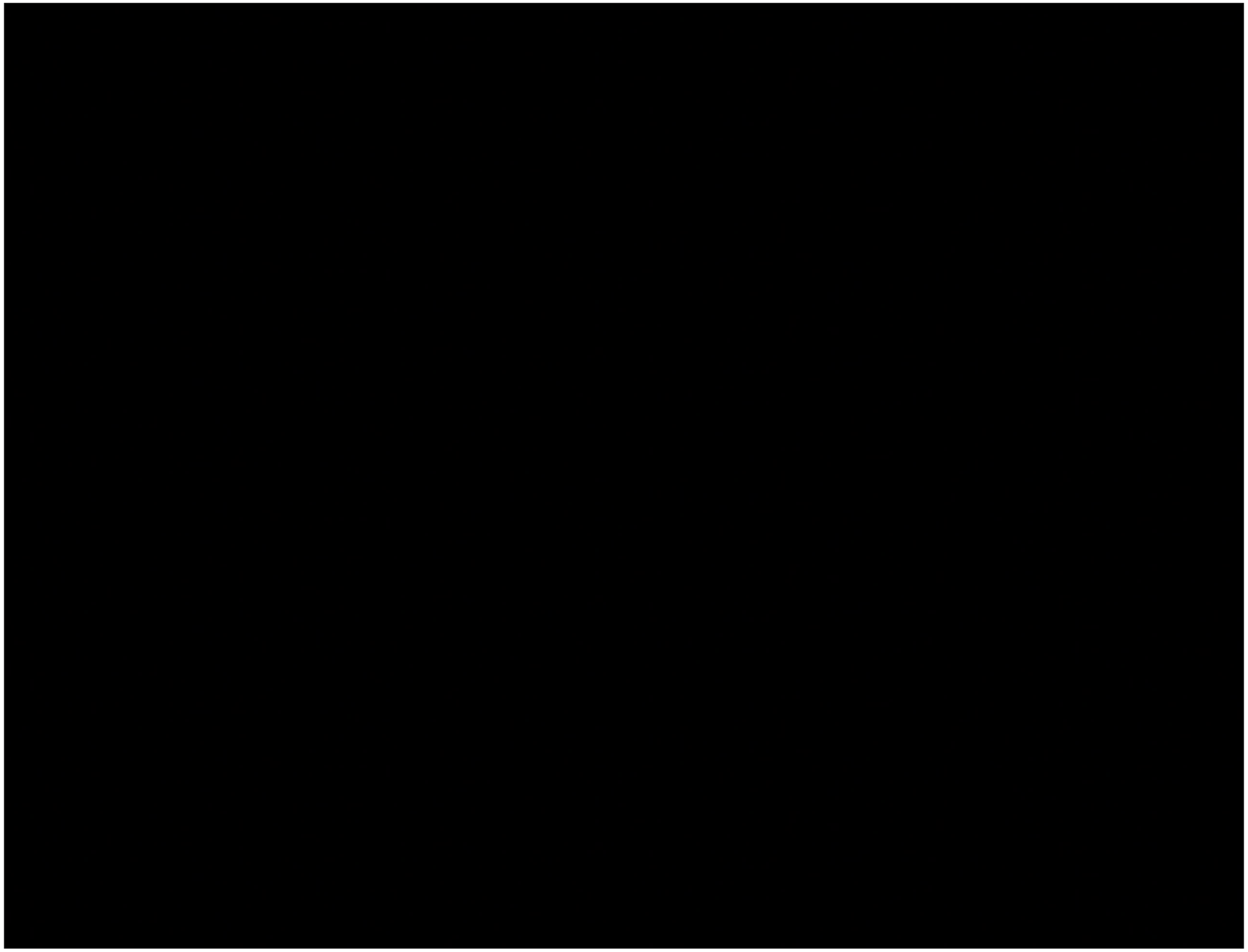
Waves

How large can waves get?



WATER FOR LIFE

Waves

How large can waves get?

WATER FOR LIFE

Waves

How large can waves get?

WATER FOR LIFE

Waves

How large can waves get?

WATER FOR LIFE

WAVES

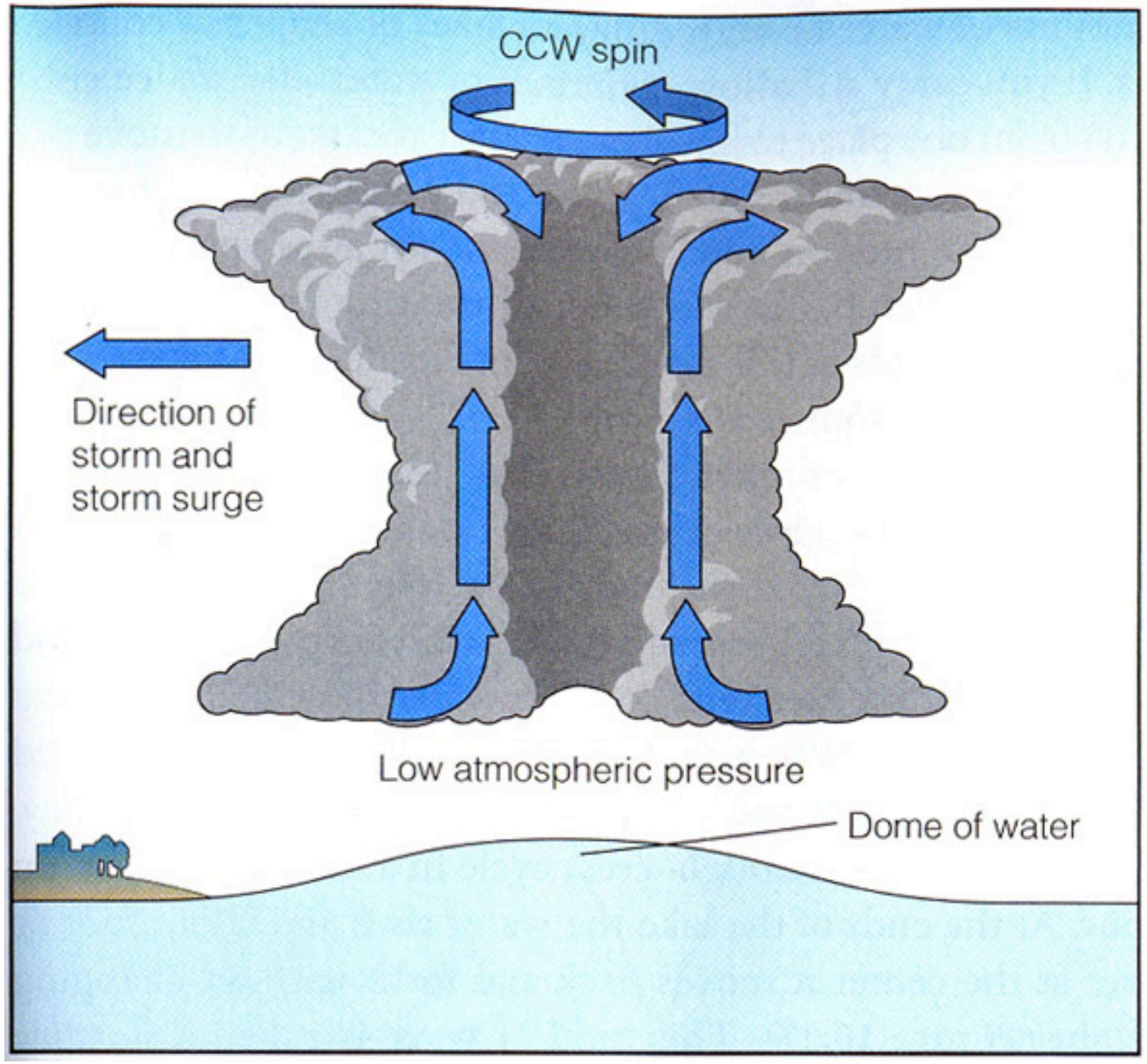
HOW LARGE CAN WAVES GET?

Waves

What is a storm surge?

Typhoons can create localized low atmospheric pressure area. The underlying ocean surface responds to this and forms a few-meters tall dome of water called a **storm surge**.

Technically, a storm surge is not a wave. It's a giant bulge that temporarily exists below a low atmospheric pressure area.

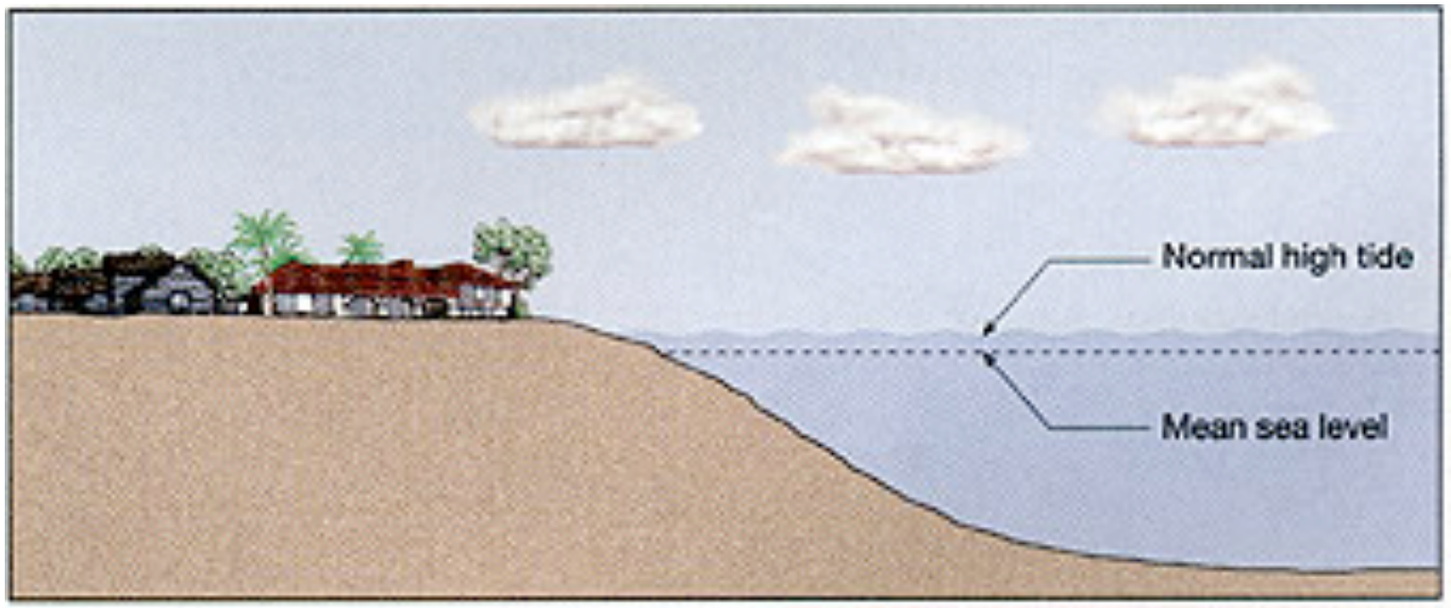


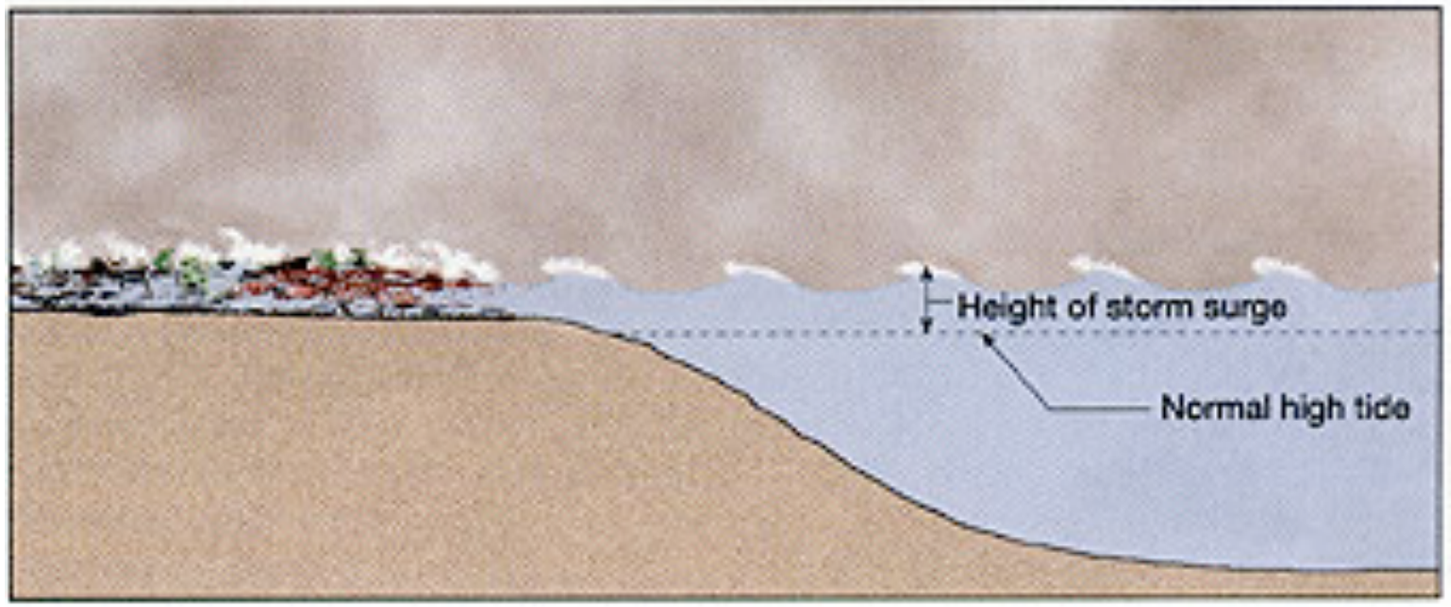
Waves

What is a storm surge?

It can be over 1 m above normal sea level. It moves along with the storm, so when storm makes landfall, the storm surge hits the shore and looks like a massive wave, several meters taller than normal. It can cause much destruction (*e.g., Hurricane Katrina*), especially if confined into bays or estuaries where it can reach great heights.

Storm surge does not reach land as a single breaking wave, but rushes inland like a sudden "windblown tide".





WATER FOR LIFE

Tides

Tides are recurrent daily risings and lowerings of the sea level. The rising is called the high tide and the lowering is called the low tide.

What causes tides?

What are spring and neap tides?

WATER FOR LIFE

Tides

Tides are recurrent daily risings and lowerings of the sea level. The rising is called the high tide and the lowering is called the low tide.

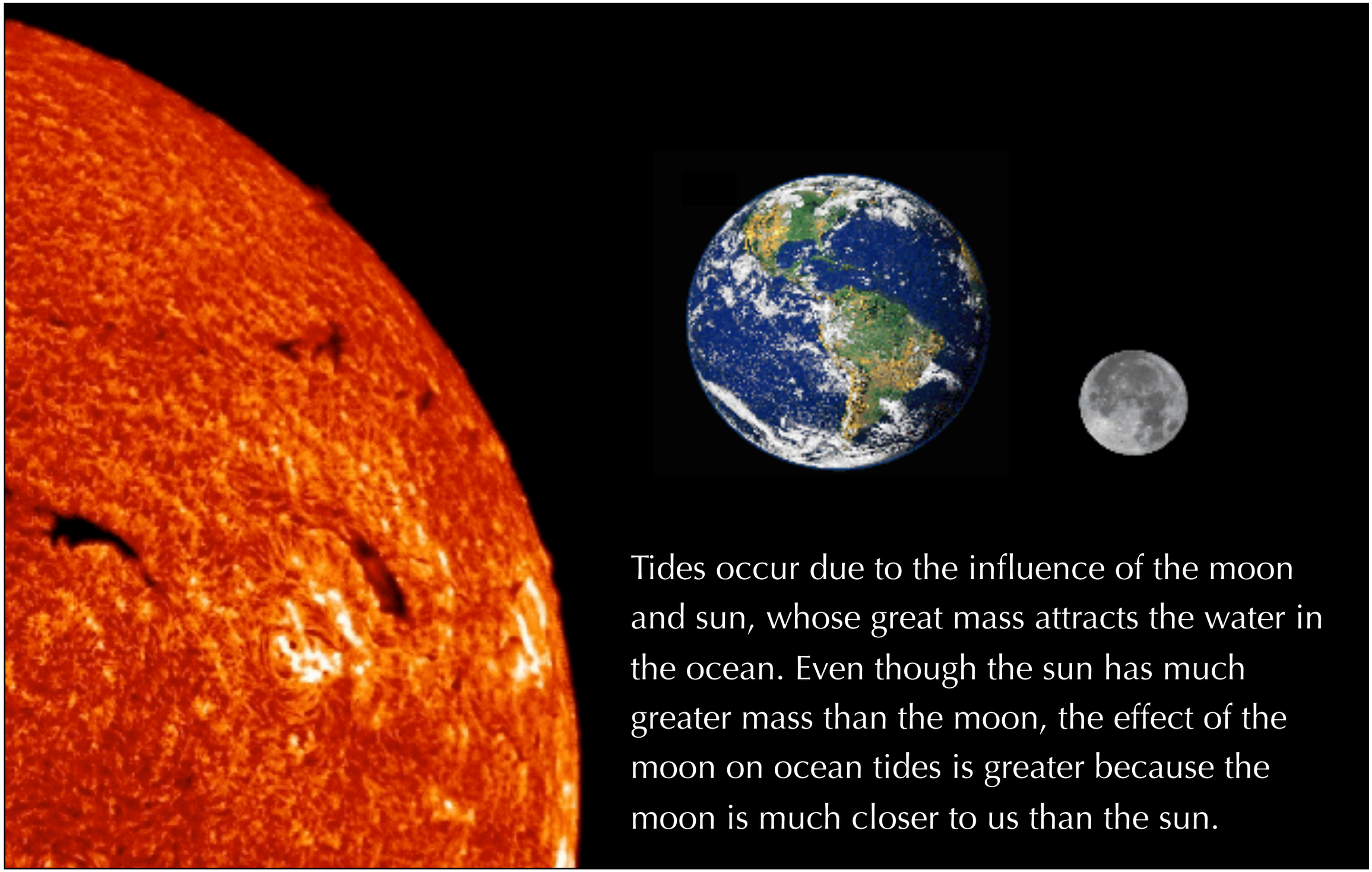
What causes tides?

What are spring and neap tides?

WATER FOR LIFE

Tides

What causes tides?



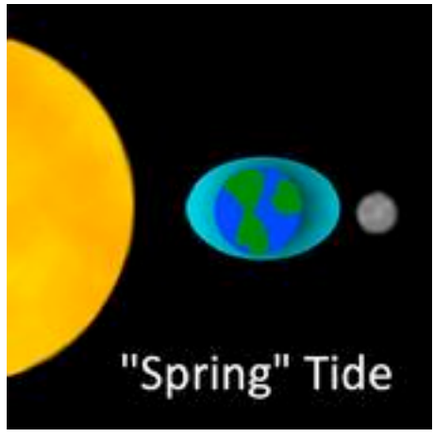
Tides occur due to the influence of the moon and sun, whose great mass attracts the water in the ocean. Even though the sun has much greater mass than the moon, the effect of the moon on ocean tides is greater because the moon is much closer to us than the sun.

Tides

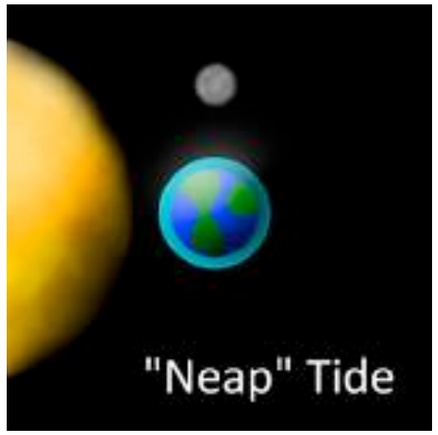
What causes tides?

TIDES

WHAT ARE SPRING AND NEAP TIDES?



When the Earth, sun, and the moon are aligned)-- solar and lunar gravity reinforce each other's effect and cause higher high tides and lower low tides: **SPRING TIDES**.

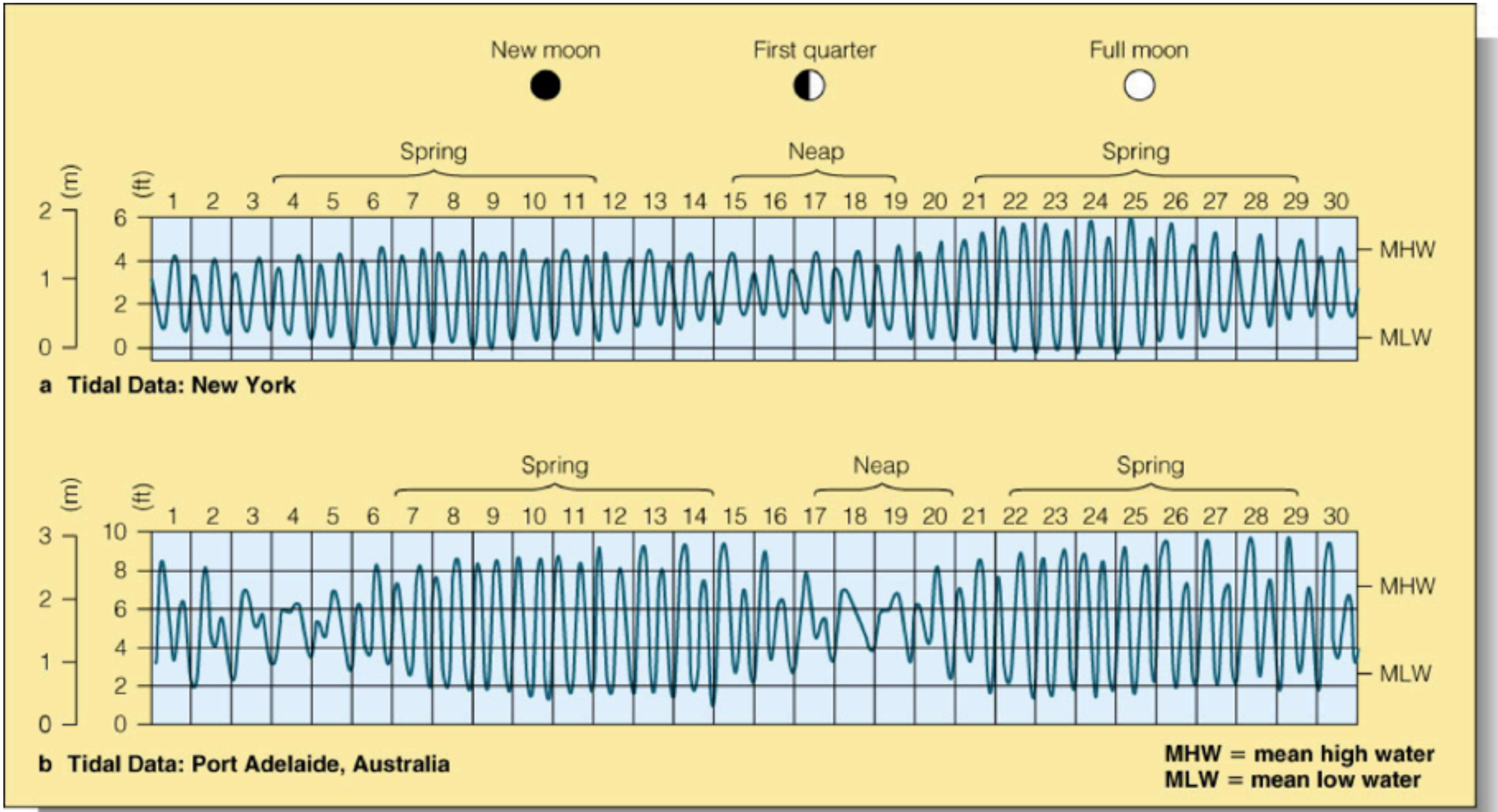


At times when the Earth, sun, and the moon form a right angle -- solar and lunar gravity diminish each other's effect and cause lower high tides and higher low tides: **NEAP TIDES**.

That is the reason why during young moon and full moon the high tide is quite high and the low tide is quite low. During 1st and 3rd quarter moons, the high tide is not so high and the low tide is not so low.

TIDES

WHAT ARE SPRING AND NEAP TIDES?



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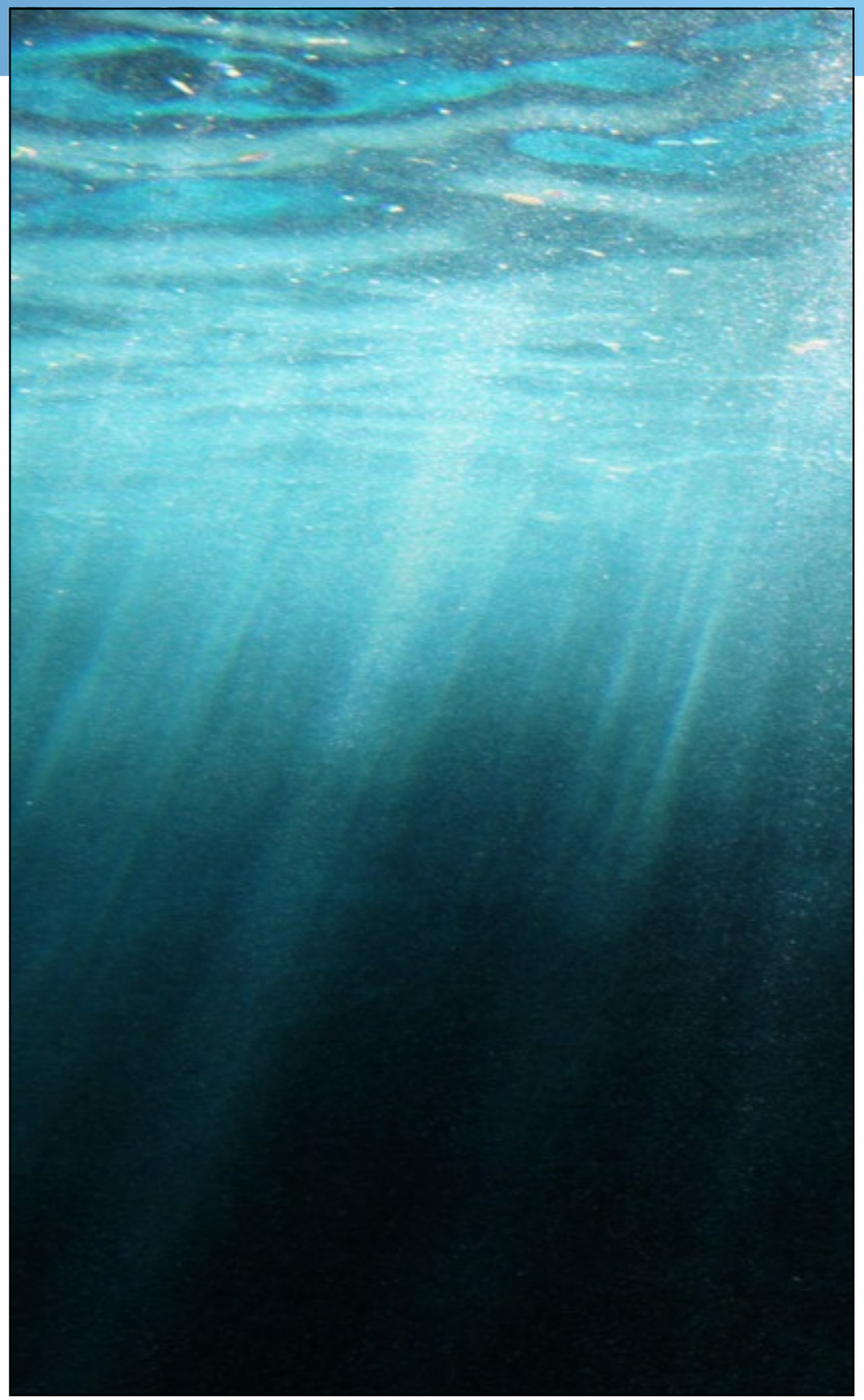
WATER FOR LIFE

Light in the Ocean

Light is visible form of electromagnetic radiation. It travels in waves. Light does not travel well in the ocean. When sunlight hits the ocean surface, much of it is reflected. The rest is absorbed by water molecules and scattered, resulting in rapid **attenuation** of light with depth.



How deep does light reach?

Is most of the ocean dark?

WATER FOR LIFE

LIGHT IN THE OCEAN

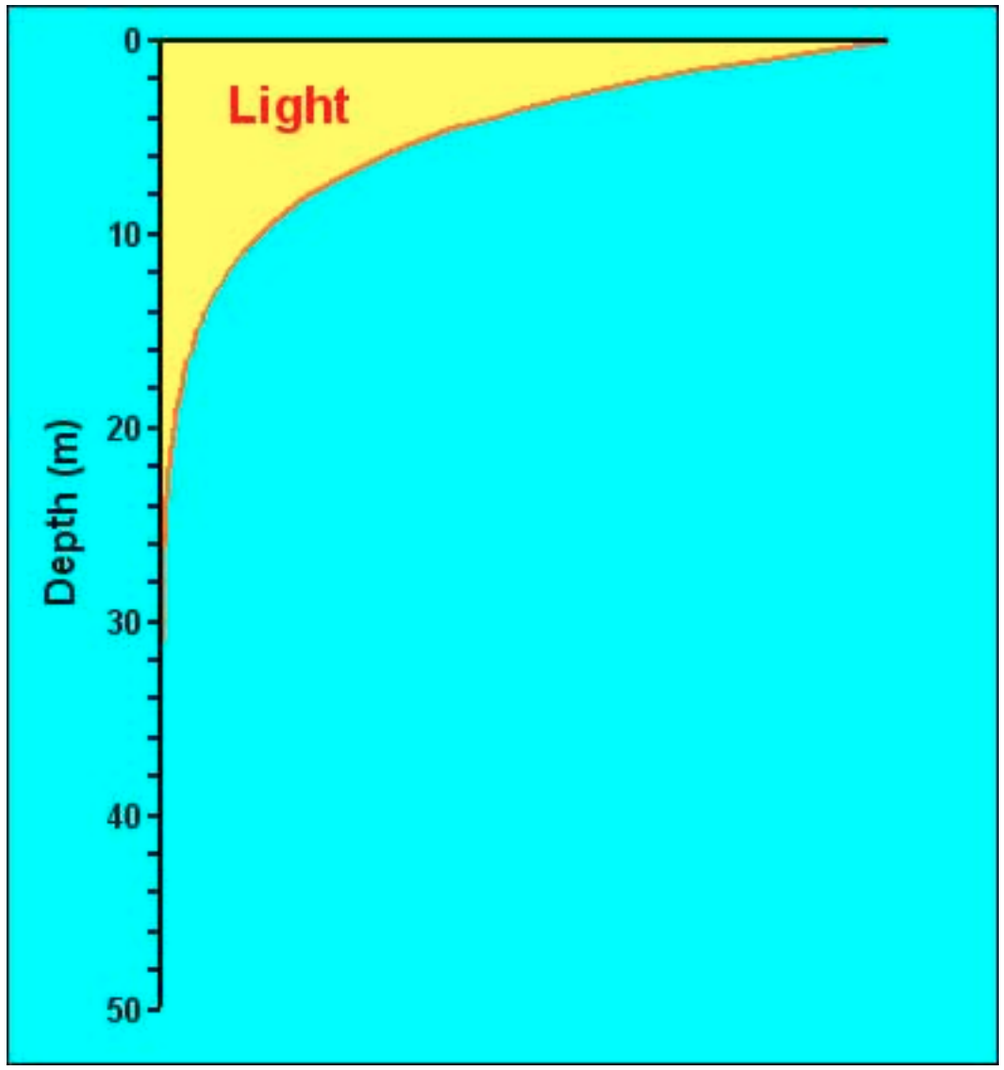
HOW DEEP DOES LIGHT REACH?

Intensity of light decreases with depth:

60% absorbed by 1 m

80% absorbed by 10 m

only 1% reaches 100 m



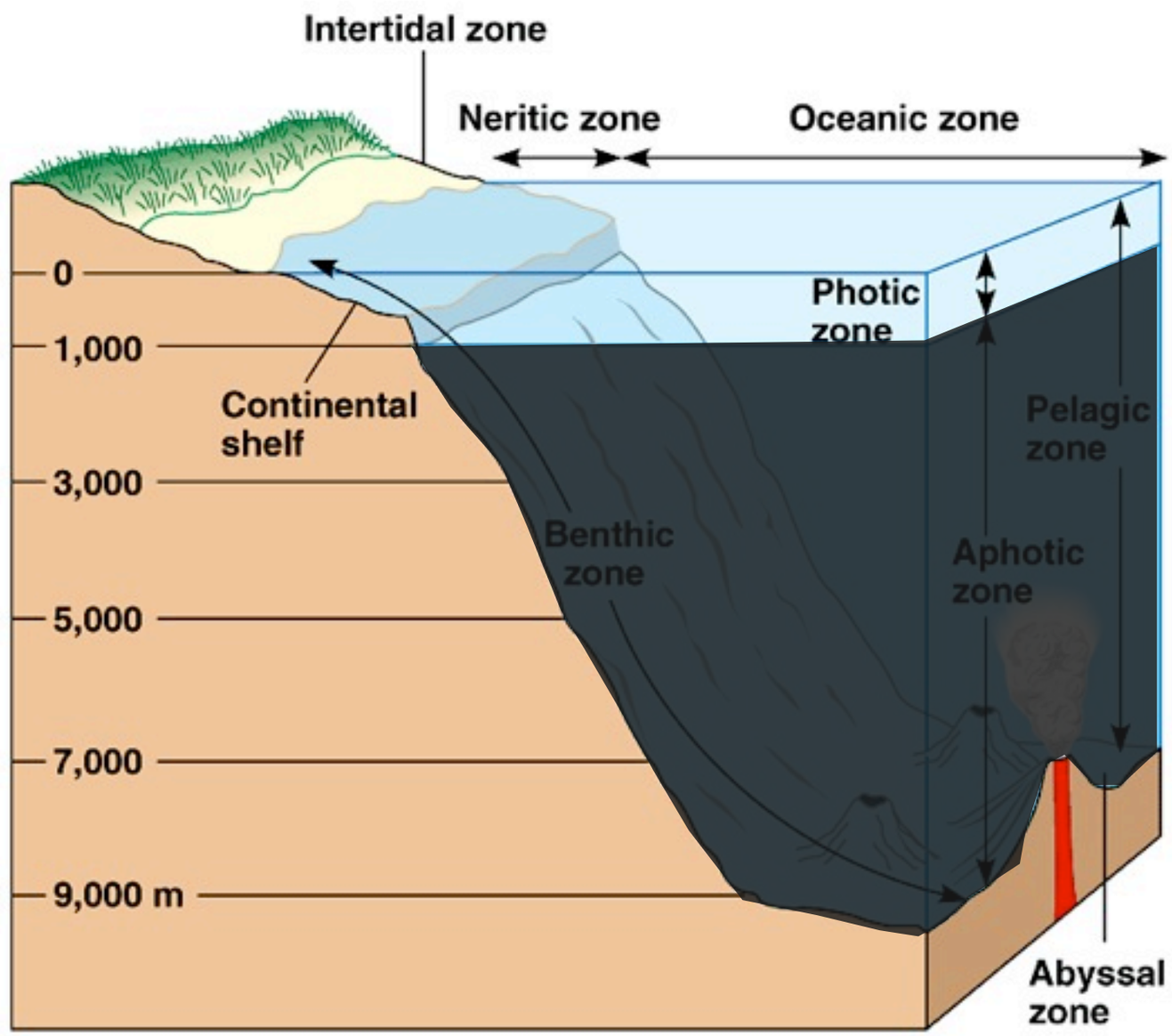
2 The Oceans

WATER FOR LIFE

LIGHT IN THE OCEAN

IS MOST OF THE OCEAN DARK?

Zone of light penetration is **photic zone**. Photosynthesis in ocean can occur only here. Below is **aphotic zone**, with no light penetration. Below few hundred meters, the ocean lies in complete and permanent darkness.



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photic zone life

aphotic zone life

KEY POINTS

- ★ Seawater is a solution of many different salts. In some small concentration, it contains practically every element found on Earth.
- ★ Total salt concentration in seawater is called salinity. It is different in different parts of the ocean. However, proportions of different components of salinity are always the same.
- ★ Seawater also has dissolved gasses. Their amount depends on temperature and pressure and is different in different parts of the ocean.
- ★ Different parts of the ocean surface and ocean depths have different temperature.
- ★ Due to differences in temperature and salinity, different water masses in the ocean have different densities. The ocean is layered into distinct water masses of different densities.
- ★ Any dense water at the surface will sink below less dense water in the depths. Such differences in density of water drive ocean circulation.

KEY POINTS

- ★ Waves are disturbances in the ocean surface. They are created by energy absorbed from the wind. Waves are energy that travels long distances. Water particles do not travel along waves.
- ★ Tides are regular and cyclical changes in sea level that are driven by gravitational attraction exerted by the Moon and the Sun on Earth, and specifically on the Earth's ocean.
- ★ Light is quickly absorbed in water. The vast majority of the ocean is permanently dark.