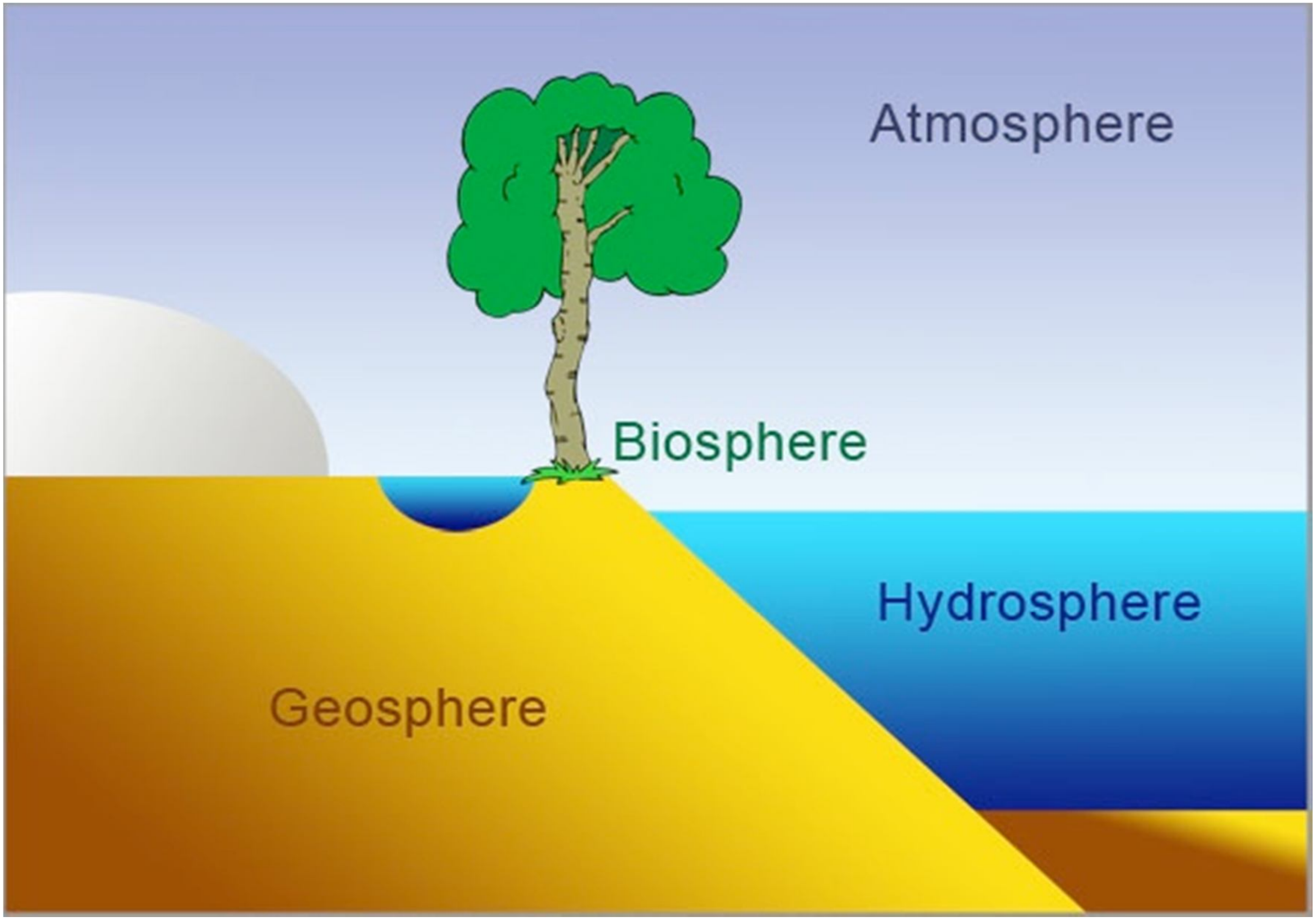
The Dynamic Earth

The Earth as a System

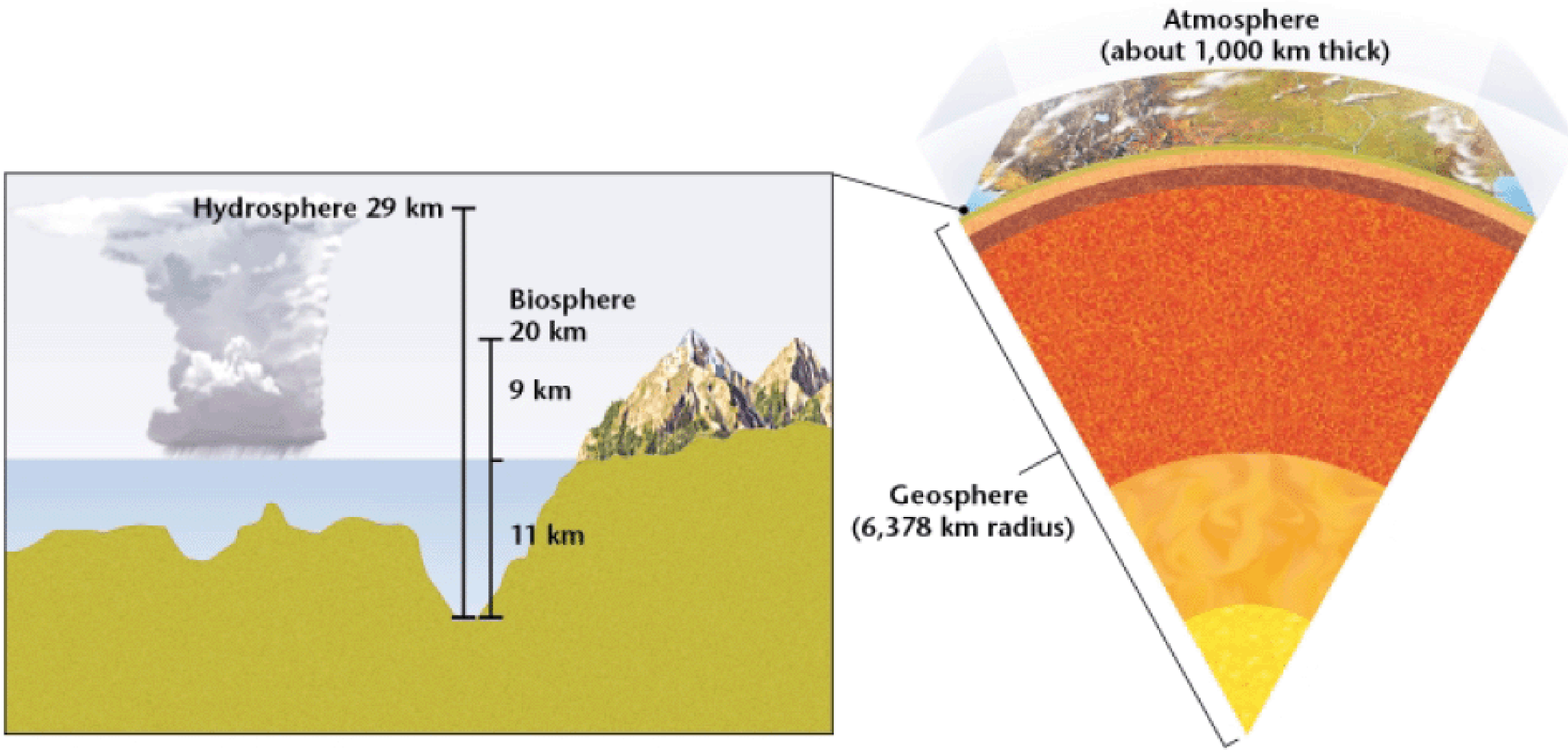
The Earth is an integrated system that consists of rock, air, water, and living things that all interact with each other.

Scientists divided this system into four parts:

- The Geosphere (rock)
- The Atmosphere (air)
- The Hydrosphere (water)
- The Biosphere (living things)


Atmosphere
Biosphere
Hydrosphere
Geosphere

The Earth as a System

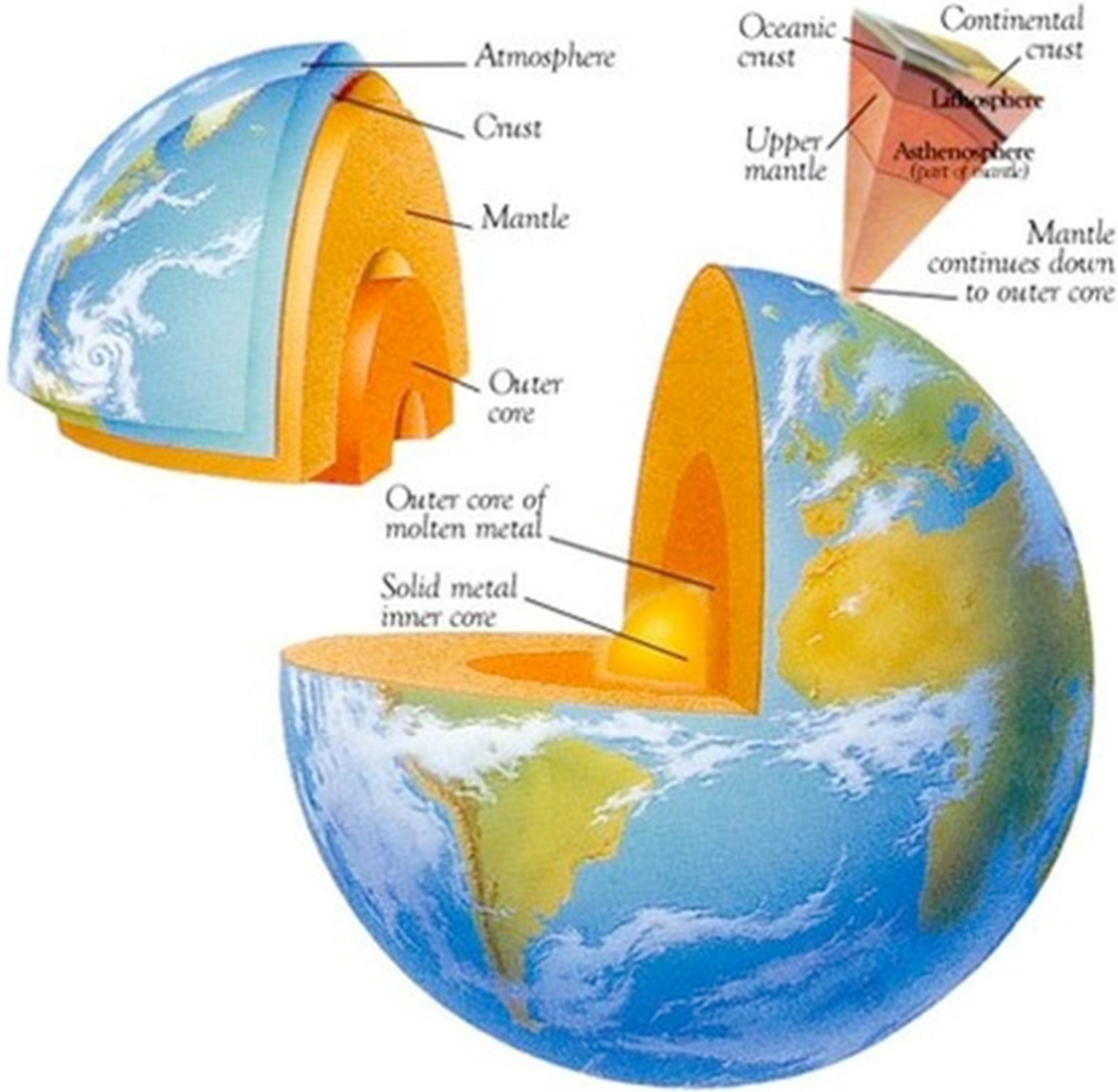


The Earth as a System

The **geosphere** is the mostly solid, rocky part of the Earth that extends from the center of the core to the surface of the crust.

The atmosphere is the mixture of gases that makes up the air we breathe.

Nearly all of these gases are found in the first 30 km above the Earth’s surface.

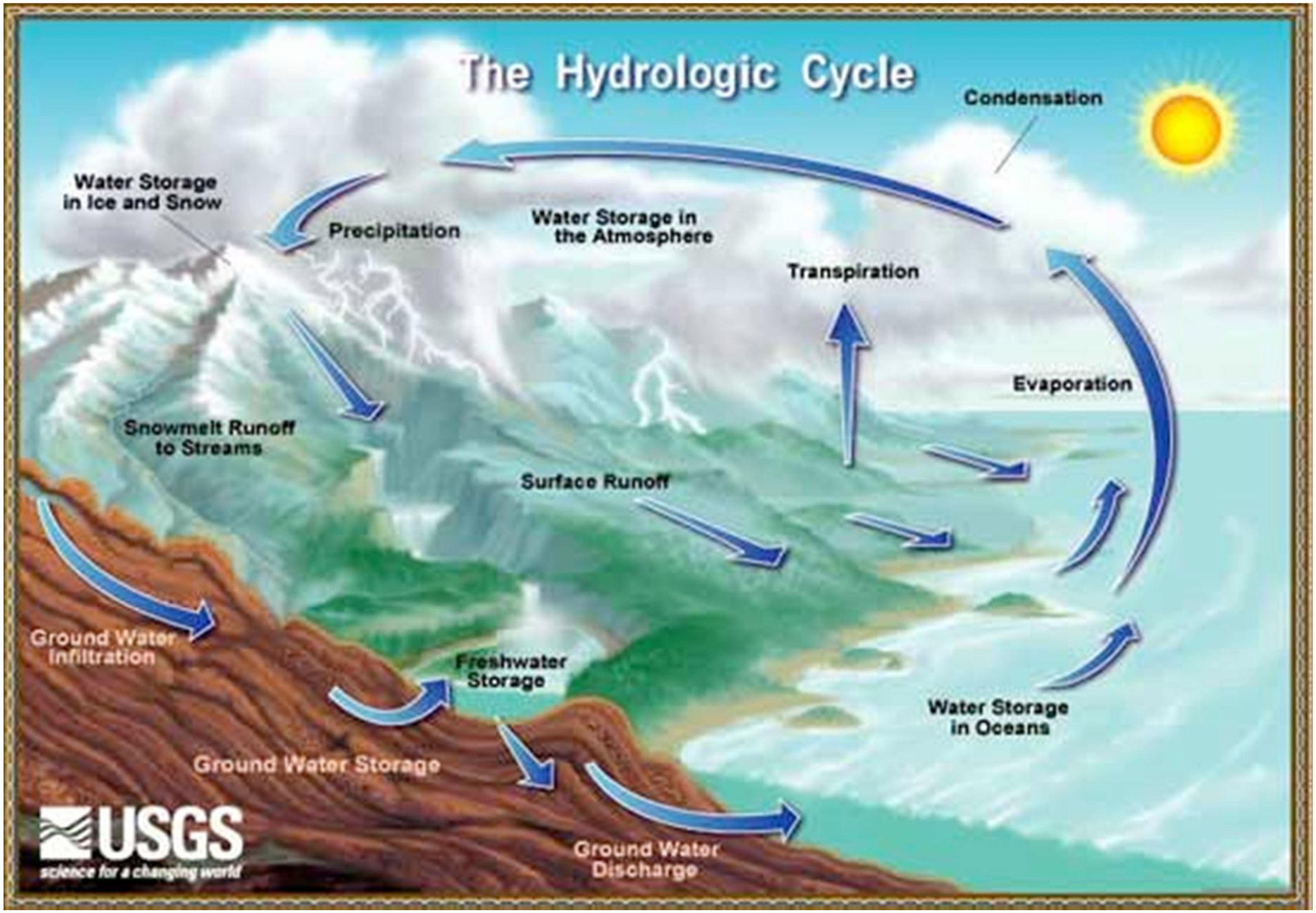

Atmosphere
Crust
Mantle
Outer core
Oceanic crust
Continental crust
Lithosphere
Upper mantle
Asthenosphere
Mantle continues down to outer core
Outer core of molten metal
Solid metal inner core

The Earth as a System

The **hydrosphere** makes up all of the water on or near the Earth's surface.

Much of this water is in the oceans, which cover nearly three-quarters of the globe.

However, water is also found in the atmosphere, on land, and in the soil.


The Hydrologic Cycle
Condensation
Water Storage
in Ice and Snow
Precipitation
Water Storage in
the Atmosphere
Transpiration
Evaporation
Snowmelt Runoff
to Streams
Surface Runoff
Ground Water
Infiltration
Freshwater
Storage
Water Storage
in Oceans
Ground Water Storage
Ground Water
Discharge
USGS
science for a changing world

The Earth as a System

The **biosphere** is the part of the Earth where life exists.

It is a thin layer at the Earth's surface that extends from about 9 km above the Earth's surface down to the bottom of the ocean.

The biosphere is therefore made up of parts of the geosphere, the atmosphere, and the hydrosphere.

Discovering Earth's Interior

Scientists use seismic waves to learn about Earth's interior.

Seismic waves are the same waves that travel through Earth's interior during an earthquake.

A similar process would be you tapping on a melon to see if it is ripe.

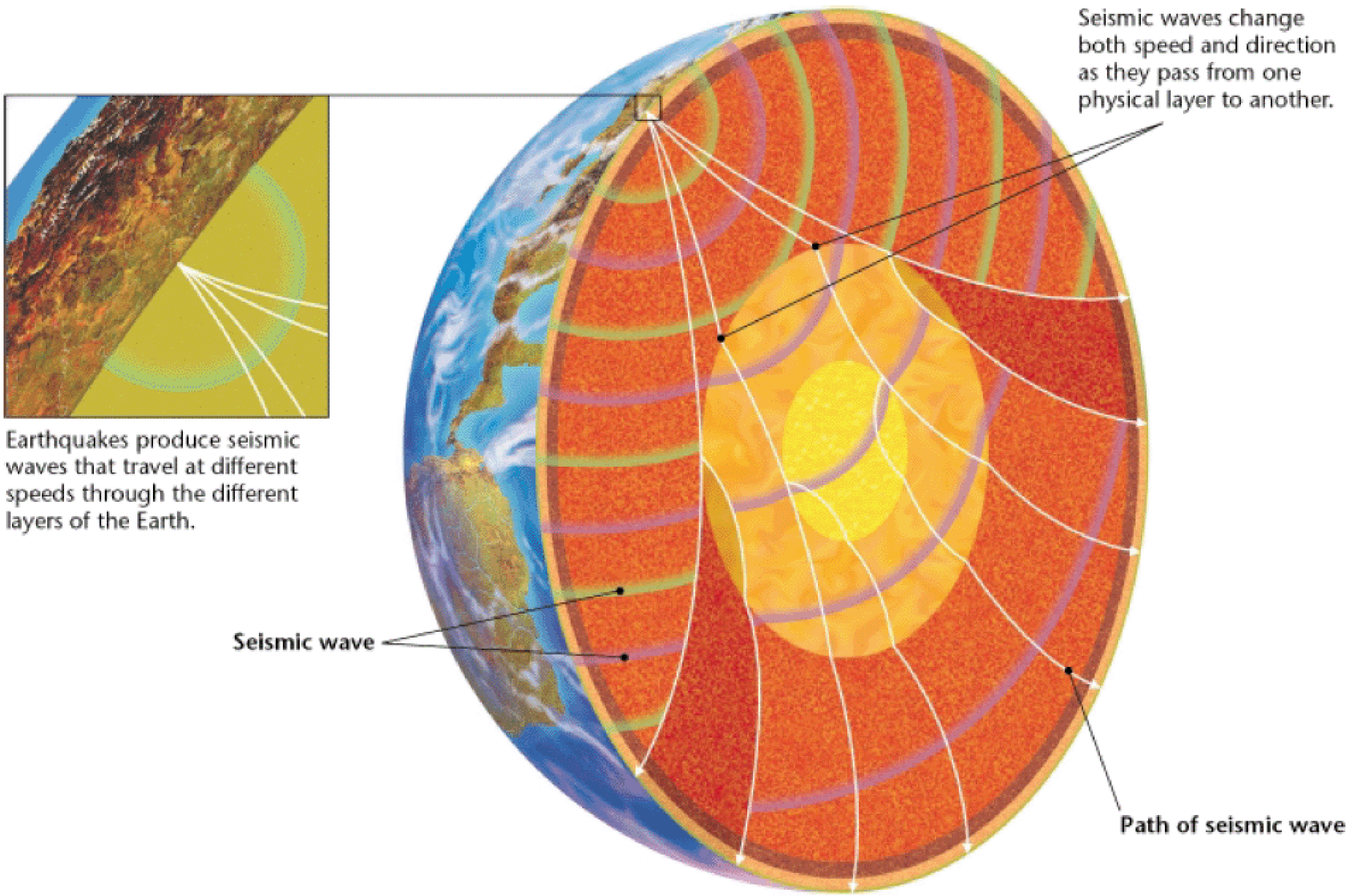
Discovering Earth ’ s Interior

A seismic wave is altered by the nature of the material through which it travels.

Seismologists measure changes in the speed and direction of seismic waves that penetrate the interior of the planet.

With this technique seismologists have learned that the Earth is made up of different layers and have inferred what substances make up each layer.

Discovering Earth ’ s Interior



The Composition of the Earth

Scientists divide the Earth into three layers:

- The crust
- The mantle
- The core

These layers are made up of progressively denser material toward the center of the Earth.

The Composition of the Earth

The **crust** is the thin and solid outermost layer of the Earth above the mantle.

It is the thinnest layer, and makes up less than 1 percent of the planet’s mass.

It is 5 km to 8 km thick beneath the oceans and is 20 km to 70 km thick beneath the continents.

The Composition of the Earth

The **mantle** is the layer of rock between the Earth’s crust and core.

The mantle is made of rocks of medium density, and makes up 64 percent of the mass of the Earth.

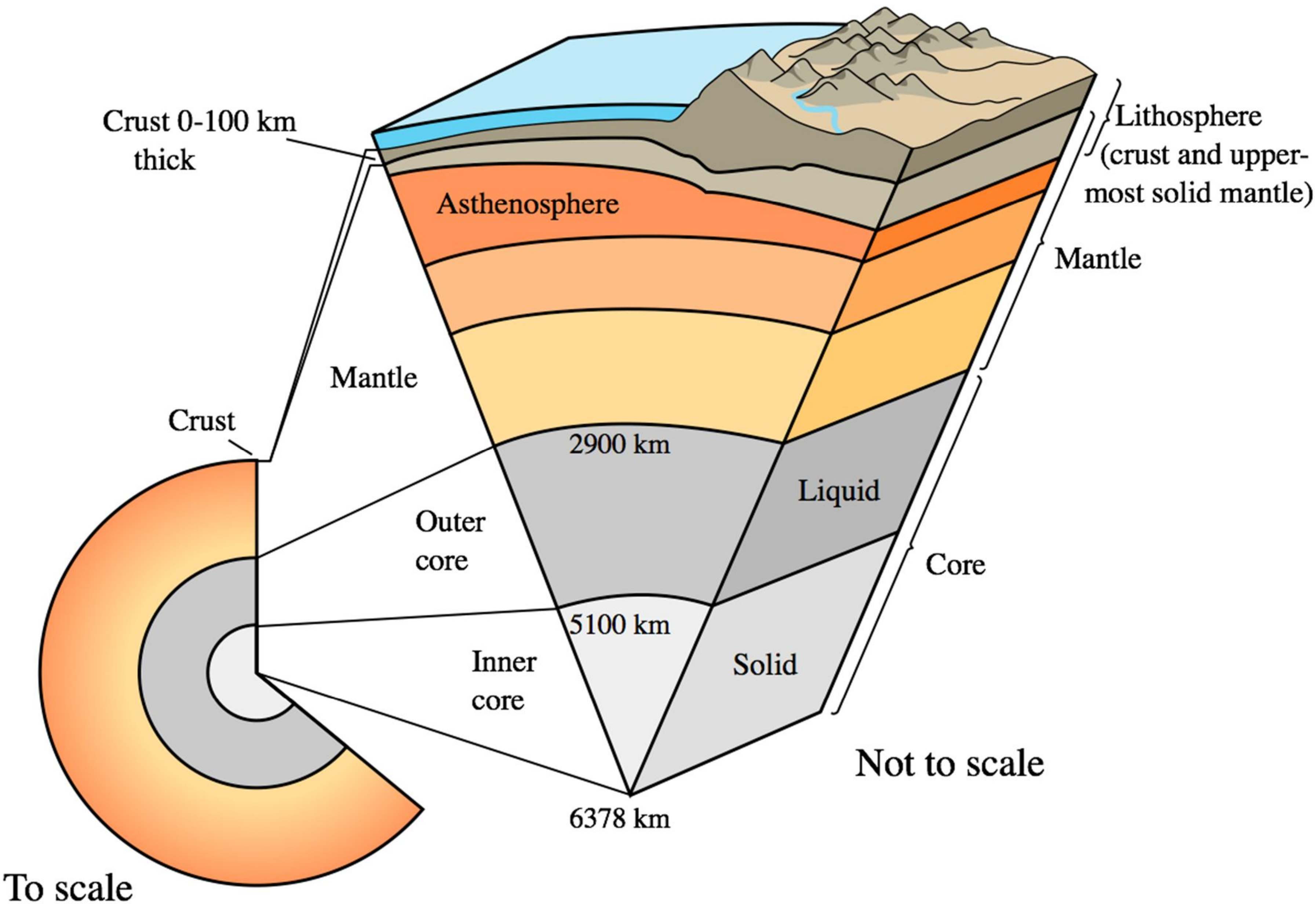
The **core** is the central part of the Earth below the mantle, and is composed of the densest elements.

The Structure of the Earth

The Earth can be divided into five layers based on the physical properties of each layer.

The **lithosphere** is the solid, outer layer of the Earth that consists of the crust and the rigid upper part of the mantle.

It is a cool, rigid layer that is 15 km to 300 km thick and is divided into huge pieces called tectonic plates.


Crust 0-100 km
thick
Lithosphere
(crust and upper-
most solid mantle)
Asthenosphere
Mantle
Mantle
Crust
2900 km
Liquid
Outer
core
Core
5100 km
Inner
core
Solid
Not to scale
6378 km
To scale

The Structure of the Earth

The **asthenosphere** is the solid, plastic layer of the mantle beneath the lithosphere.

It is made of mantle rock that flows slowly, which allows tectonic plates to move on top of it.

Beneath the asthenosphere is the mesosphere, the lower part of the mantle.

The Structure of the Earth

The Earth's outer core is a dense liquid layer.

At the center of the Earth is a dense, solid inner core, which is made up mostly of iron and nickel.

Although the temperature of the inner core is estimated to be between 4,000°C to 5,000°C, it is solid because it is under enormous pressure.

The inner and outer core make up about one-third of Earth's mass.

Plate Tectonics

Tectonic plates are blocks of lithosphere that consist of the crust and the rigid, outermost part of the mantle and glide across the underlying asthenosphere.

The continents are located on tectonic plates and move around with them.

The major tectonic plates include the Pacific, North America,South America, Africa, Eurasian, and Antarctic plates.

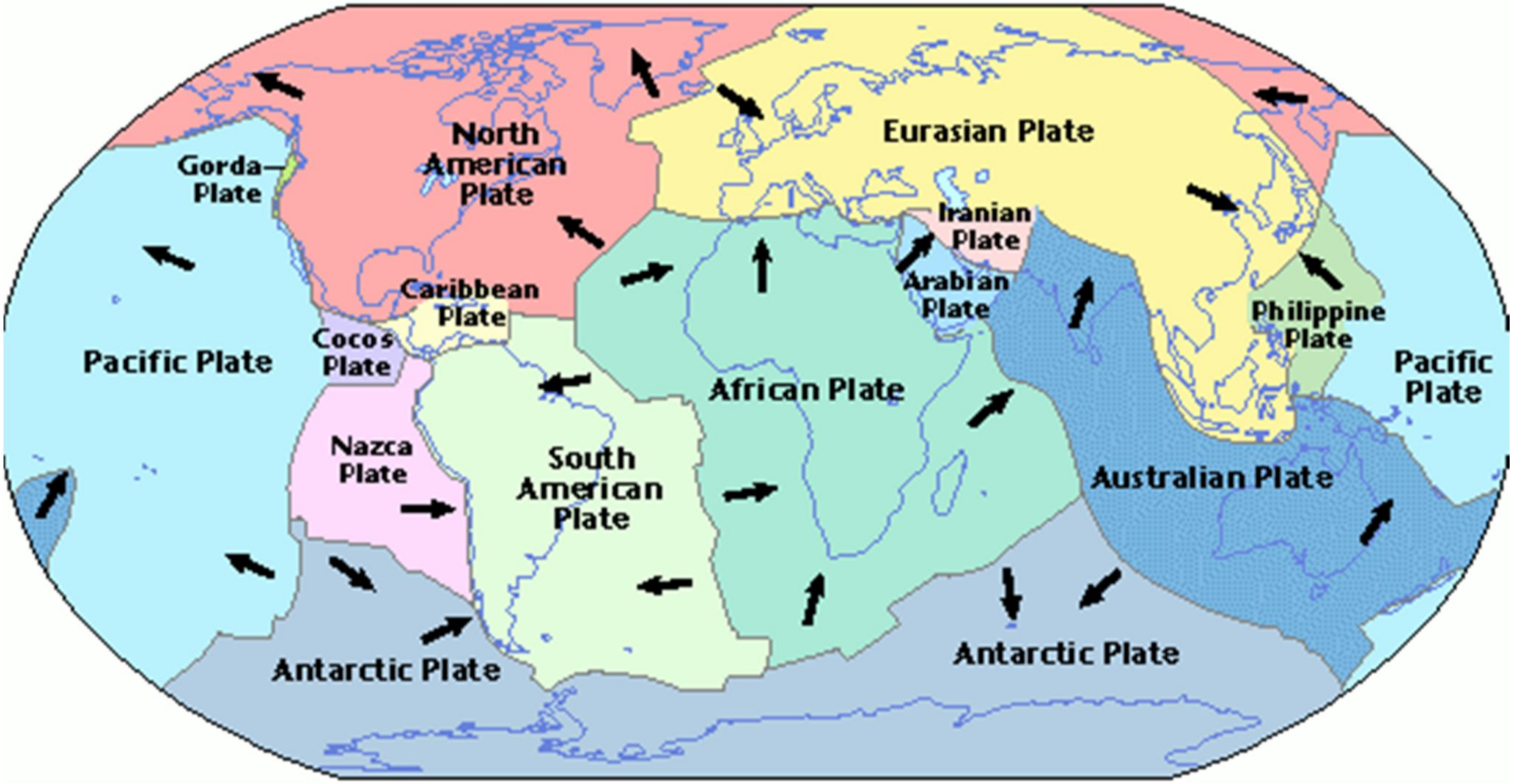

North American Plate
Eurasian Plate
Gorda Plate
Iranian Plate
Caribbean Plate
Arabian Plate
Philippine Plate
Cocos Plate
Pacific Plate
African Plate
Pacific Plate
Nazca Plate
South American Plate
Australian Plate
Antarctic Plate
Antarctic Plate

Plate Boundaries

Much of the geological activity at the surface of the Earth takes place at the boundaries between tectonic plates.

Tectonic plates may separate, collide, or slip past one another.

Enormous forces are generated with these actions causing mountains to form, earthquakes to shake the crust, and volcanoes to erupt along the plate boundaries.

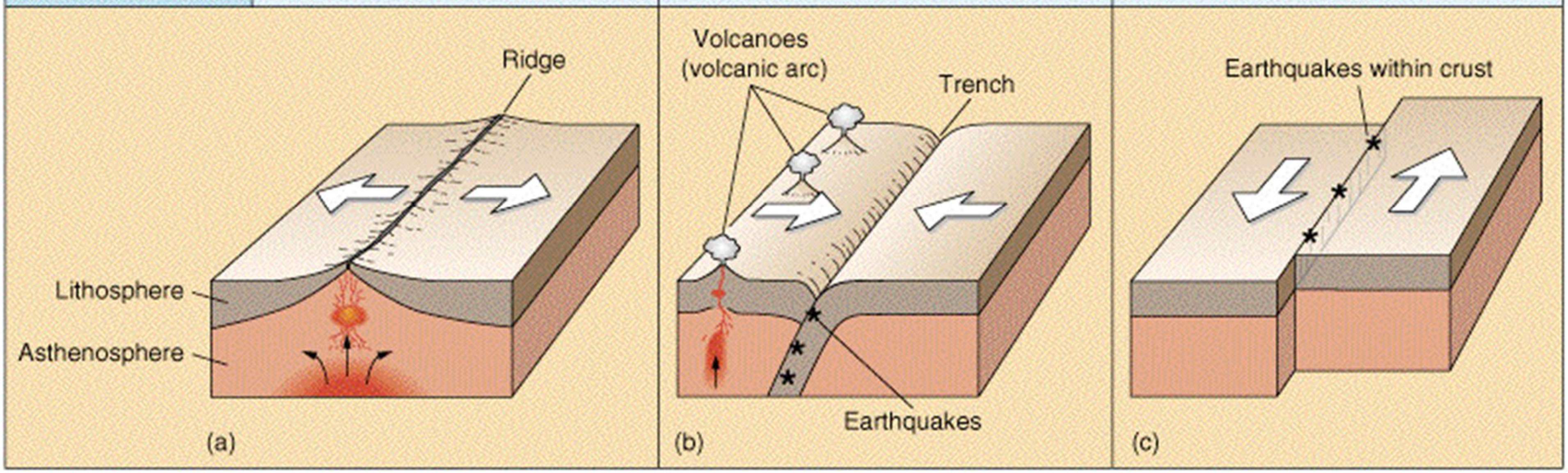
Plate Tectonics and Mountain Building

Tectonic Plates are continually moving around the Earth's surface.

When tectonic plates collide, slip by one another, or pull apart, enormous forces cause rock to break and buckle.

Where plates collide, the crust becomes thicker and eventually forms mountain ranges, such as the Himalaya Mountains.

Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No



Earthquakes

A fault is a break in the Earth’s crust along which blocks of the crust slide relative to one another.

When rocks that are under stress suddenly break along a fault, a series of ground vibrations, known as earthquakes, is set off.

Earthquakes are occurring all the time. Many are so small that we cannot feel them, but some are enormous movements of the Earth ’ s crust that cause widespread damage.

Earthquakes

The measure of the energy released by an earthquake is called *magnitude.*

The smallest magnitude that can be felt is 2.0, and the largest magnitude ever recorded is 9.5. Magnitudes greater than 7.0 cause widespread damage.

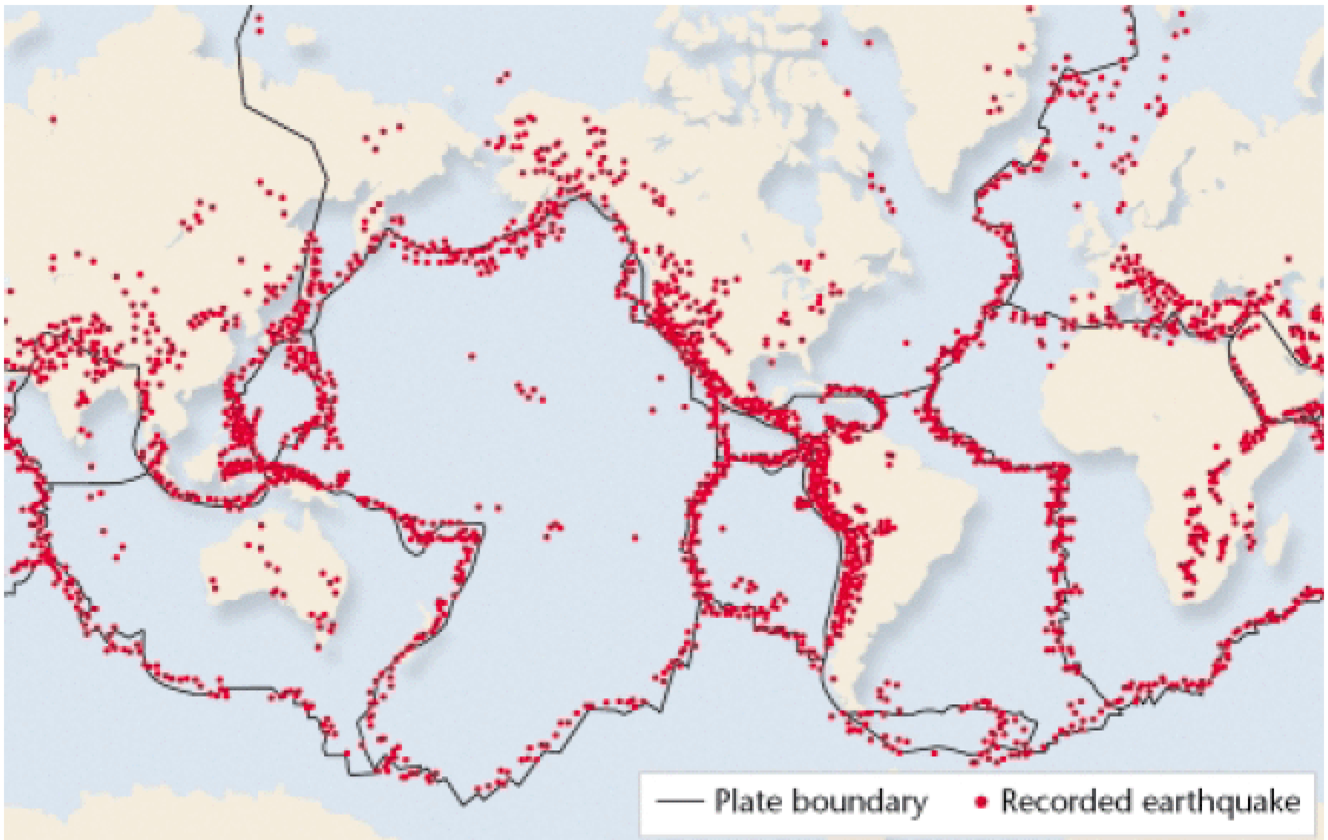
Each increase of magnitude by one whole number indicates the release of 31.7 times more energy than the whole number below it.

Where do Earthquakes Occur?

The majority of earthquakes take place at or near tectonic plate boundaries because of the enormous stresses that are generated when tectonic plates separate, collide or slip past each other.

Over the past 15 million to 20 million years, large numbers of earthquakes have occurred along the San Andreas fault in California, where parts of the North America plate and the Pacific plate are slipping past one another.

Where do Earthquakes Occur?



Earthquake Hazard

Scientists cannot predicts when earthquakes will take place. However, they can help provide information about where earthquakes are likely to occur helping people prepare.

An area's earthquake-hazard level is determined by past and present seismic activity.

Earthquake-resistant buildings, built in high risk areas, are slightly flexible so that they can sway with the ground motion preventing them from collapsing.

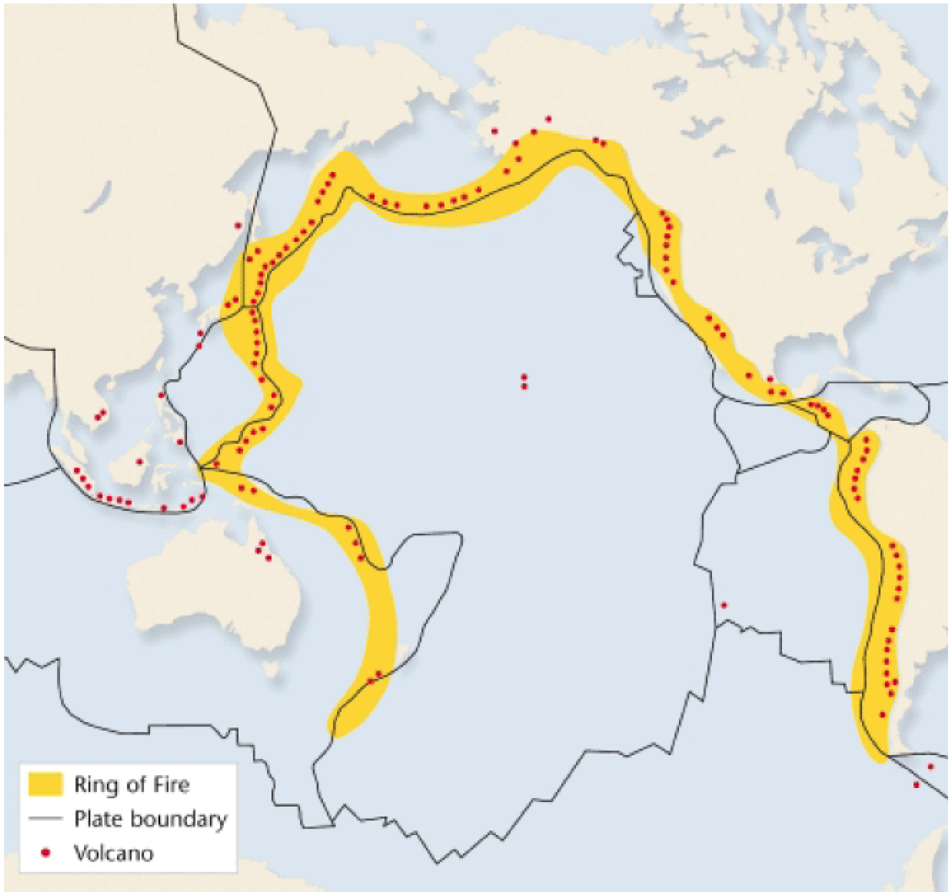
Volcanoes

A volcano is a mountain built from magma, or melted rock, that rises from the Earth's interior to the surface, and can occur on land or in the sea.

Volcanoes are often located near tectonic plate boundaries where plates are either colliding or separating from one another.

The majority of the world's active volcanoes on land are located along tectonic plate boundaries that surround the Pacific Ocean.

Volcanoes: The Ring of Fire

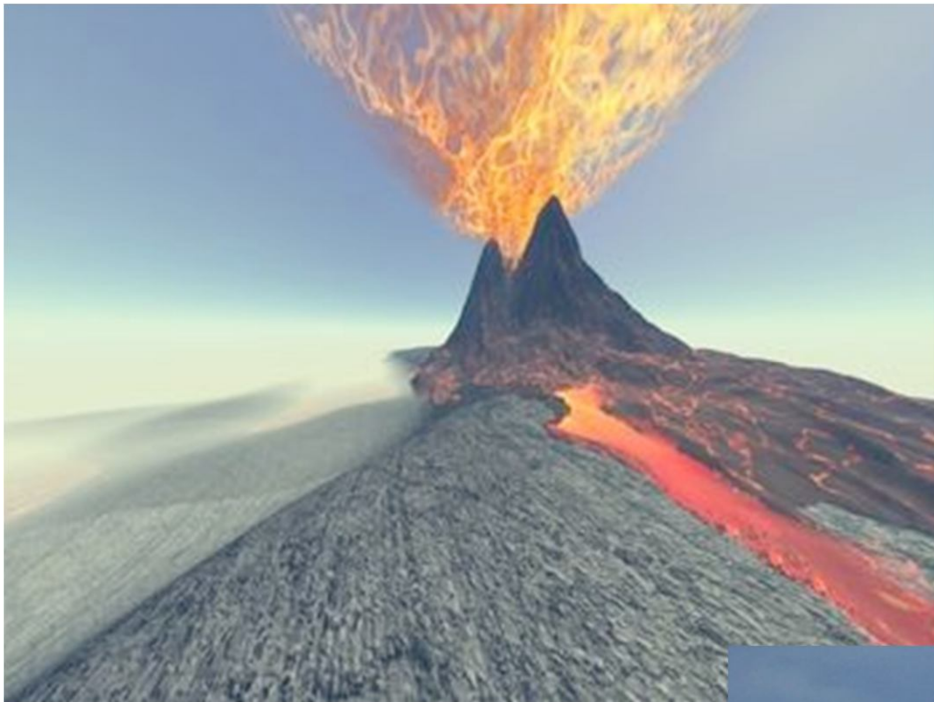


Local Effect of Volcanic Eruptions

Clouds of host ash, dust, and gases can flow down the slope of a volcano at speeds of up to 200 km/hr and sear everything in their path.

During an eruption, volcanic ash can mix with water and produce mudflow that runs downhill.

In addition, ash that falls to the ground can cause buildings to collapse under its weight, bury crops, damage the engines of vehicles, and cause breathing difficulties.




Global Effects of Volcanic Eruptions

Major volcanic eruptions can change Earth's climate for several years.

In large eruptions, clouds of volcanic ash and sulfur rich gases may reach the upper atmosphere, and spread across the planet reducing the amount of sunlight that reaches the Earth's surface.

The reduction in sunlight can cause a drop in the average global surface temperature.

Erosion

The Earth’s surface is continually battered by wind and scoured by running water, which moves rocks around and changes their appearance.

Erosion is the process in which the materials of the Earth’s surface are loosened, dissolved, or worn away and transported form one place to another by a natural agent, such as wind, water, ice or gravity.

Erosion wears down rocks and makes them smoother as times passes. Older mountains are therefore smoother than younger ones.

Water Erosion

Erosion by both rivers and oceans can produce dramatic changes on Earth's surface.

Waves from ocean storms can erode coastlines to give rise to a variety of landforms,

Over time, rivers can carve deep gorges into the landscape.

Wind Erosion

Wind also changes the landscape of the planet.

In places where few plants grow, such as beaches and deserts, wind can blow soil away very quickly.

Soft rocks, such as sandstone, erode more easily than hard rocks, such as granite do.


© Dany Marique

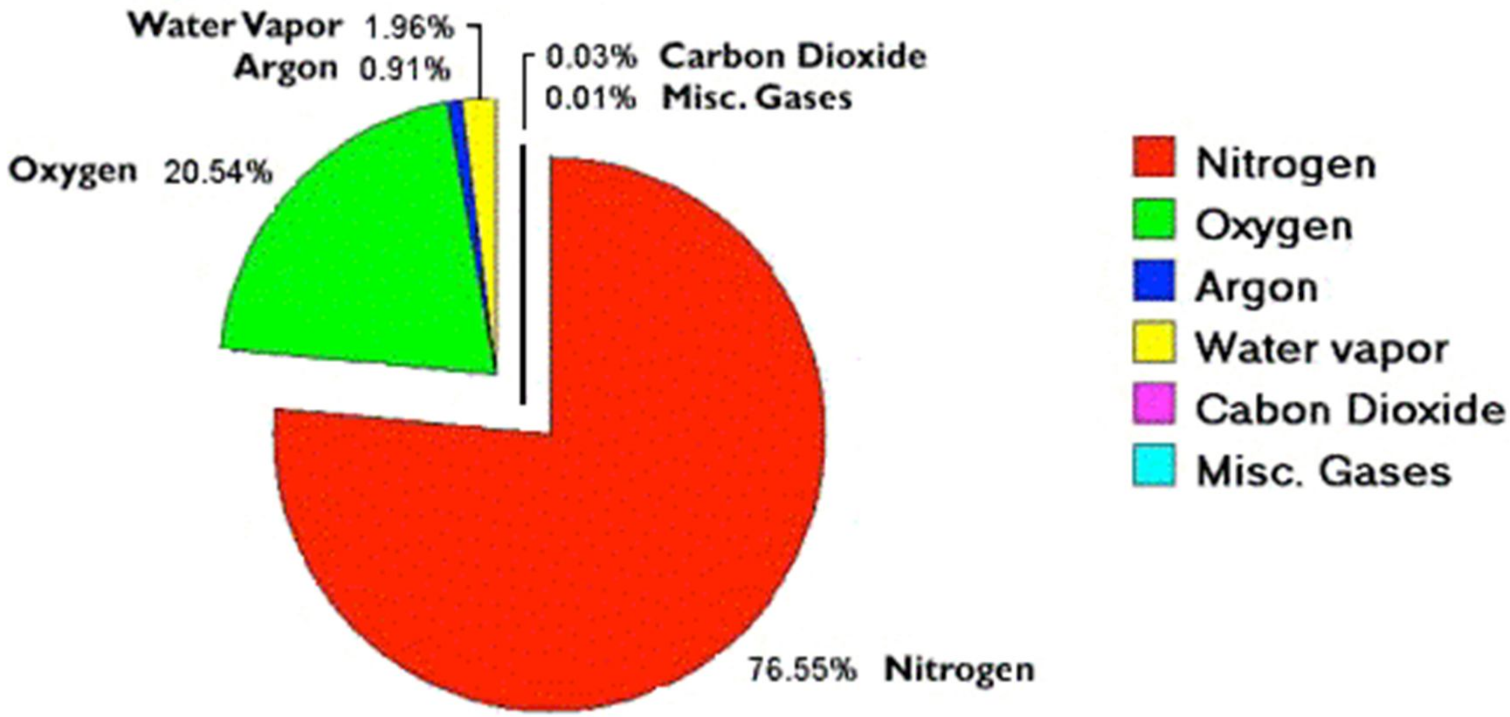
The Atmosphere

The **atmosphere** is a mixture of gases that surrounds a planet, such as Earth.

Nitrogen, oxygen, carbon dioxide, and other gases are all parts of this mixture.

Gases can be added to and removed from the atmosphere through living organisms. For example, animals remove oxygen when they breathe in and add carbon dioxide when they breath out.

The Gases That Comprise Earth's Atmosphere



The Atmosphere

Volcanic eruptions also add gases to the atmosphere, while vehicles both add and remove gases.

The atmosphere also insulates Earth's surface.

This insulation slows the rate at which the Earth's surface loses heat and keeps Earth temperature at which living things can survive.

Composition of the Atmosphere

Nitrogen makes up 78 percent of the Earth's atmosphere, and enters the atmosphere when volcanoes erupt and when dead plants and animals decay.

Oxygen is the second most abundant gas in the atmosphere and is primarily produced by plants.

In addition to gases, the atmosphere contains many types of tiny, solid particles, or atmospheric dust.

Air Pressure

Earth’s atmosphere is pulled toward Earth’s surface by gravity and as a result, the atmosphere is denser near the Earth’s surface.

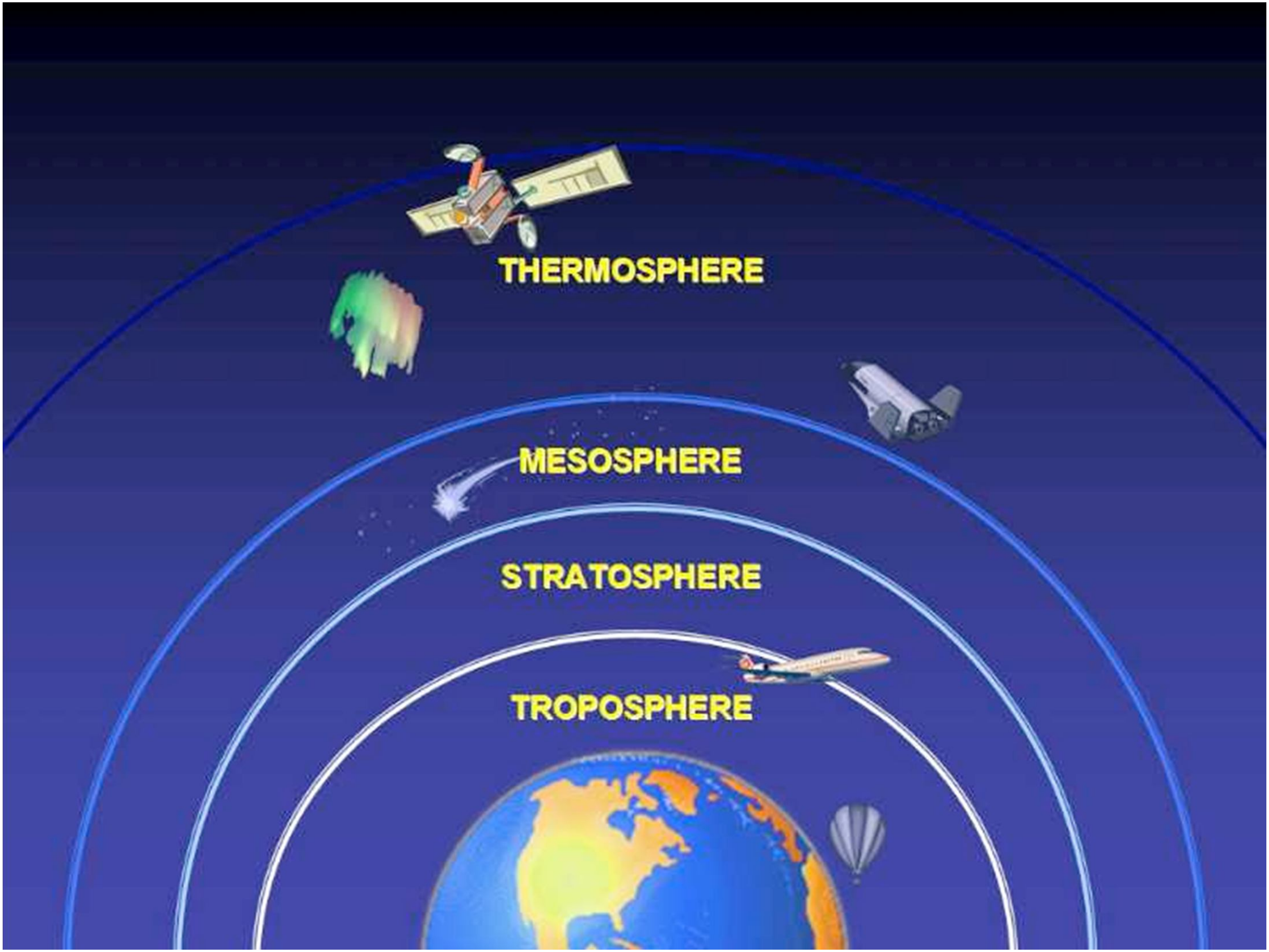
Almost the entire mass of Earth’s atmospheric gases is located within 30 km of the surface.

Air also becomes less dense with elevation, so breathing at higher elevations is more difficult.

Layers of the Atmosphere

The atmosphere is divided into four layers based on temperature changes that occur at different distances above the Earth's surface.

- The Troposphere
- The Stratosphere
- The Mesosphere
- The Thermosphere


THERMOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE

The Troposphere

The **troposphere** is the lowest layer of the atmosphere in which temperature drops at a constant rate as altitude increases.

This is the part of the atmosphere where weather conditions exist.

The troposphere is Earth's densest atmospheric layer and extends to 18 km above Earth's surface.

The Stratosphere

The **stratosphere** is the layer of the atmosphere that lies immediately above the troposphere and extends from about 10 to 50 km above the Earth's surface.

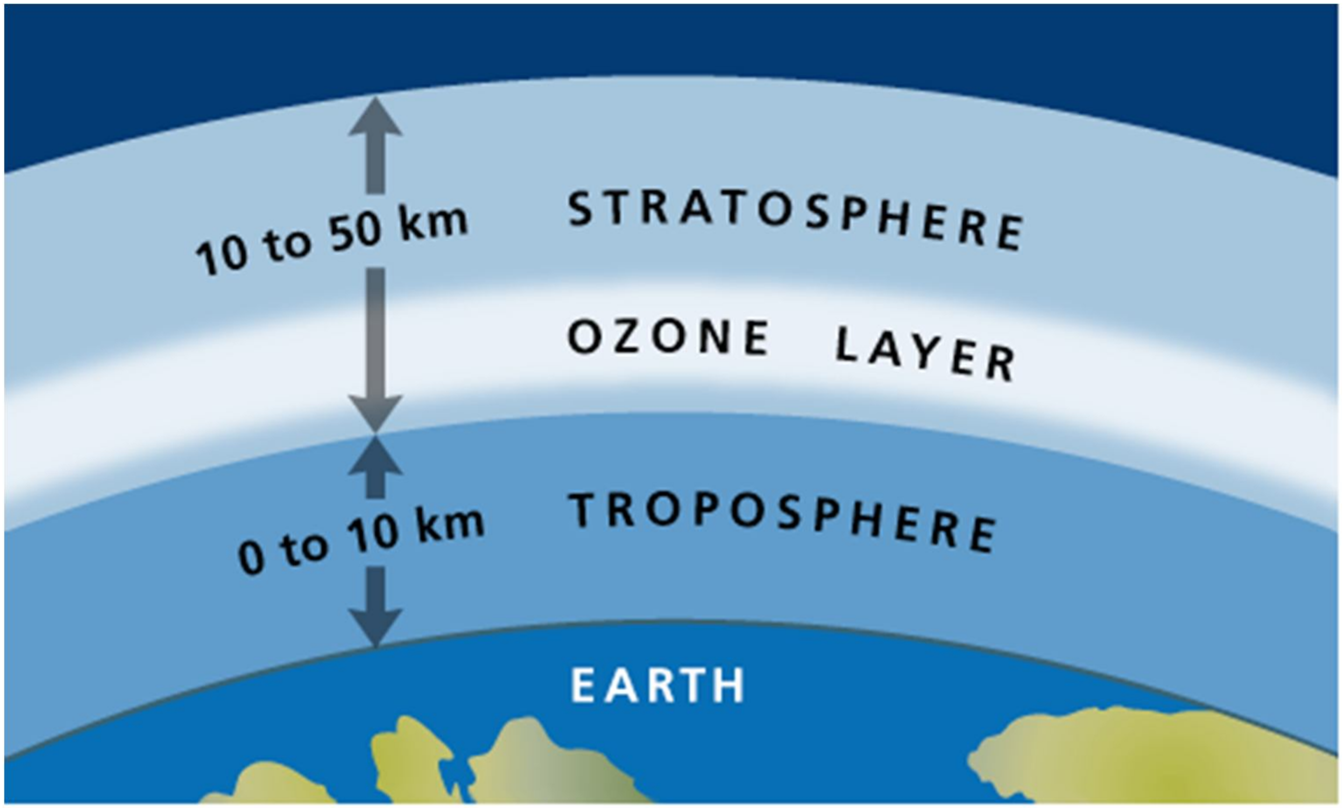
Temperature rises as altitude increases because ozone in the stratosphere absorbs the sun's ultraviolet (UV) energy and warms the air.

The Stratosphere

Ozone is a gas molecule that is made up of three oxygen atoms.

Almost all of the ozone in the atmosphere is concentrated in the stratosphere.

Because ozone absorbs UV radiation, it reduces the amount of UV radiation that reaches the Earth. UV radiation that does reach Earth can damage living cells.


STRATOSPHERE
10 to 50 km
OZONE LAYER
TROPOSPHERE
0 to 10 km
EARTH

The Mesosphere

The layer above the stratosphere is the mesosphere.

This layer extends to an altitude of about 80 km.

This is the coldest layer of the atmosphere where temperatures have been measured as low as
–93^{o}C.

The Thermosphere

The atmospheric layer located farthest from Earth's surface is the thermosphere.

Here, nitrogen and oxygen absorb solar radiation resulting in temperatures measuring above 2,000 ^{o}C.

The air in the thermosphere is so thin that air particles rarely collide, so little heat is transferred, and would therefore not feel hot to us.

The Thermosphere

The absorption of X rays and gamma rays by nitrogen and oxygen causes atoms to become electrically charged.

Electrically charged atoms are called ions, and the lower thermosphere is called the ionosphere.

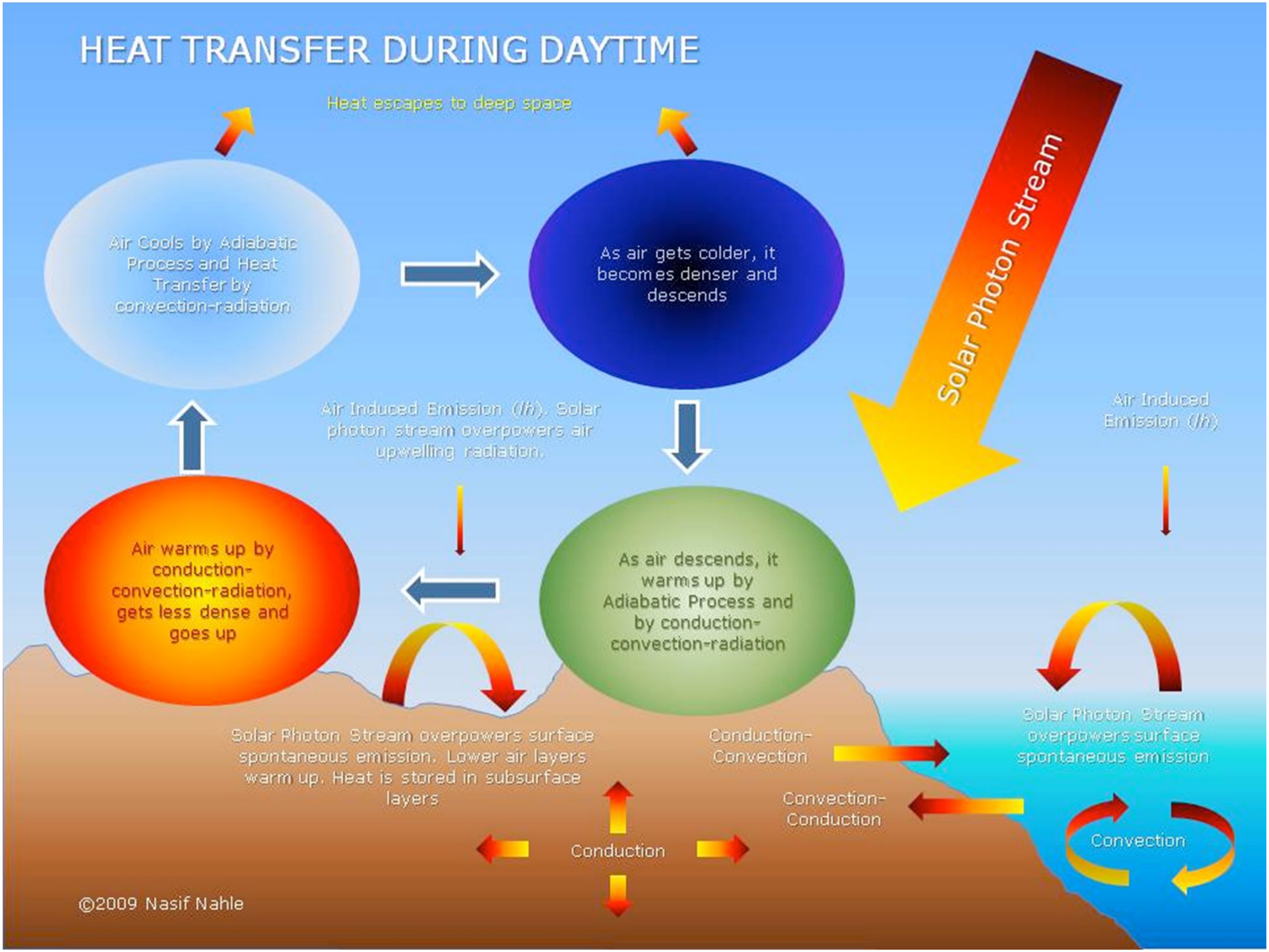
Ions can radiate energy as light, and these lights often glow in spectacular colors in the night skies near the Earth’s North and South Poles.

Energy Transfer in the Atmosphere

Radiation is the energy that is transferred as electromagnetic waves, such as visible light and infrared waves.

Conduction is the transfer of energy as heat through a material.

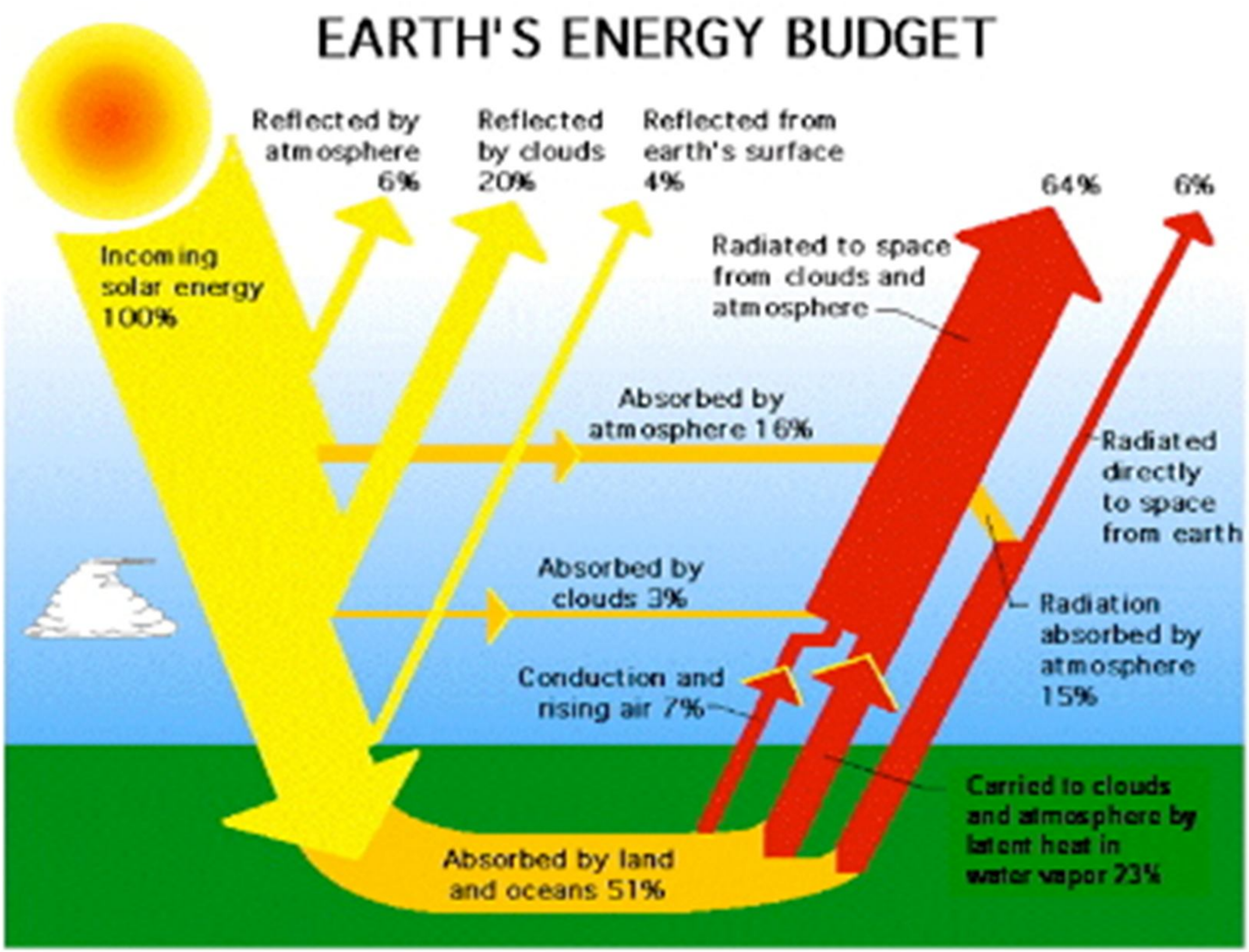
Convection is the movement of matter due to differences in density that are caused by temperature variations an can result in the transfer of energy as heat.


HEAT TRANSFER DURING DAYTIME
Heat escapes to deep space
Air Cools by Adiabatic Process and Heat Transfer by convection-radiation
As air gets colder, it becomes denser and descends
Solar Photon Stream
Air Induced Emission (Ih). Solar photon stream overpowers air upwelling radiation.
Air Induced Emission (Ih)
Air warms up by conduction-convection-radiation, gets less dense and goes up
As air descends, it warms up by Adiabatic Process and by conduction-convection-radiation
Solar Photon Stream overpowers surface spontaneous emission. Lower air layers warm up. Heat is stored in subsurface layers
Conduction-Convection
Solar Photon Stream overpowers surface spontaneous emission
Convection-Conduction
Conduction
Convection
©2009 Nasif Nahle

Heating of the Atmosphere

Solar energy reaches the Earth as electromagnetic radiation, which includes visible light, infrared radiation, and ultraviolet light.

About half of the solar energy that enters the atmosphere passes through it and reaches the Earth's surface, while the rest of the energy is absorbed or reflected in the atmosphere by clouds, gases, and dust or it is reflected by Earth's surface.


EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmosphere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

Heating of the Atmosphere

The Earth does not continue to get warmer because the oceans and the land radiate the absorbed energy back into the atmosphere.

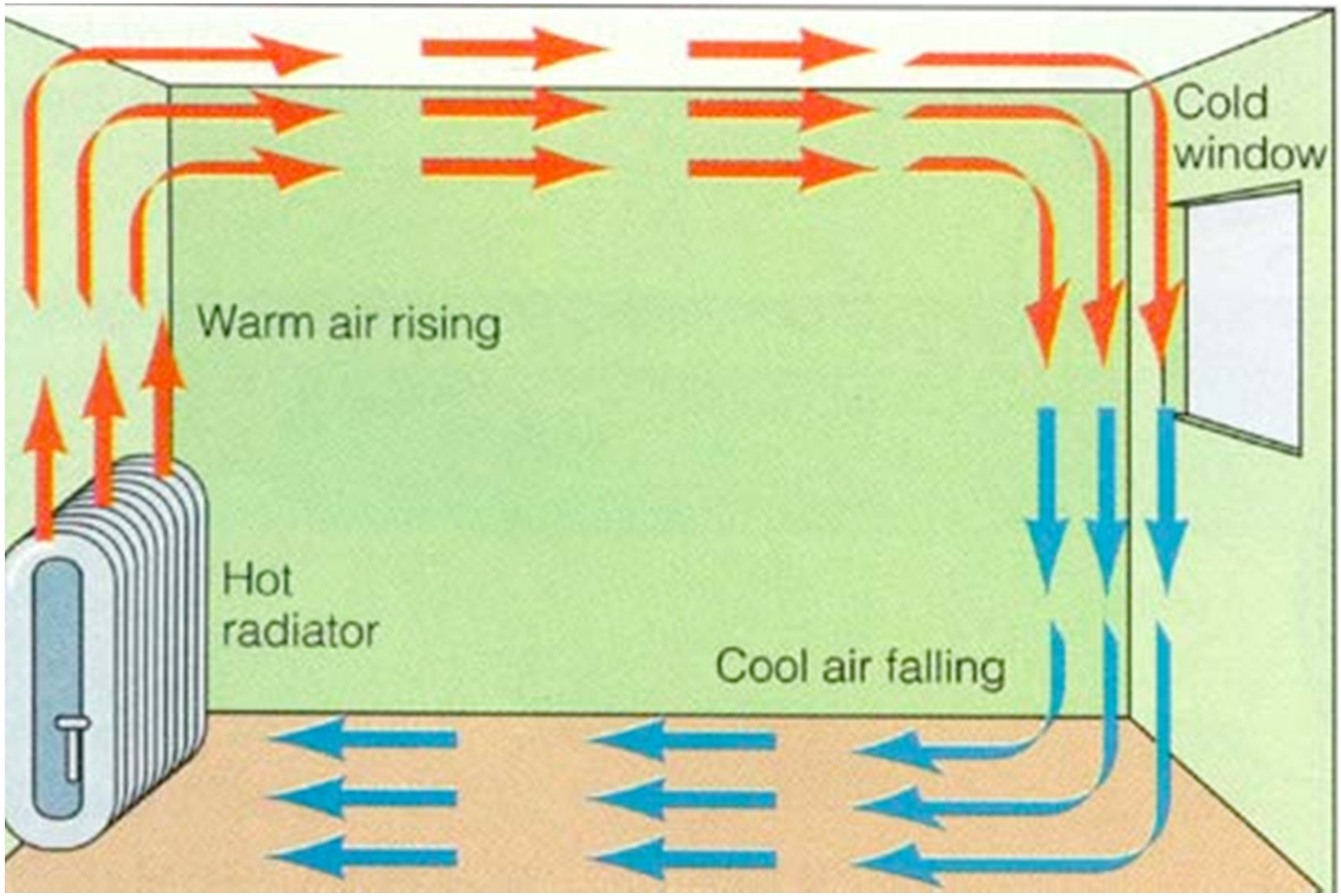
Dark-colored objects absorb more solar radiation that light-colored objects, so dark colored objects have more energy to release as heat.

This is one reason the temperature in cities is higher that the temperature in the surrounding countryside.

The Movement of Energy in the Atmosphere

As a current of air, warmed by the Earth's surface, rises into the atmosphere, it begins to cool, and eventually becomes more dense than the air around it and sinks. This current then moves back toward the Earth until heated and less dense and then begins to rise again.

The continual process of warm air rising and cool air sinking and moving air in a circular motion is called a *convection current.*

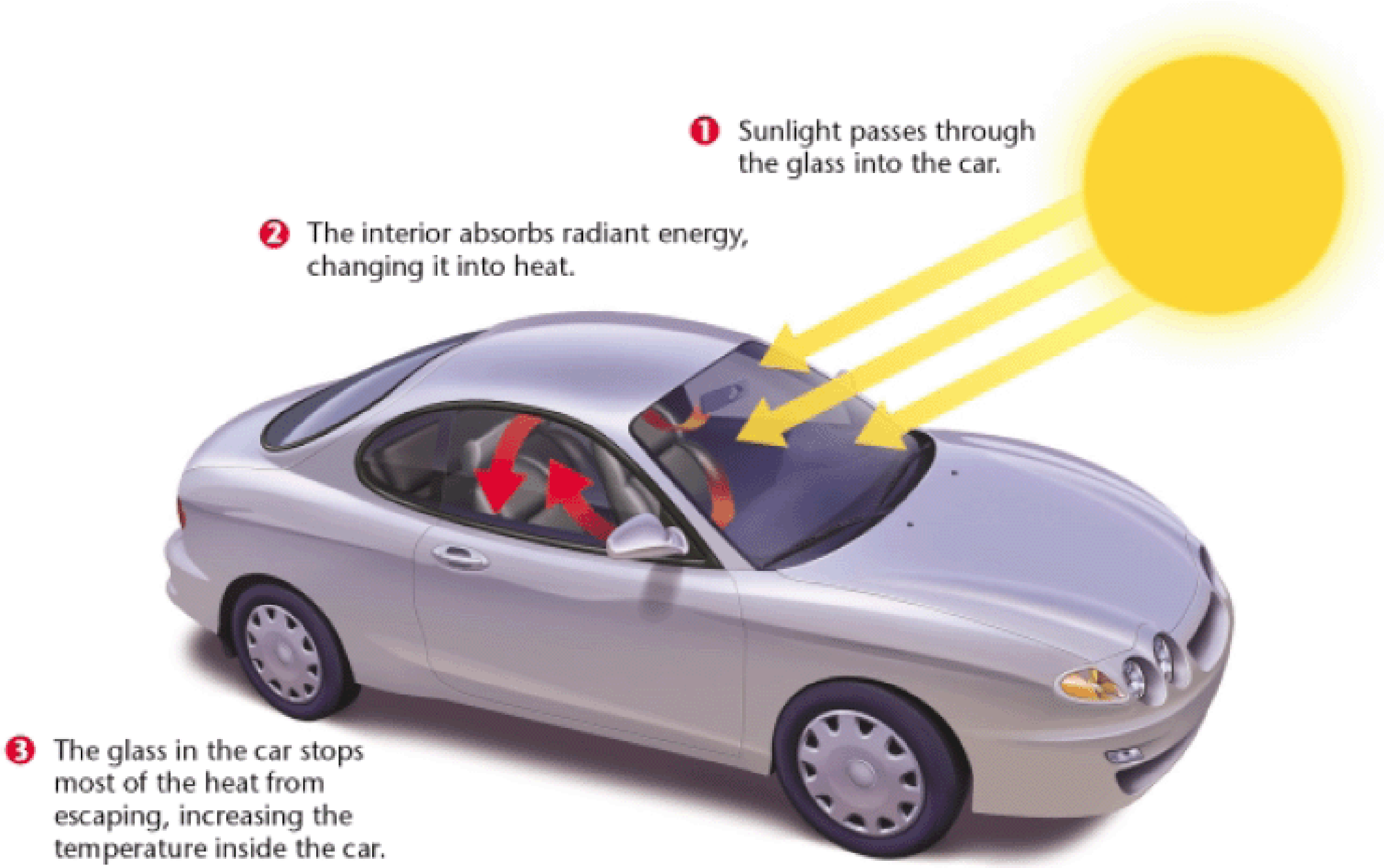

Cold window
Warm air rising
Hot radiator
Cool air falling

The Greenhouse Effect

The **greenhouse effect** is the warming of the surface and lower atmosphere of Earth that occurs when carbon dioxide, water vapor, and other gases in the air absorb and reradiate infrared radiation.

Without the greenhouse effect, the Earth would be too cold for life to exist.

The Greenhouse Effect

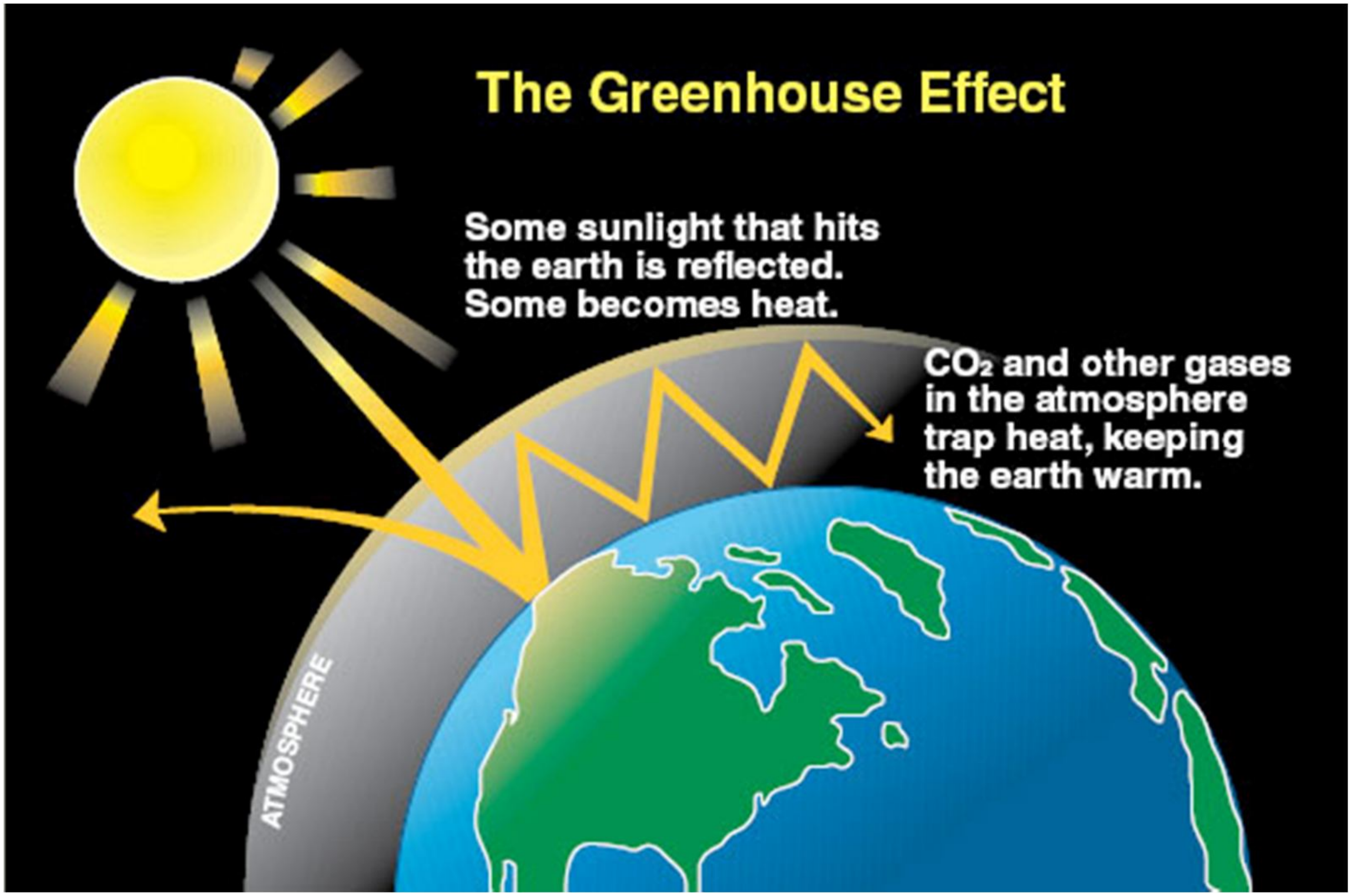


The Greenhouse Effect

The gases in the atmosphere that trap and radiate heat are called greenhouse gases.

The most abundant greenhouse gases are water vapor, carbon dioxide, methane, and nitrous oxide, although none exist in high concentrations.

The quantities of carbon dioxide and methane in the atmosphere vary considerably as a result of natural and industrial processes.


The Greenhouse Effect
Some sunlight that hits the earth is reflected. Some becomes heat.
CO2 and other gases in the atmosphere trap heat, keeping the earth warm.
ATMOSPHERE

The Hydrosphere

The hydrosphere includes all of the water on or near the Earth's surface.

This includes water in the oceans, lakes, rivers, wetlands, polar ice caps, soil, rock layers beneath Earth's surface, and clouds.

The Water Cycle

The **water cycle** is the continuous movement of water from the ocean to the atmosphere to the land and back to the ocean.

Evaporation is the change of a substance from a liquid to a gas.

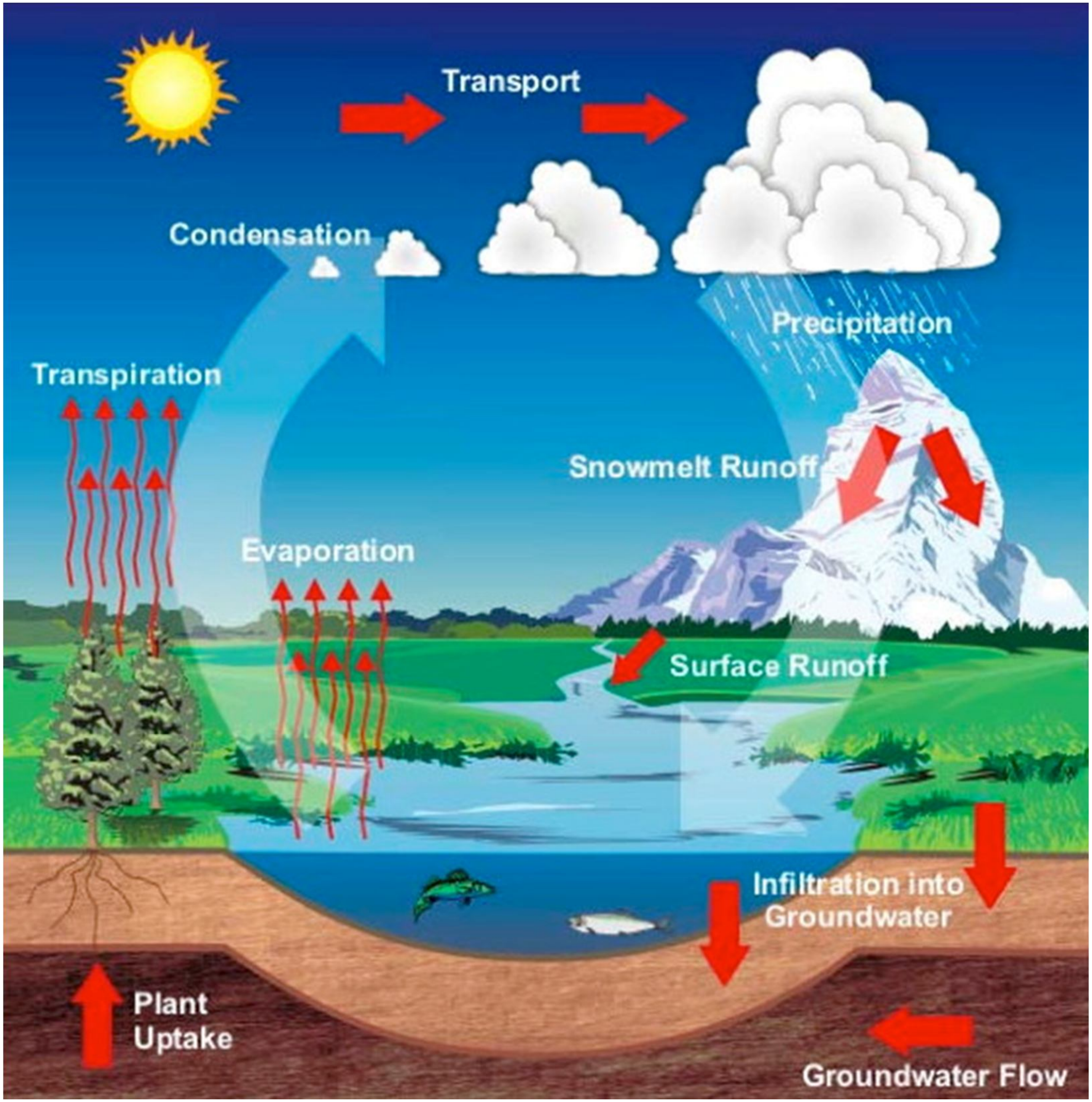
Water continually evaporates from the Earth's oceans, lakes, streams, and soil, but the majority evaporates from the oceans.

The Water Cycle

Condensation is the change of state from a gas to a liquid.

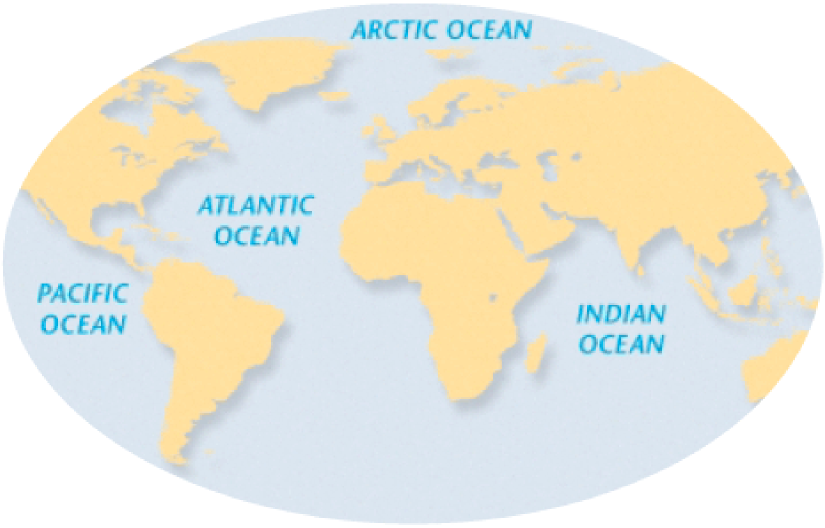
Water vapor forms water droplets on dust particles which then form clouds in which the droplets collide to create larger, heavier drops that then fall from the clouds as rain.

Precipitation is any form of water that falls to the Earth's surface from the clouds, and includes rain, snow, sleet, and hail.


Transport
Condensation
Precipitation
Transpiration
Snowmelt Runoff
Evaporation
Surface Runoff
Infiltration into Groundwater
Plant Uptake
Groundwater Flow

Earth's Oceans

All of the oceans are joined in a single large interconnected body of water called the world ocean. The world oceans play important roles in the regulation of the planet's environment.



Earth ' s Oceans

The largest ocean on Earth is the Pacific Ocean with a surface area of about 165,640,000 km^2.

The deepest point on the ocean floor, the Challenger Deep, is found in the Pacific Ocean.

The Challenger Deep is located east of the Philippine islands at the bottom of the Mariana Trench and is 11,033m below sea level which is deeper than Mount Everest is tall.

Earth ' s Oceans

Oceanographers often divide the Pacific Ocean into the North Pacific and South Pacific based on the direction of the surface current flow in each half of the Pacific Ocean.

Surface currents in the Pacific move in a clockwise direction north of the equator.

Surface currents in the Pacific move in a counter-clockwise direction south of the equator.


North Pacific
Ocean
Mariana
Trench
South Pacific
Ocean

Earth's Oceans

The second largest ocean on Earth is the Atlantic Ocean, and covers about half the area of the Pacific Ocean which is a surface area of about 81,630,000 km^2.

Like the Pacific Ocean, the Atlantic Ocean can be divided into a north and south half based on the directions of surface current flow north and south of the equator.


North
Atlantic
Ocean
South
Atlantic
Ocean

Earth ' s Oceans

The Indian Ocean is the third largest ocean on Earth with a surface area of 73,420,000 km^2.

The smallest ocean is the Artic ocean which covers 14,350,000 km^2.

The Artic Ocean is unique because much of its surface is covered by floating ice, called pack ice, which forms when either waves or wind drive together frozen seawater, known as sea ice, into a large mass.


Indian
Ocean


Arctic
Ocean
North
Pole

Ocean Water

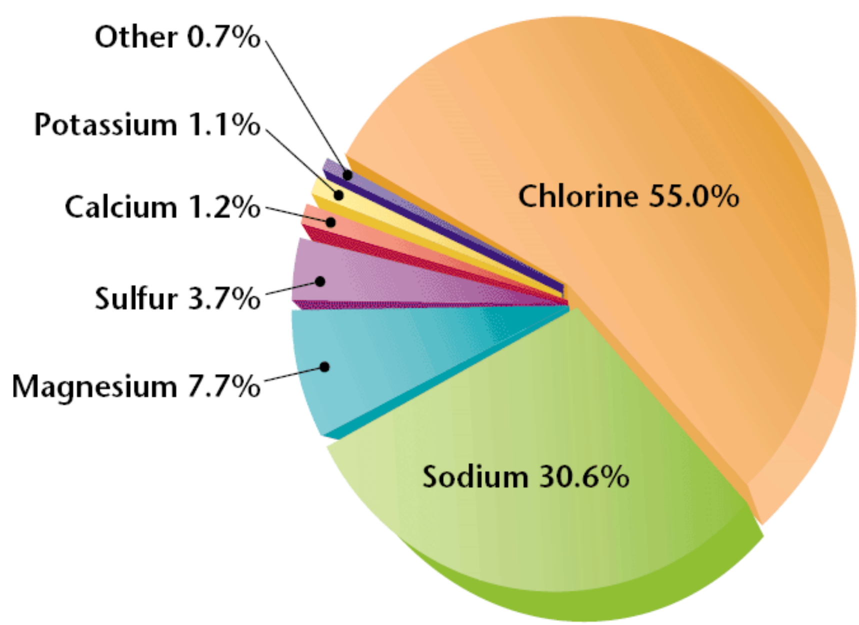
The difference between ocean water and fresh water is that ocean water contains more salts.

Salinity is a measure of the amount of dissolved salts in a given amount of liquid.

Salinity is lower in places that get a lot of rain or in places where fresh water flows in to the sea. In contrast, salinity is higher where water evaporates rapidly and leaves the salts behind.

Ocean Water

Most of the salt in the ocean is sodium chloride, which is made up of the elements sodium and chloride, although many other elements can be found in the ocean as well.



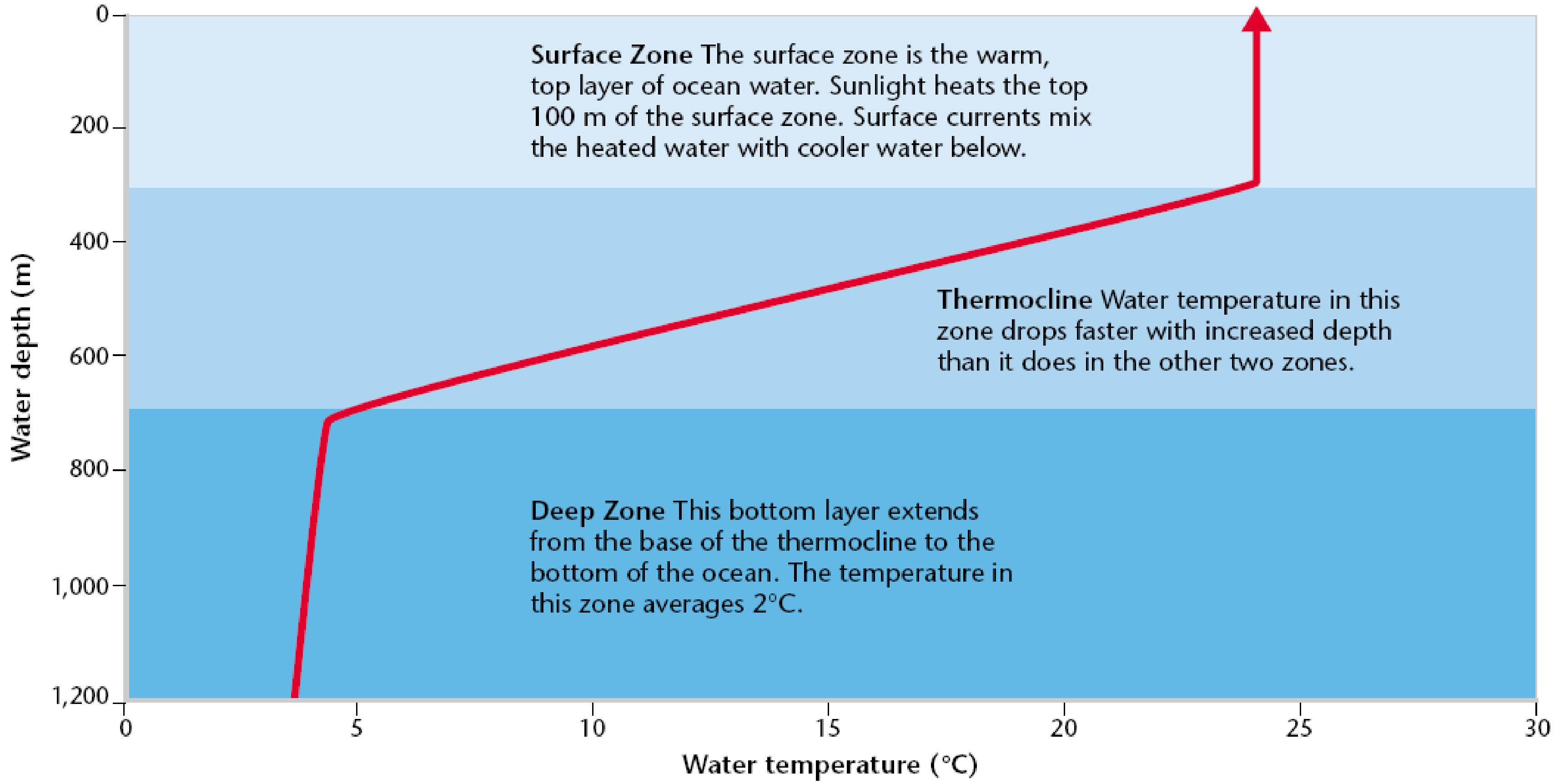
Temperature Zones

The surface of the ocean is warmed by the sun, while the depths of the ocean, where sunlight never reaches, are very cold, just above freezing.

Surface waters are stirred up by waves and currents so the warm surface zone may be as much as 350 m deep.

Below the surface zone is the thermocline, which is a layer about 300 to 700 m deep where the temperature falls rapidly.

Temperature Zones



A Global Temperature Regulator

One of the most important functions of the world ocean is to absorb and store energy from sunlight which in turn regulates temperatures in Earth's atmosphere.

Because the ocean both absorbs and releases heat slower than land, the temperature of the atmosphere changes more slowly.

If the ocean did not regulate atmospheric and surface temperatures, temperatures would be too extreme for life to exist on Earth.

A Global Temperature Regulator

Local temperatures in different areas of the planet are also regulated by the world ocean.

Currents circulate warm water causing land areas they flow past to have more moderate climates.

For example, the British Isles are warmed by the waters of the Gulf Stream.

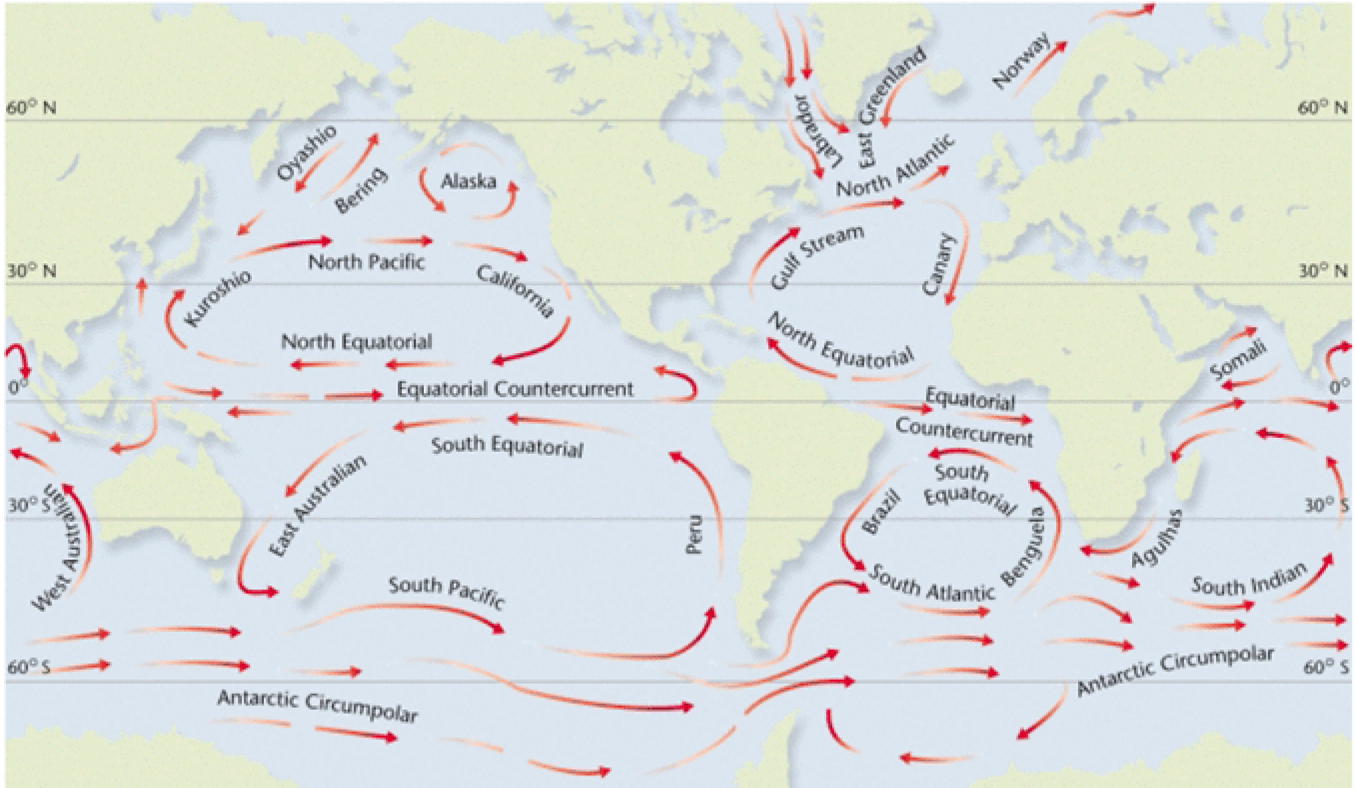
Ocean Currents

Streamlike movements of water that occur at or near the surface of the ocean are called **surface currents.**

Surface currents are wind driven and result from global wind patterns.

Surface currents can be warm or cold water currents. However, currents of warm water and currents of cold water do not readily mix with one another.

Ocean Currents



Ocean Currents

Deep currents are streamlike movements of water that flow very slowly along the ocean floor.

Deep currents form when the cold, dense water from the poles inks below warmer, less dense ocean water and flows toward the equator.

The densest and coldest ocean water is located off the coast of Antarctica and flows very slowly northward producing a deep current called the Antarctic Bottom Water.

Fresh Water and River Systems

Fresh water is water that contains insignificant amounts of salts.

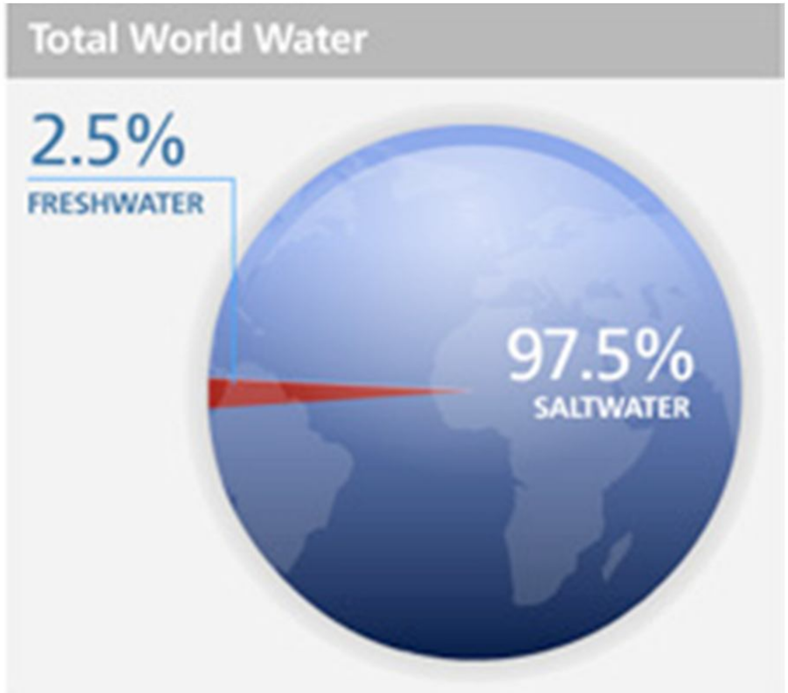
Most of the fresh water is locked up in icecaps and glaciers while the rest is found in places like lakes, rivers, wetlands, the soil and atmosphere.

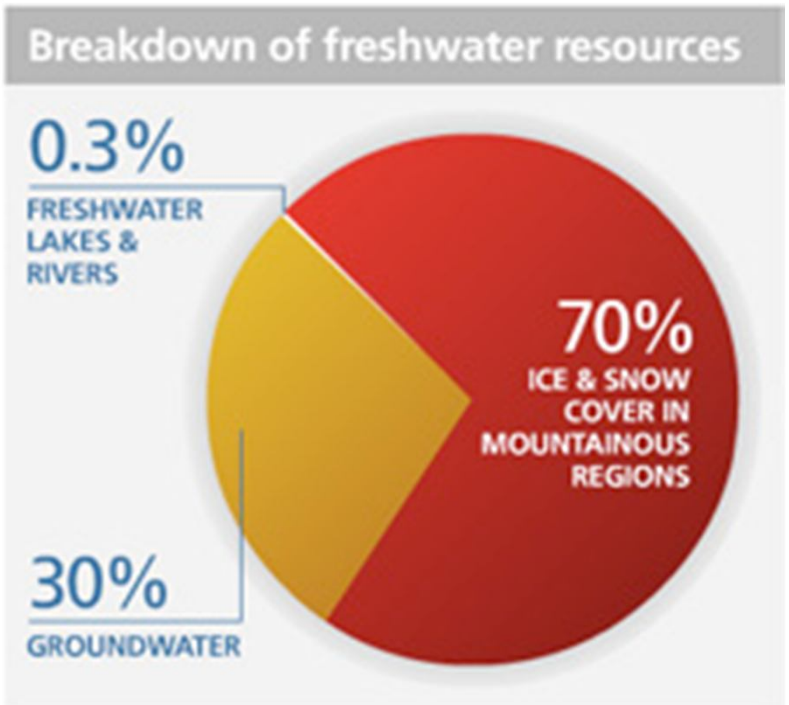
A river system is a network of streams that drains an area of land and contains all of the land drained by a river including the main river and all its smaller streams or rivers that flow into larger ones, or tributaries.

Ground water

Rain and melting snow sink into the ground and run off the land. Most of this water trickles down through the ground and collects as groundwater.

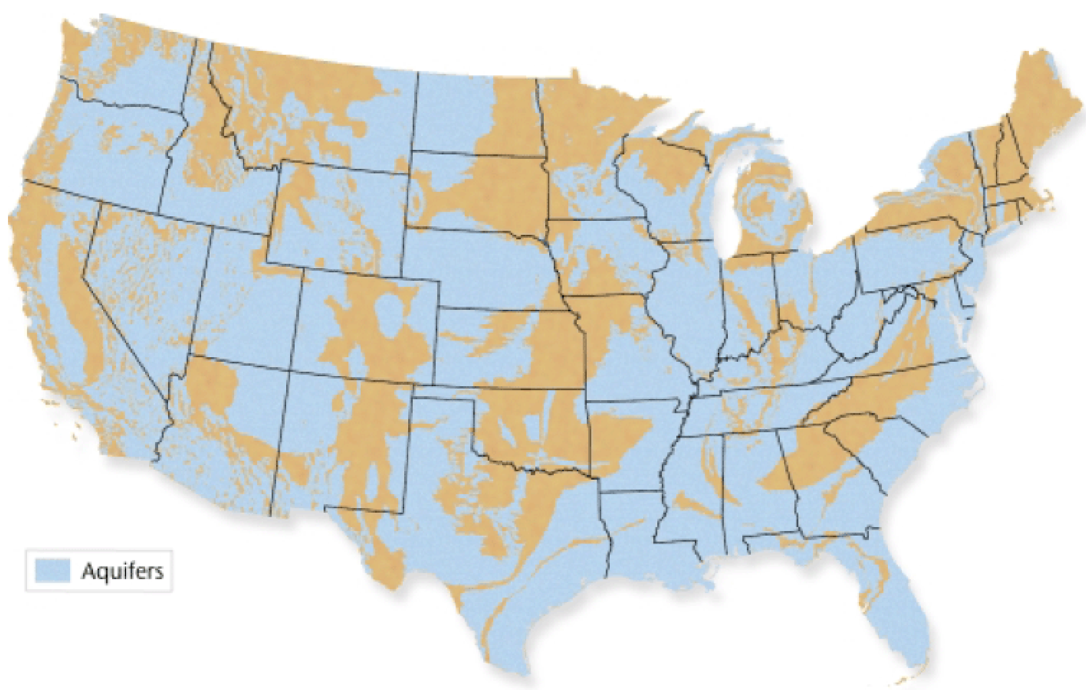
Although it makes up only 1 percent of all the water on Earth, groundwater fulfills the human need for fresh drinking water, and supplies agricultural and industrial need.


Total World Water
2.5%
FRESHWATER
97.5%
SALTWATER


Breakdown of freshwater resources
0.3%
FRESHWATER
LAKES &
RIVERS
70%
ICE & SNOW
COVER IN
MOUNTAINOUS
REGIONS
30%
GROUNDWATER

Aquifers

A rock layer that stores and allows the flow of groundwater is called an aquifer.



The Biosphere

The **biosphere** is the part of Earth where life exists, extending about 11 km into the ocean and about 9 km into the atmosphere.

The materials that organisms require must be continually recycled. Gravity allows a planet to maintain an atmosphere and to cycle materials.

Suitable combinations that organisms need to survive are found only in the biosphere.

The Biosphere

The biosphere is located near Earth's surface because most of the sunlight is available near the surface.

Plants need sunlight to produce their food, and almost every other organism gets its food from plants and algae.

Most of the algae float at the surface of the ocean and is known as phytoplankton.

Energy Flow in the Biosphere

The energy used by organisms must be obtained in the biosphere and must be constantly supplied for life to continue.

When an organism dies, its body is broken down and the nutrients in it become available for use by other organisms.

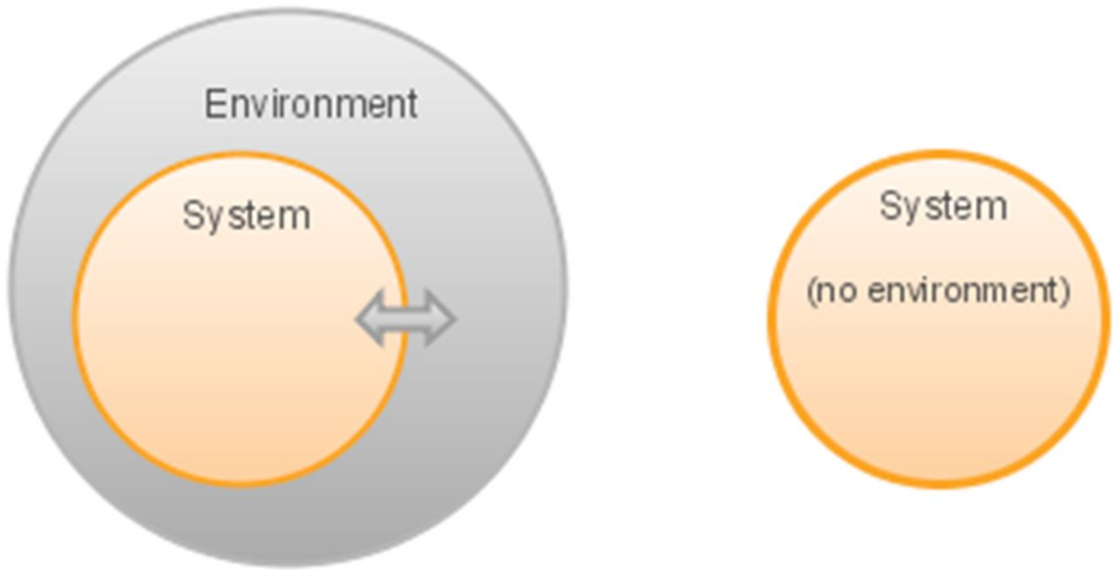
This flow of energy allows life on Earth to continue to exist.

Energy Flow in the Biosphere

Closed systems are systems that cannot exchange matter or energy with its surroundings.

Open systems are systems that can exchange both matter and energy with its surroundings.

Today, the Earth is essentially a closed system with respect to matter, but an open system for energy as energy travels from plant to animal which is eaten by other animals. In the process, some energy is lost as heat to the environment.



Open System **Closed System**