Objective 5

The student will demonstrate an understanding of Earth and space systems.

My Notes

Through your studies in science, you should be able to demonstrate an understanding of Earth and space systems.

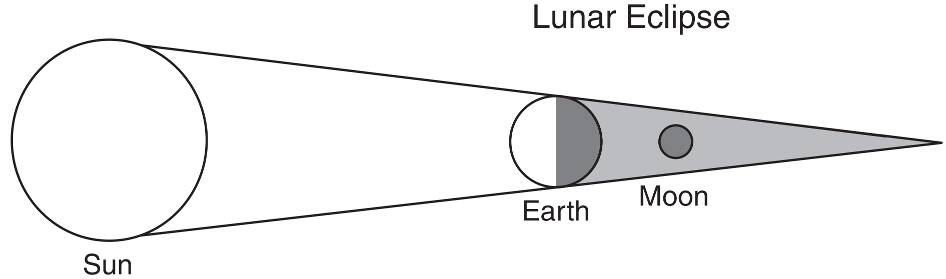
I saw something recently. It was really cool. The full moon turned orange and then got really dark. What was it?

What you saw is called a lunar eclipse. What could have made the full moon turn dark like that?

Something must have moved between the sun and the moon, right?

Correct. A *lunar eclipse* occurs when Earth blocks sunlight from reaching the moon. This puts the moon in Earth's shadow. The model below shows the positions of the sun, Earth, and moon during a lunar eclipse.

Lunar Eclipse



Note: Sizes and distances are not to scale.

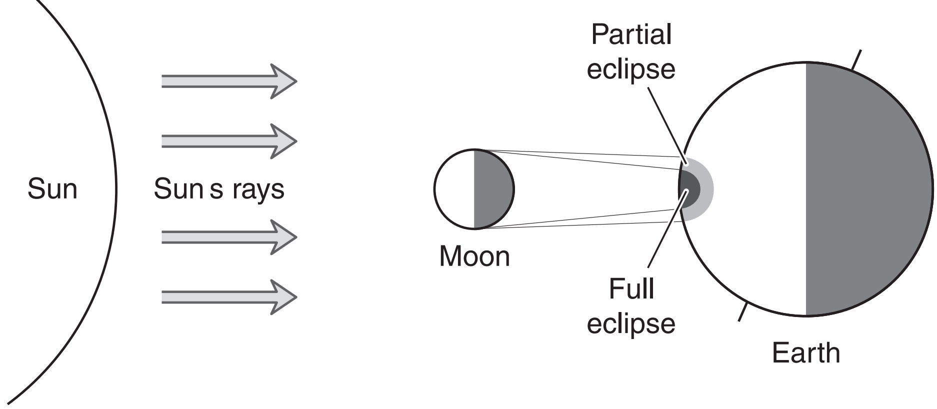
What happens when the moon moves between the sun and Earth?

When the moon is aligned so that its shadow falls on Earth's surface, the sun's light is blocked from reaching part of Earth. This kind of eclipse is called a *solar eclipse* because it is the sun that is being blocked from our view.

My Notes

Since the moon is much closer to Earth than the sun is, the moon's shadow is cast over only a small portion of Earth's sunlit side. For this reason, a solar eclipse is not observed over the entire surface of Earth. The diagram below shows the positions of the sun, Earth, and moon during a solar eclipse.

Solar Eclipse



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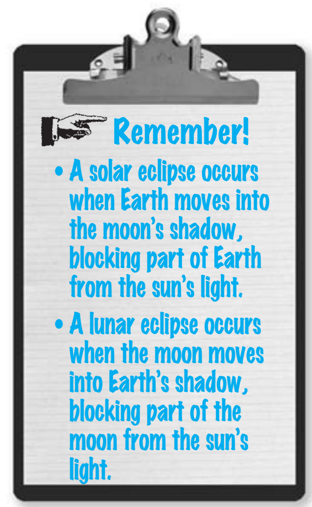
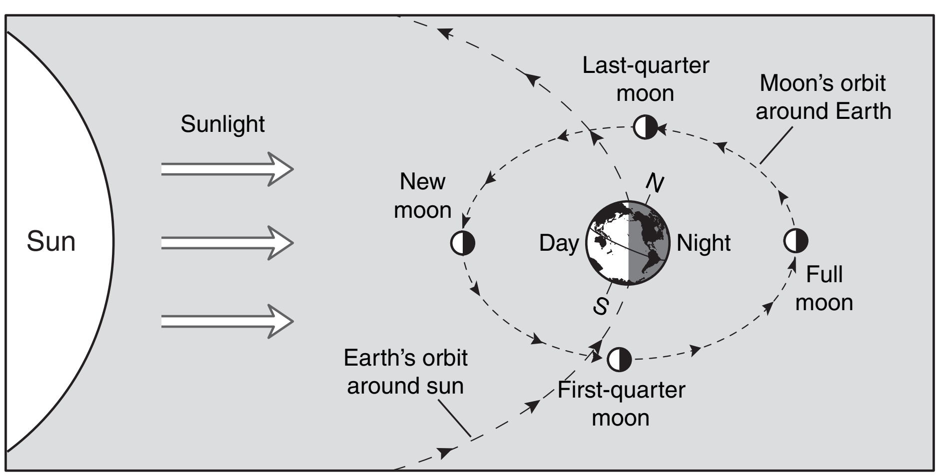


I see. So how does the moon change positions?

The moon revolves around Earth in a regular orbit. One orbit takes about 30 days. The moon's position relative to Earth and the sun gradually changes each day. The moon also rotates once on its axis about every 30 days. As a result, we always see the same side of the moon from Earth.

Positions of Earth, the Sun, and the Moon

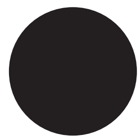


My Notes

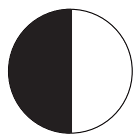
Why does the moon's appearance change from day to day? Sometimes it's round like a disc, and other times it's a half circle or shaped like the tip of a fingernail.

The moon doesn't orbit Earth quite as fast as Earth rotates on its axis. The time of moonrise and moonset occurs later by almost an hour each day. This causes the moon's position in our sky to change each day. The sun's rays strike the moon from a slightly different angle each day. These regular changes in the moon's appearance are called *moon phases*.

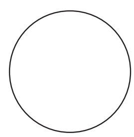
There are four main phases of the moon.



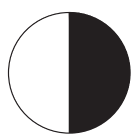
(1) The *new moon* rises around sunrise and sets around sunset. The entire side of the moon we see from Earth is in shadow and appears dark. Also, the moon is in the sky during the daytime, making it even harder to see clearly.



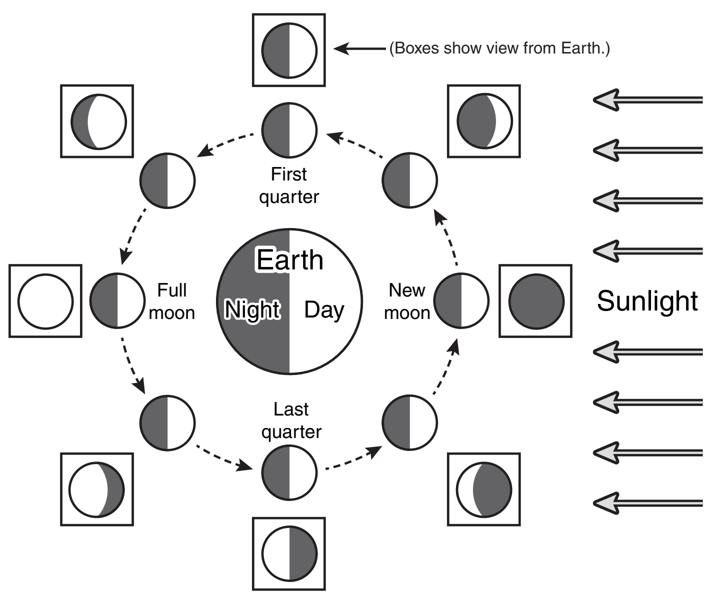
(2) The *first-quarter moon* rises around noon and sets around midnight. The side of the moon we see from Earth is half sunlit and half in shadow.



(3) The *full moon* rises around sunset and sets around sunrise. The entire side of the moon visible from Earth is sunlit.



(4) The *last-quarter moon* rises around midnight and sets around noon. The side of the moon we see from Earth is half sunlit and half in shadow.



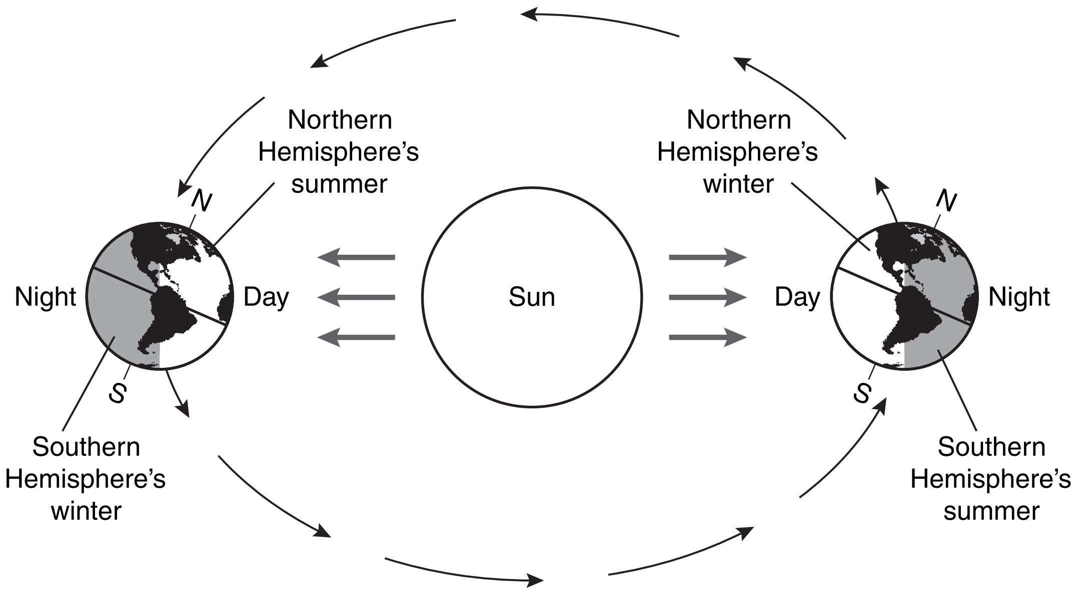
As the moon revolves around Earth, Earth revolves around the sun, right?

That's right. It takes just a little over 365 days (one Earth year) for Earth to revolve around the sun.

My Notes

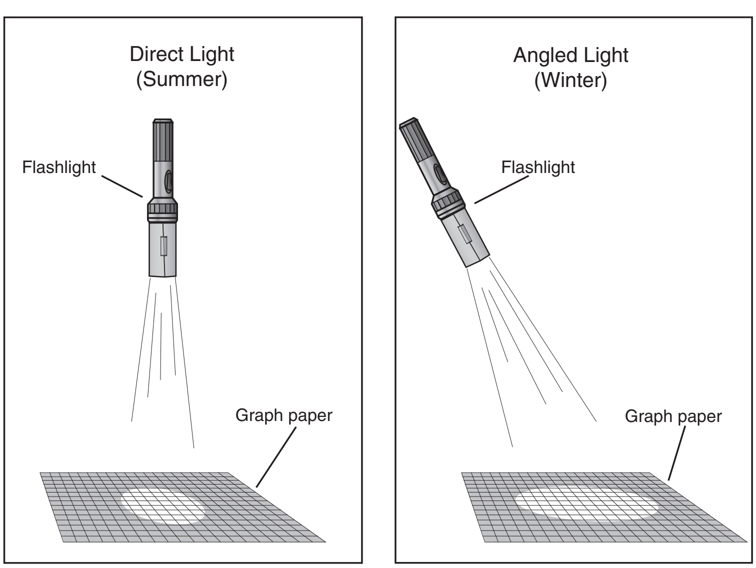
I remember hearing that Earth's tilt while it orbits the sun is the reason we have seasons. Is that correct?

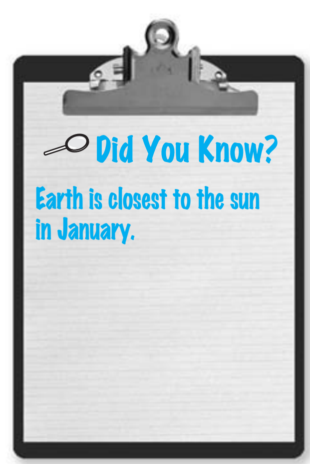
It sure is. Have you ever noticed that the sun travels lower across the sky in winter than in summer? This is because Earth is tilted on its axis at a 23.5° angle.



During winter part of Earth tilts away from the sun. This causes the sun's rays to strike that part of Earth at a lower angle than in the summer.

To demonstrate this, use a flashlight shining on a piece of graph paper. Shine the light directly over (at a 90° angle) the graph paper. Then tilt the light source (at ~20° angle) so that the same amount of light is spread out over a greater area of the graph paper.





My Notes

Days are shorter and nights are longer during winter. The shortest day of winter is called the winter solstice. The winter solstice occurs in December for the Northern Hemisphere and in June for the Southern Hemisphere. Each hemisphere receives less sunlight and therefore less heat energy during winter. This is why temperatures are colder during winter.

So how does winter change to summer?

Earth's revolution around the sun causes a part of Earth to tilt more toward the sun at different times of the year. This causes that part of Earth to receive sunlight at a more direct angle. This is also why the days are longer and the nights are shorter in summer. The longest day of summer is called the summer solstice. The summer solstice occurs in June for the Northern Hemisphere and in December for the Southern Hemisphere.

You've told me about Earth, the moon, and the sun, but how do they fit into the entire universe?

Earth, the moon, and the sun are all part of our solar system. Our solar system contains many things, such as the sun, the planets that orbit the sun, the asteroid belt, the Oort cloud, and the many moons that orbit some of the planets. Scientists who study the solar system are always looking for signs of more planets, so the number of planets may change.

What else do scientists know about other planets in our solar system?

The planets in our solar system follow regular orbits around the sun. Some planets are made of rock. Others are made mostly of frozen chemicals that would be gases at the temperatures we have on Earth. The planets vary in size and temperature. Some planets have many moons, while others have only a few or none at all. The table below displays some basic physical data for eight known planets in our solar system.

Planet	Primary Composition	Average Distance from the Sun (x 1,000,000 km)	Diameter (x 1,000 km)	Average Temperature (°C)
Mercury	Rock	57.90	5.49	167
Venus	Rock	108.2	12.1	464
Earth	Rock	149.6	12.8	15
Mars	Rock	228.0	6.80	–65
Jupiter	Gas	778.0	143	–110
Saturn	Gas	1,427	121	–140
Uranus	Gas	2,869	51.2	–195
Neptune	Gas	4,497	49.5	–200

Did You Know?

The modern calendar we use today is based on Earth's period of revolution around the sun. Some of the calendars used throughout history were based instead on the movements of the moon and planets.

Did You Know?

Alaska is often called the "land of the midnight sun." In the northern parts of Alaska in the summer, the sun never sets below the horizon. This happens because northern Alaska is above the Arctic Circle.

My Notes

Why do all the planets revolve around the sun?

The sun is the largest body in our solar system, so its gravity is much greater than any planet's gravity. The sun's strong gravity holds the planets in their orbits. The sun is a star similar to the billions of other stars in our universe.

Is our sun really a star?

Yes, our sun is a medium-size yellow star. In the sun, hydrogen undergoes nuclear *fusion*, a process that releases vast amounts of energy. During fusion hydrogen atoms join to form helium atoms. Hydrogen fusion is the source of light, heat, and other radiation from the sun.

What other objects are there in our solar system?

Well, besides the sun, planets, and their moons, there are also *comets* and *asteroids*, which are both much smaller than planets or moons. Comets are usually made of various solids and ice crystals. When their orbits take them close to the sun, dust and ice heat up and produce a "tail" behind the comet. Larger comets may even become visible without the aid of a telescope.

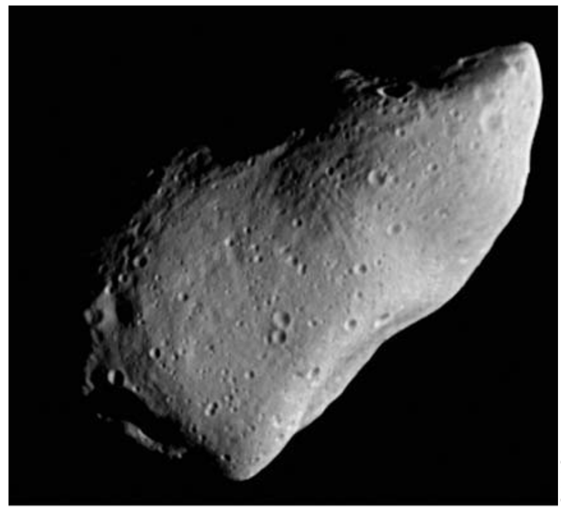
Comet Halley

© NASA

My Notes

Asteroids are rocky and usually follow regular orbits around the sun. One area between Mars and Jupiter contains a large number of asteroids orbiting the sun. This area is called the asteroid belt.

Asteroid Gaspra



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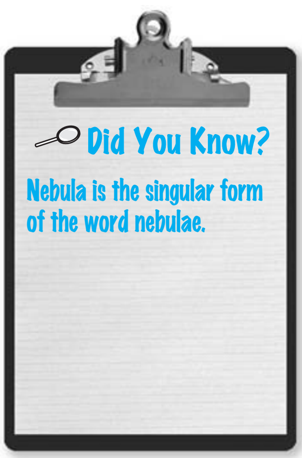


What kinds of objects exist beyond our solar system?

There are actually quite a few different kinds of objects. The most easily observed objects are stars, nebulae, and galaxies.

O.K., I know that our sun is a star, but what are nebulae?

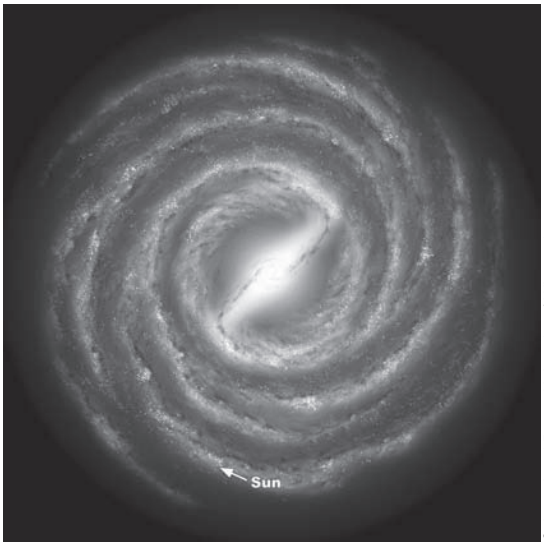
Nebulae are huge clouds of dust and gas. Some scientists think that our solar system was formed from a nebula.

I've heard that our solar system is part of the Milky Way galaxy. What is a galaxy?

Yes, our solar system is part of the Milky Way galaxy. *Galaxies* are groups of millions or billions of stars. Our Milky Way galaxy, for example, has over 100 billion stars and would take 100,000 years to travel across at the speed of light! And remember that light travels extremely fast—almost 300,000,000 meters per second.

My Notes

Milky Way Galaxy



That's too huge to even imagine! How close is the nearest star to us, besides our sun?

The nearest star is Proxima Centauri. Traveling at the speed of light, it would take about 4 years and 3 months to reach Proxima Centauri from Earth. Or, to put it another way, it is about 280,000 times farther away from Earth than our sun.

How many other galaxies are there besides the Milky Way?

Scientists think that there are billions of galaxies in the universe. Most of these are too far away to see, so we can only estimate the actual number.

Remember!

The speed of light is 3×10^8 m/s. That is a 3 with eight zeros, or 300,000,000 meters per second.

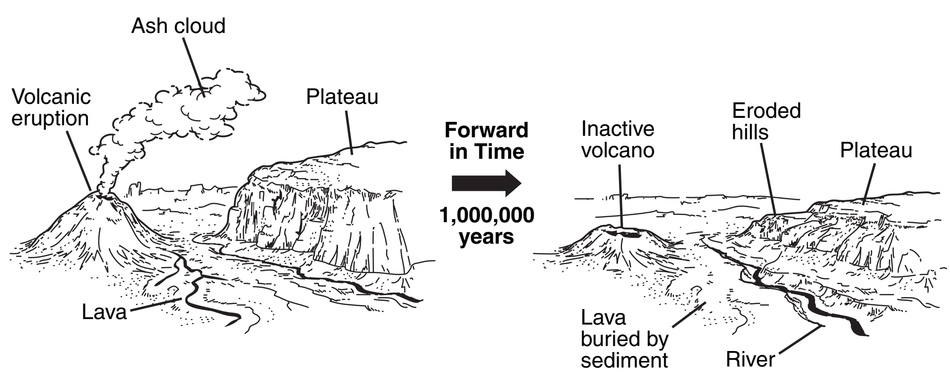
My Notes

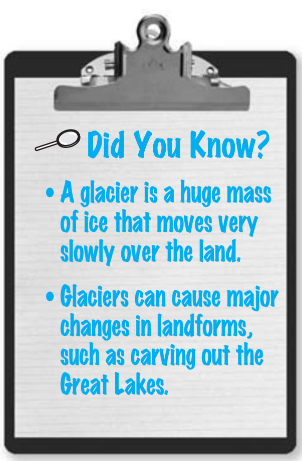
Space systems are amazing! O.K., I'd like to come back to Earth now. What about some of those Earth systems you mentioned earlier?

Earth systems can be found as deep as the inner layers of Earth and as far out as the upper layers of Earth's atmosphere. Earth systems are all driven by energy, and many of these systems occur in cycles. Energy for Earth's rock cycle comes from heat energy in Earth's core. Energy for Earth's water and nutrient cycles comes mainly from the sun's radiant heat and light energy.

You mentioned the rock cycle. What is the rock cycle?

The *rock cycle* is the continuous change of rocks from one type to another. When we see Earth's crust, it usually looks solid and stable. But imagine that we could watch a time-lapse video of Earth's crust. Suppose this imaginary video could show us what has happened over the last 3,000,000 years in only a few minutes of time. We would see a very different picture of Earth's crust.





So, what would we see in a time-lapse video covering 3,000,000 years of time?

Suppose we let the video show the first 1,000,000 years. At first we might see mountains, hills, and plateaus. Volcanoes would spit out ashes and chunks of rock again and again. Volcanic rock would pile up all around the volcanoes. Layer after layer of volcanic ash would settle on the ground. In some places, rivers of lava would flow like melted candle wax across Earth's surface.

In reality most of these changes happen too slowly for us to notice. But our time-lapse video would allow us to see Earth's changes more easily.

I get it. We're watching what really took thousands of years happen in just a few seconds. What else would we see?

Let's fast-forward our video a million years. Now we see that the mountains, hills, and plateaus have changed. Some of the exposed rock is worn away before our eyes by wind and water. This process of rock breaking down into smaller pieces is called *weathering*.

My Notes

In our time-lapse video, soil seems to flow like water. Weathered particles of rock are transported by gravity, living organisms, water, glaciers, and wind. This movement of particles from one location to another is called *erosion*.

O.K., pause the video for a second. Soil doesn't really move like water. What is actually happening to the eroded particles?

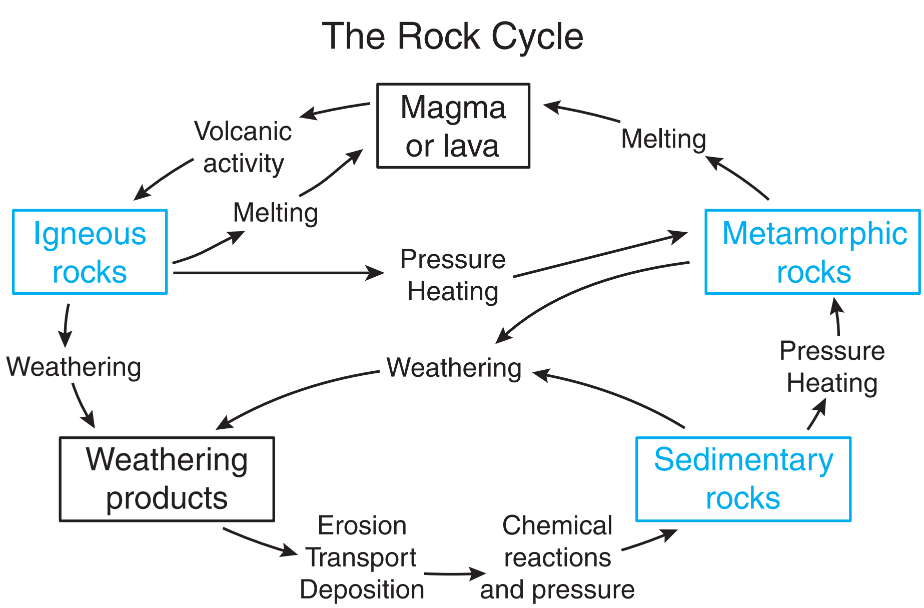
Good question. Eroded particles settle wherever they are transported by wind or water as sediment. This process is called *deposition*. Many of the soil particles that were eroded from higher areas settled in valleys and plains. The soil in these areas became deeper. From our viewpoint, it just appeared as though soil was flowing into these lower areas.

Suppose our video could also show the activity beneath oceans and lakes. We would see layers of mud, sand, and other materials steadily build up on the ocean and lake floors. These particles were washed by runoff into bodies of water and slowly settled there over time.

I know cycles have to come back around to where they started. So how do deposited particles like soil and the ocean floor become rock again?

Good point. Chemical reactions and the pressure of many layers deposited with time gradually change sediment into rock again. Sediment that gets transformed into solid rock is called *sedimentary rock*.

The lower levels of buried rock were also pushed deeper into Earth's crust. Here this rock came under great pressure and heat. These stresses caused the properties of this rock to change. Rock that has been transformed by intense heat and pressure is called *metamorphic rock*.



My Notes

Remember!

There are three basic types of rock.

- Sedimentary rock is hardened layers of deposited sediment.
- Igneous rock is solidified lava or magma.
- Metamorphic rock is rock transformed by heat and/or pressure into rock with different properties.

Our time-lapse video showed lots of volcanic activity. What caused all these volcanoes?

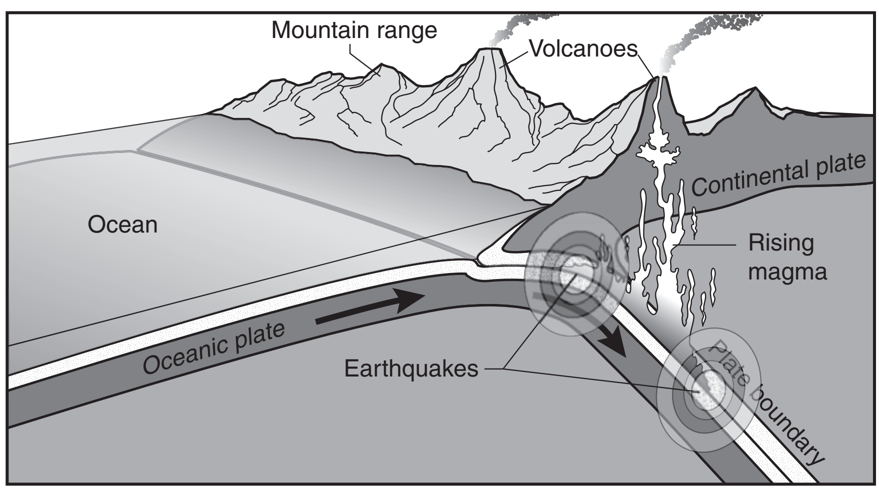
Extreme heat and pressure deep in the ground caused rock to *melt*, changing it into its liquid form, which is called *magma*. At cracks in Earth's crust, magma erupted onto Earth's surface as *lava*. The lava then cooled and hardened, forming solid rock again. Rock formed from hardened magma or lava is called *igneous rock*.

O.K., that explains a lot. But I'm still curious how some of the mountains, hills, and plateaus were pushed up from Earth's crust. What caused that?

If you watched the time-lapse video closely, you may have noticed that Earth's crust seemed to be moving gradually in different directions. A theory called *plate tectonics* explains the movement of large sections of Earth's crust called tectonic plates. The force behind tectonic plate movement is thought to be currents of magma flowing in Earth's mantle.

The tectonic plates slowly collide against one another along *plate boundaries*. As a result of these collisions, sections of the plates may break off and be pushed down, up, or to the side. This is why mountain ranges, ocean trenches, earthquakes, and volcanic activity are all common along plate boundaries.

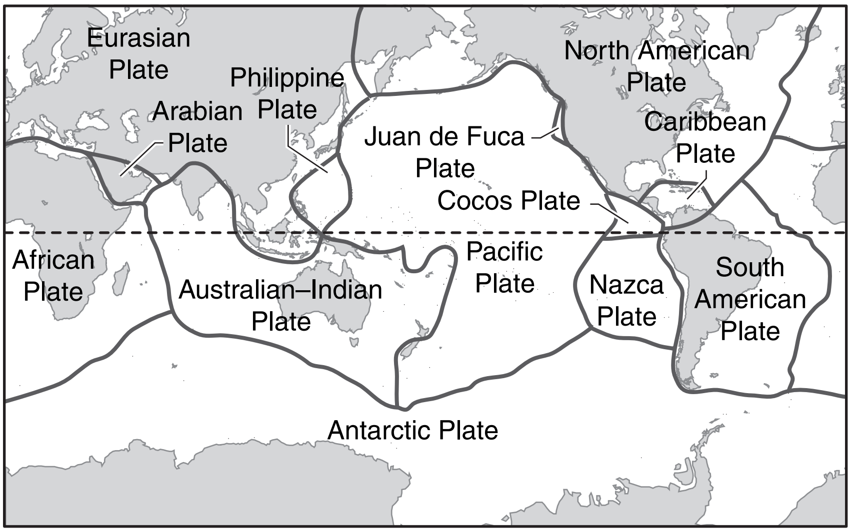
Tectonic Plate Boundary



Some plates move apart, allowing magma to rise up and cool to form new land. Earthquakes also occur around these locations. An example is the mid-Atlantic ridge, where new seafloor and land are being formed slowly. Some plate boundaries slide past each other, causing earthquakes. An example is the San Andreas Fault in California.

My Notes

Major Tectonic Plates of Earth



We've looked above and below the land and at the bottom of the ocean in our time-lapse video. What would we see if we looked along the ocean shoreline?

Well, the daily tides caused by the gravitational pull of the moon and sun would be just a blur on a time scale of thousands of years per second! But ocean waves carry a lot of energy, and over time this energy can move a lot of beach soil. The process of ocean waves changing the form of the shoreline is called *beach erosion*. We would see shorelines grow, shrink, and change shape in various areas over the entire 3,000,000 years of our imaginary video.

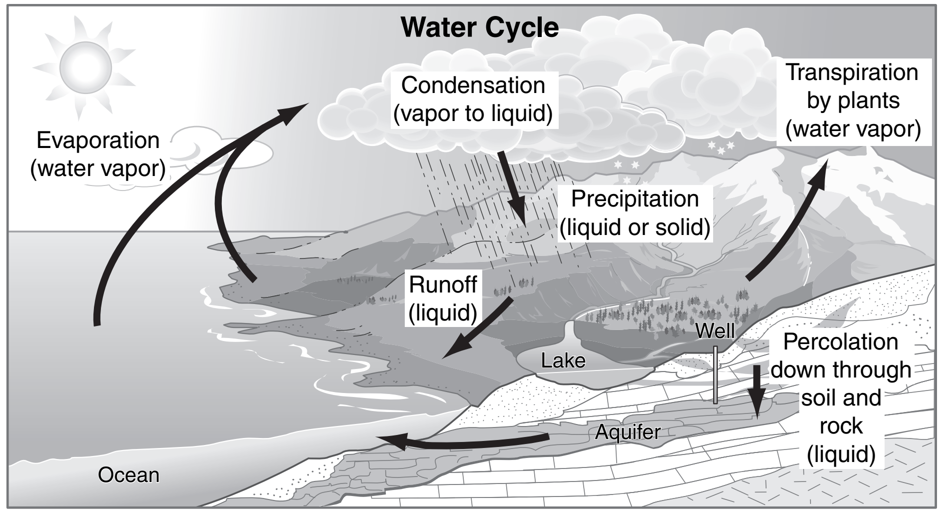
Does water go through a cycle?

Water does go through a cycle. Water naturally occurs as a solid (ice), a liquid (water), and a gas (steam, water vapor) in the range of Earth's temperatures. As water changes between these states, it moves between land, bodies of water, and the atmosphere. When water moves over the surface of Earth, it is called *surface water*. Water that percolates (soaks) down through soil and rock is called *groundwater*. Some groundwater may collect in underground reservoirs called *aquifers*. This movement of water through its different states of matter is called the *water cycle*.

Remember!

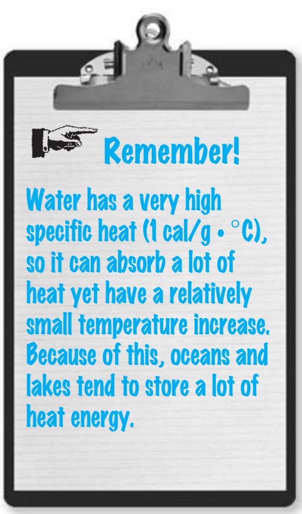
When water changes state, it gains or loses heat energy. This movement of heat energy is an important force that drives weather systems.

My Notes



If water keeps cycling, why do some cities have to conserve water?

Good question. Even though water moves in cycles, there is only a limited amount in aquifers, lakes, and rivers at any one time. Once the water is used, it takes time for these water sources to be replenished by the water cycle. In hot, dry weather people may use large amounts of water from these sources in a short amount of time. Shallow wells may become dry or polluted, and ecosystems that depend on lake and river water become threatened.



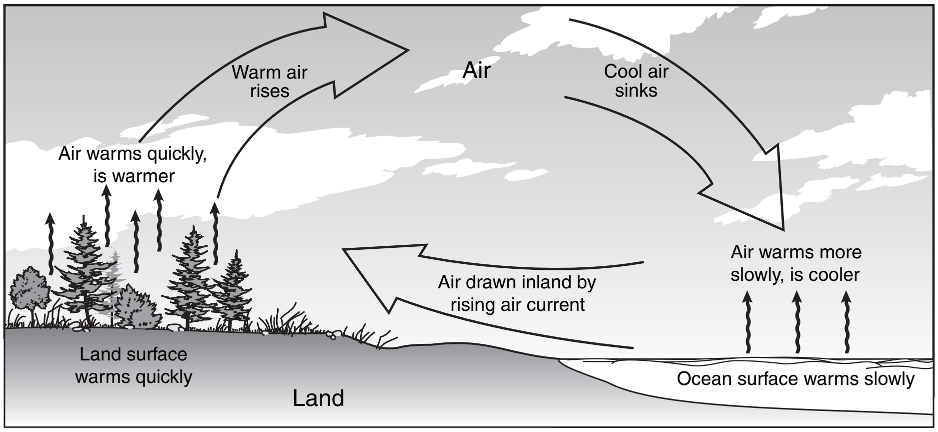
The diagram of the water cycle shows that water vapor can form clouds. Do oceans affect the climate on land?

Nice observation. There are two important ways that oceans affect the climate on land:

(1) Land heats up faster than water because land has a lower specific heat than water does. This causes the air over land to heat faster than the air over water. The warm air rises, starting a convection current that pulls air toward land from the ocean. This pattern is seen on all the continents of Earth. This keeps air over the land from getting too hot. It also brings moist ocean air inland.

My Notes

Daytime Convection Currents
Caused by Different Heating of Ocean and Land



(2) Warm air holds more water vapor than cold air does. When warm, moist air is cooled, clouds form and can produce precipitation. This warm air can be cooled by rising into the colder upper atmosphere, by moving over cold ocean or lake water, or by mixing with colder air.

We see an example of warm air mixing with cold air when a frontal boundary moves through the atmosphere. This is the edge where the cool, dry air meets the warm, moist air. This mixing of different air masses often causes stormy weather.

O.K., I've seen how water moves in cycles. Are there other important cycles on Earth?

Yes, there are. Two other important cycles are the nitrogen cycle and the carbon cycle. In the nitrogen cycle, the element nitrogen changes back and forth from nitrogen gas to the nitrogen compounds used by plants and animals. In the carbon cycle, carbon changes back and forth from carbon dioxide gas to plant and animal carbon compounds. These cycles provide essential nutrients to plants and animals. Without them, there wouldn't be any life on Earth.

My Notes

The *nitrogen cycle* is the continuous circulation or flow of nitrogen through the environment. Nitrates from the soil are absorbed by plants, which are eaten by animals that die and decay, returning the nitrogen back to the soil.

What can you tell me about nitrogen in the environment?

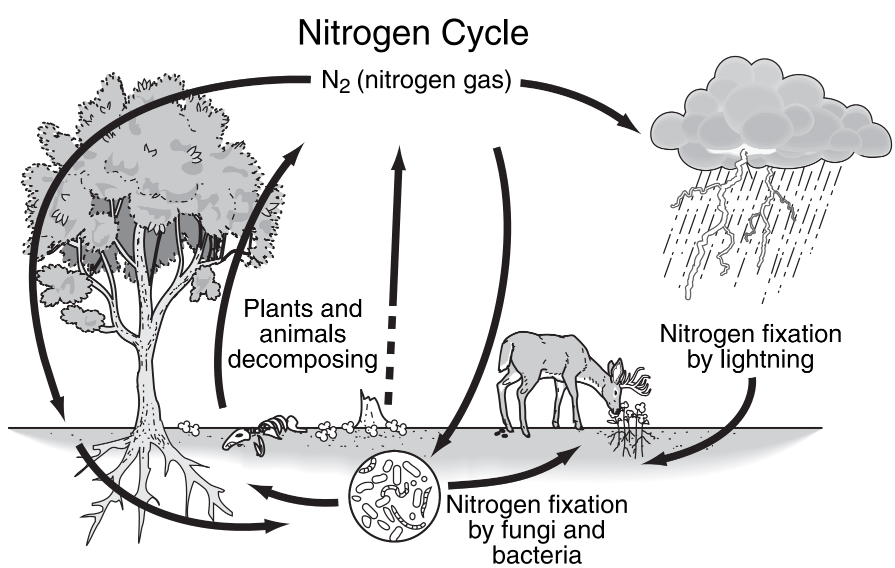
Don't some fertilizers contain nitrogen?

That's right. Some fertilizers contain nitrogen compounds because plants need nitrogen to grow. Though there is plenty of nitrogen gas in the atmosphere, plants can't use this form of nitrogen. In nature nitrogen can be changed from a gas to a form that plants can use by lightning or by soil bacteria and fungi in a process called nitrogen fixation.

Did You Know?

A chemical involved in photosynthesis is chlorophyll. One type of atom in chlorophyll molecules is nitrogen. Without nitrogen, plants could not make their own food.

Nitrogen is also passed from plants to other organisms through food webs in the ecosystem. Once plants and animals use the nitrogen, it returns to the atmosphere as a gas, completing the cycle.



So the more fertilizer containing nitrogen compounds we use, the faster plants will grow?

No, not necessarily. There is a limit to how much fertilizer is helpful. Too much nitrogen could harm the plants we are trying to help. But more importantly, all the extra fertilizer containing nitrogen could have negative effects on the ecosystem.

My Notes

What else besides the plants would be affected by too much nitrogen?

Overuse of fertilizer containing nitrogen can cause a buildup of nitrogen in groundwater and surface water in a watershed. High levels of nitrogen in a watershed can contribute to human health problems. Too much nitrogen in runoff water may also have harmful effects on fish, animals, and plants in lakes and rivers.

What about the carbon cycle?

The *carbon cycle* is the continuous circulation of carbon through the environment. Plants use the carbon dioxide from the air to make food. Animals put carbon dioxide back into the air through respiration. As fungi and bacteria break down dead plants and animals, carbon is released back into the soil.

I know plants use carbon dioxide in photosynthesis. Is this part of the carbon cycle?

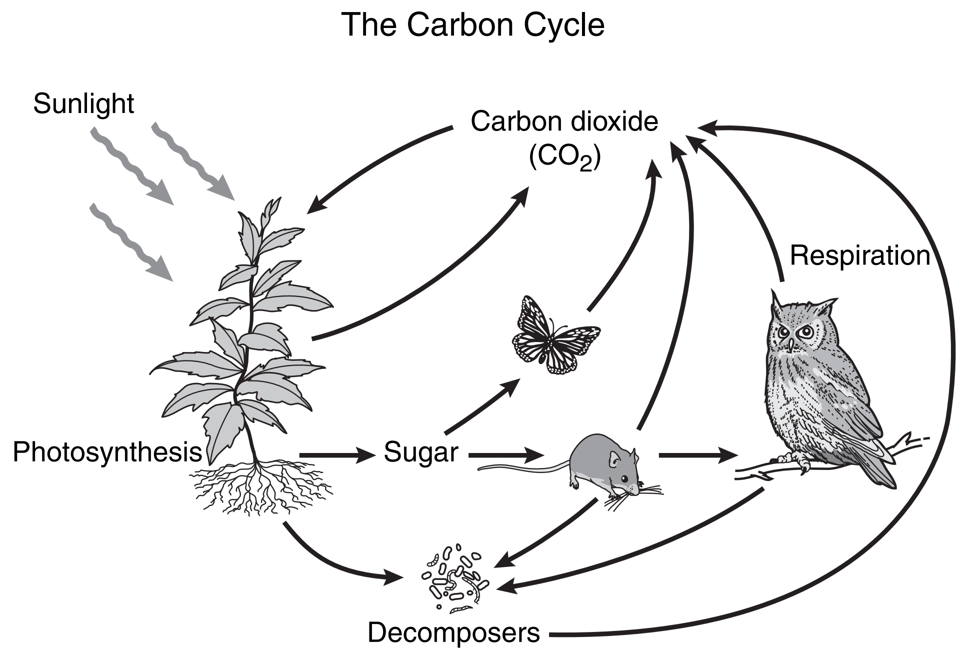
Yes, it's a very important step. All living things are built from molecules that contain carbon. Some carbon comes from the atmosphere as carbon dioxide. You may recall that plants use carbon dioxide during photosynthesis to make sugar. The carbon in sugar is used as an energy source in plant and animal cells. Sugar also serves as a basic material for building other carbon compounds that make up plant and animal tissues.

When animals eat plants and other animals, they convert these carbon compounds into energy and various materials in their bodies. Most compounds in animal tissues contain carbon.

So how do all these carbon compounds become carbon dioxide again?

When plants and animals use sugar to produce energy during respiration, carbon dioxide is given off. Decomposers change the carbon compounds in dead plants and animals into carbon dioxide. Both respiration and decomposition complete the cycle, releasing carbon dioxide back into the atmosphere.

My Notes



Do humans affect the carbon cycle?

Yes, we do. One of the biggest ways humans affect the carbon cycle is by burning fossil fuels. Fossil fuels are coal, oil, and natural gas. These fuels were formed from the buried remains of ancient plant and animal life. Over millions of years, heat and pressure have changed the carbon in these organisms into coal, oil, or natural gas. Burning these fuels transforms the carbon into carbon dioxide. Burning fossil fuels produces carbon dioxide much faster than the natural decay process does.

I see. So how does this extra carbon dioxide affect the environment?

Higher levels of carbon dioxide cause the atmosphere to hold more heat energy. Rising carbon dioxide levels may be the cause of warmer temperatures measured in recent years on Earth. This is sometimes called "the greenhouse effect." This could affect the climate in many places. The kinds of plants and animals able to survive in these climates may change if the warming continues.

Whew! That's a lot of information. Can we summarize this in a table?

Sure. Have a look at this.

My Notes

Nitrogen and Carbon Cycle Effects

Cycle	Importance to Plants	Importance to Animals	Forms in the Environment
Nitrogen	Supplies vital nutrients	Supplies vital nutrients	Water-soluble nitrogen compounds in soil and water; nitrogen gas in atmosphere
Carbon	Basic energy source (sugar); building block of organic molecules	Energy source and building material for cells, tissues, organs	Mineral carbon in rocks; carbon dioxide in atmosphere; carbon in organic products (wood, paper, meat, vegetables, etc.)

I see how human activities affect these cycles. What about when a natural disaster occurs?

Natural disasters can have far-reaching effects on Earth systems. For example, large meteorites striking Earth or volcanoes erupting can cause environmental change. These events can change the amount of sunlight and heat reaching the atmosphere, land, and water on Earth. This can affect the amount of energy available for Earth's cycles.

What would happen if a large meteorite struck the Earth?

If a very large meteorite impact or volcanic eruption occurred, it would fill the atmosphere with tiny dust particles. Dust particles can stay in the upper atmosphere for years. This would block sunlight and therefore reduce the total energy available on Earth. As Earth's cycles slowed down, climates and ecosystems would be altered. There is evidence in the fossil record of *mass extinctions* following these kinds of disasters. The extinction of the dinosaurs may have been caused by such an event.

Haven't humans also caused some species of plants and animals to become extinct?

Unfortunately, human activities have been the cause of some extinctions. Humans affect Earth in many ways. We change the quality of the air, water, and soil we use. We change ecosystems by removing plants and animals and by introducing new species, such as invasive plants and pets. *Invasive species* do not naturally live in the ecosystem where they are introduced. These species sometimes compete with or drive out *native* species. Native species are those that live naturally in an ecosystem.

Fire ants are an invasive species accidentally introduced to North America from South America. In North America they have few predators and aggressively attack and kill many kinds of native plants and animals. They have upset the balance of ecosystems in many southern states.

Did You Know?

Texas has lost several species by extinction:

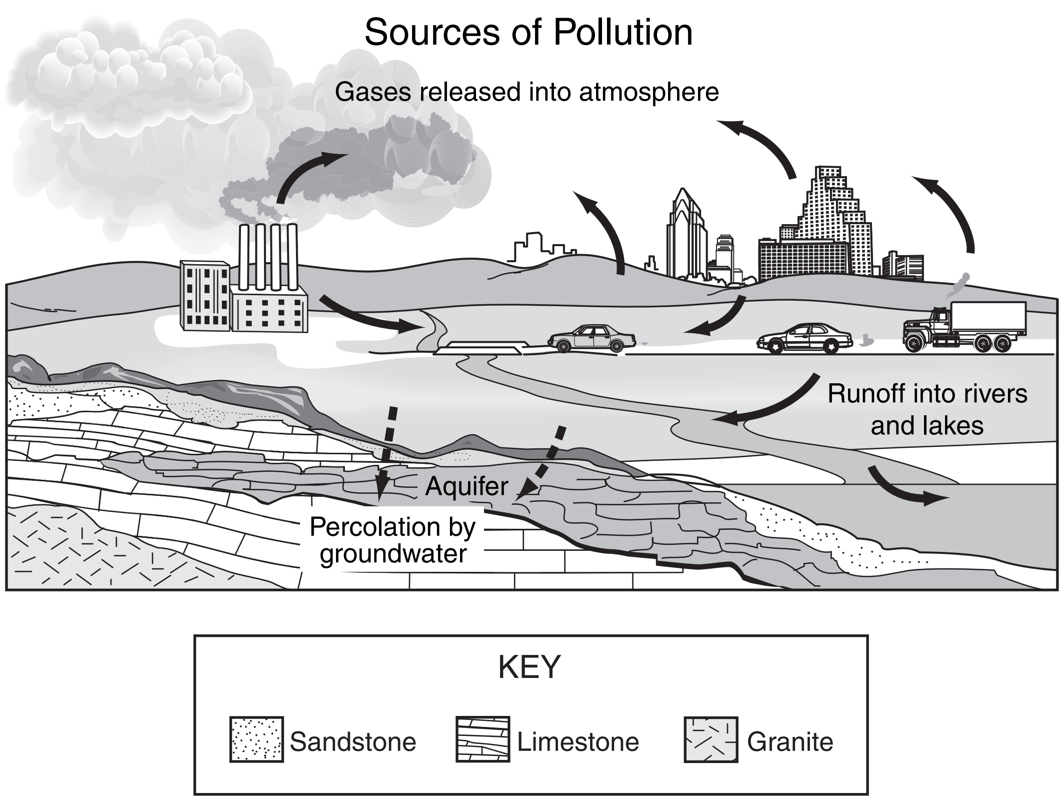
- Texas gray wolf, 1942
- Texas red wolf, 1970
- Phantom shiner (fish), 1975
- Texas Henslow's sparrow, 1983
- San Marcos gambusia (fish), 1983

My Notes

Changes in habitat can make it difficult for some species to survive. Some species are able to adapt, but others become threatened or endangered. A few species even become extinct, lost from Earth forever.

So humans change the quality of resources such as air, water, and soil. How do we do that?

We've identified some of these changes in our discussion of Earth's cycles. But there are many ways humans can alter the environment. One of the main ways we do this is by producing harmful chemical waste materials. These harmful products cause pollution. Two common forms of pollution include: (1) gases released into the atmosphere and (2) chemicals that are carried by water into a watershed.



How do chemicals harm the atmosphere?

Well, let's look at a class of chemicals called chlorofluorocarbons (CFCs). CFCs were used in air conditioners, refrigerators, and pressurized sprays. But when CFCs evaporate, they rise into the upper layers of the atmosphere. There CFCs destroy ozone, a gas that protects Earth from the sun's harmful ultraviolet rays. Once the effects of CFCs were discovered, other chemicals were used instead of CFCs in order to preserve the ozone layer.

My Notes

How does pollution affect water and soil?

Many industrial waste products are compounds that dissolve easily in water. When we clear and plow land, we expose soil to erosion. Eroded soil and waste products can move into rivers, lakes, and aquifers. These eroded materials can ultimately harm water ecosystems. Harmful chemicals may also enter the water supplies we use for drinking, cooking, and other household uses.

So pollution damages resources that we need in order to live. When we damage a resource, can we repair the damage?

That's a very important question. That depends a lot on which resource is damaged. Some resources may recover in just a few years, and others may not recover for thousands of years or more.

Which resources can recover quickly from damage?

Renewable resources usually recover sooner than other types of resources. Renewable resources are replaced regularly through natural events once they have been damaged. Surface water, for example, will re-enter the water cycle after it has been polluted. Evaporation will usually separate pure water from any pollutants in it. The evaporated water will eventually fall to Earth as precipitation, and we will be able to use it again.

What other types of resources are there besides renewable resources?

Resources that have a limited supply and are not being recycled or replaced naturally are *nonrenewable*. Fossil fuels are an example of a nonrenewable energy resource because they take many millions of years to form.

What if a resource is so plentiful that we will never run out of it?

Inexhaustible resources are so abundant or continuous that they do not require replacement. An example of this is sunlight. It arrives daily over most of the planet in vast amounts. It is probably impossible for us to use all the sunlight that Earth receives.

Well, obviously most resources aren't that plentiful. That means we have to be careful how we use our resources, right?

Exactly. Fossil fuels are a good example. The supply of underground crude oil we use to make gasoline and diesel fuel decreases every year. Yet we keep pumping more oil from wells. If this continues, oil and gasoline will become so rare in the future that we won't be able to use them as much as we do now.

Remember!

The chemicals we use will end up in our environment somewhere. We should always be alert to the possibility of problems caused by waste products we release into the environment.

Objective 5

My Notes

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What will we use for energy when that happens?

We will have to find other sources of energy. Ideally, we will use renewable or inexhaustible resources so the supply won't run out. To replace fossil fuels, new energy resources must be found to produce large amounts of energy at a reasonable cost.