SCIENCE

Unit 5

System Earth

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Contents

Specific aims	Lesson 1 Above the Earth	
Knowing science: Content	Learning about the atmosphere, its layers and composition	
Investigating science	Investigating how Earth's magnetic field makes life on Earth possible	Calculating atmospheric layer thicknesses
Science in society	Determining the role of atmosphere in radio communications	Learning about Earth's ozone layer and magnetic field protect life on Earth
Science process skills	Extracting key scientific data from text	Interpreting diagrams and applying scientific knowledge
Language skills	Interpreting scientific text	Writing logical and coherent responses to questions

Specific aims	Lesson 2 On the Earth	
Knowing science: Content	Learning about the hydrosphere and lithosphere	Understanding the basic concept and mechanism of plate tectonics
Investigating science	Understanding how today's landscapes are formed by lithospheric forces	
Science in society	Understanding the relationship between the water cycle human society	
Science process skills	Relating diagrams of tectonic plate boundaries to earthquake and volcano activity	Drawing bar graphs from data provided
Language skills	Reading scientific text for accurate meaning	Writing logical and coherent responses to questions

Specific aims	Lesson 3 Inside the Earth	
Knowing science: Content	Learning about Earth's core and mantle	Learning about earthquakes and volcanoes
Investigating science	Exploring the different temperatures and zones within Earth	Explaining how plate tectonics relates to earthquake activity
Science in society		Asking questions about why some people live in danger zones (earthquakes and volcanoes)
Science process skills		Interpreting maps and extracting scientific generalisations
Language skills		Writing logical and coherent responses to questions

Specific aims	Lesson 4 Biogeochemical cycles
Knowing science: Content	Learning about the water cycle, rock cycle, carbon cycle, nitrogen cycle
Investigating science	Understanding how nature provides water purification services "free of charge"
Science in society	Showing how biochemical cycles are critical for the health of our planet and life on the planet
Science process skills	Using diagrams to explain different biogeochemical cycles
Language skills	Writing coherent responses to questions

Specific aims	Lesson 5 Seasons
Knowing science: Content	Learning about the relationship between orientation of the Earth on its axis and location within its orbit around the Sun to seasons
Investigating science	Using a model to understand and explain seasons
Science in society	Understanding how seasons affect humans and other life processes
Science process skills	Using diagrams to communicate and explaining and interpreting diagrams to draw out scientific knowledge
Language skills	Writing logical and coherent responses to questions

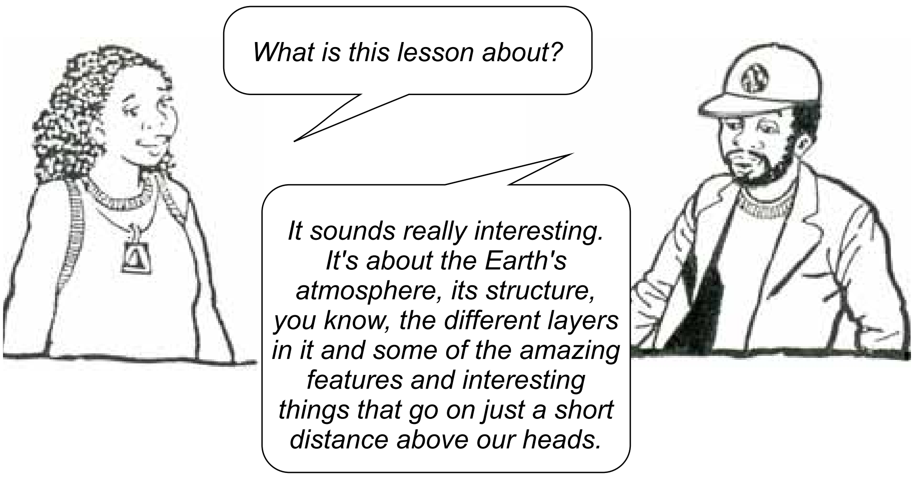
Specific aims	Lesson 6 Earth as a system
Knowing science: Content	Learning how Earth operates as a system with feedback and regulatory mechanisms that help keep system equilibrium
Investigating science	Investigating the concept of equilibrium, regulatory mechanisms and relationship to climate
Science in society	Examining humans' place in the Earth system and questioning our role
Science process skills	Using diagrams to communicate and explaining and interpreting diagrams to draw out scientific knowledge
Language skills	Writing logical and coherent responses to questions

Specific aims	Lesson 7 Climate change
Knowing science: Content	Learning about the five major climate changes over the lifetime of the Earth, their causes and consequences
Investigating science	Using graphical evidence of climate data to interpret trends and drawing conclusions
Science in society	Examining the consequences of climate change for human survival
Science process skills	Using multiple data sources to draw logical conclusions
Language skills	Writing logical and coherent responses to questions

Specific aims	Lesson 8 Greenhouse effect
Knowing science: Content	Learning about the greenhouse effect, effects of human activity, historical record
Investigating science	Investigating the role of humans in changing the conditions for life on this planet
Science in society	Asking questions relating to human activity, ‘progress’ and the cost of progress
Science process skills	Interpreting diagrams and extracting data present within diagrams to draw conclusions
Language skills	Writing logical and coherent responses to questions

Above the Earth

About this lesson



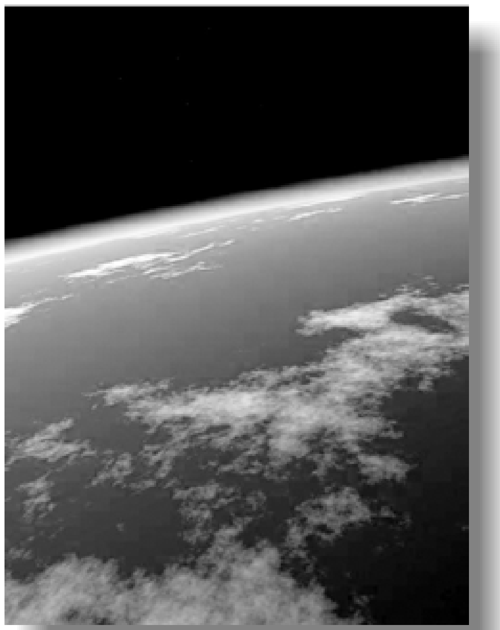
In this lesson you will:

- learn about the structure of the atmosphere
- describe the mix of gases in the atmosphere
- work out where the majority of the air is in the atmosphere
- find out how a layer with ionised particles can assist radio communication
- learn about the Earth's magnetic field and make an electromagnet as a model for understanding the geomagnetic field
- find out how the Earth's magnetic field makes it possible for life on Earth to survive
- discover how the natural lights called Aurora are created
- discover how the ozone layer in the stratosphere is another feature of our atmosphere that makes it possible for life to survive on Earth
- understand why it gets colder and then warmer again as we move up in the atmosphere.

The atmosphere

atmosphere: ***the layer of gases around a planet or star***

The **atmosphere** on Earth is the layer of gases that we call the air. The air around us is made up of a mixture of different gases. A very important gas is oxygen because that is what our bodies use when we breathe in air. Later in this unit, you will learn about other gases in the atmosphere. The atmosphere extends above us for about 100 kilometres. The air becomes more spread out, or thinner, as we go upwards. No humans live in settlements higher than about 5 kilometres above sea level. Beyond 10 or 11 kilometres above us, the air is so thin that there is not enough oxygen to keep us alive. 99% of all air is below 31 kilometres. Above this there is only the remaining 1% of air! Molecules at this height can be separated by metres or kilometres with no matter between them. We normally consider that space starts at about 100 kilometres. Once we get higher than about 120 kilometres there is no air at all.



Planet Earth showing the thin layer of atmosphere

diameter: *distance across*

This photo shows Earth and a very thin layer of air around it. It is so thin at this scale that it is difficult to see. The **diameter** of Earth is about 12 756 kilometres at the Equator, so the 100 kilometres of atmosphere is less than 1% of that distance (0.78%).

Composition of the atmosphere

The atmosphere consists of a mixture of gases. Table 1 on the next page shows the composition of dry air. If we include water vapour, which is also a gas, then we need to add about 1% of water vapour. This amount changes slightly all the time.

Substance	% by volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon Dioxide	0.033
Other gases	0.0027
Ozone	0.000001

Table 1: Composition of dry air

We mainly refer to Nitrogen, Oxygen, Carbon Dioxide and then 'all the other gases'. Argon might be the third most abundant gas in the atmosphere but we almost never refer to it. The other gases together add up to only 0.007% of air in the atmosphere. We have kept Ozone in this table even though it is extremely scarce in the atmosphere. Can you think why?

COMMENT

Carbon Dioxide is a very important gas for life on Earth, so even though it is 28 times less abundant than Argon, it is much more important to us.

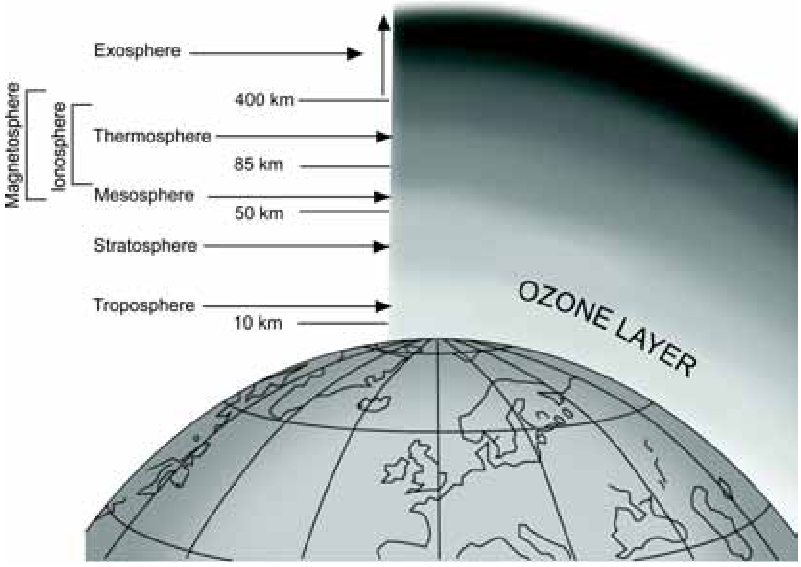
ACTIVITY 1

1. Name the two most abundant gases in our atmosphere. What percentage of the atmosphere do they make up together?
2. At what height does the atmosphere end and space begins?
3. What is important about the altitude of 31 km above sea level?
4. Draw a bar graph of the five most abundant gases in the atmosphere. Use the bar graph to show the percentages of each gas.

ANSWERS ON PAGE 129

Layers in the atmosphere

The atmosphere is made up of different layers. Each layer has its own special characteristics. The main layers in the atmosphere are shown in the diagram on the next page. We will examine each of these in turn in the next few sections.



The structure of the atmosphere

ACTIVITY 2

Read the information on page 2 and compare it with this diagram. Use the two sources to answer these questions.

1. Name the layer where most of the air is.

2. Which of the layers are in what we normally think of as space?

3. Describe the amount or abundance of ozone gas in the ozone layer?

4. Passenger jets usually fly in the stratosphere. What is one important challenge for them that the information on page 2 tells you?

ANSWERS ON PAGE 129

The Ionosphere

Molecules are normally electrically neutral. They have a balance between negatively charged electrons and the positive charge of the rest of the molecule. In the ionosphere, which is between about 85 and 250 kilometres above the Earth's surface, the intense energy of ultraviolet radiation, X-rays and other radiation from the Sun can split electrons from molecules, resulting in positively charged ions. This radiation is called **ionising radiation** because it produces positively charged ions. This is why we call this zone the ionosphere. Ionising radiation is very harmful as it causes cancer.

molecules:
extremely small particles that are the building blocks of matter. They are made up of atoms and other even smaller particles

ionising radiation:
rays that can split molecules into electrons and positively charged ions.

The top of the ionosphere, the zone where it becomes the exosphere, is called the ionopause. Look again at the diagram on page 4 to remind yourself where the ionosphere is.

The ionosphere and radio communication

Most radio waves do not need to travel in direct lines to radio receivers. They can bounce and bend (reflect and refract). The ionosphere is a very important way that some radio waves can travel very far distances around the curved shape of the Earth. These radio waves, mostly the shorter wavelengths, can zig-zag up to five times between the surface of the Earth and the ionosphere. We call these 'skywaves'.

Radio waves reflecting off the ionosphere (the outer line) during skywave radio propagation

Interference with skywave radio propagation

Skywave **propagation** depends on the **ionised particles** in the ionosphere. At night the ionising rays from the Sun are reduced, which means that night-time shortwave radio signals can weaken. Any changes to the radiation coming from the Sun can also interfere with skywave propagation.

Sometimes the Sun is more active than at other times (think of flames in a fire, sometimes flaring up, or dying down). If Sun activity increases, it increases the ionisation taking place, which, in turn, increases the absorption of radio signals passing into the ionosphere.

During the strongest solar activity, almost total absorption of radio signals that use the ionosphere on the sunlit side of the Earth can occur. This causes bad disruption of some radio communication and GPS accuracy.

propagation:
the spreading or transmitting of something.

ionised particles:
molecules that have been split into negatively charged electrons and positively charged ions, which is what remains when an electron has been removed.

COMMENT

Most emergency transmitter equipment, communication with aircraft over oceans and other important communications now use satellites to avoid interference from increased solar activity.

ACTIVITY 3

1. What is the ionopause and at what altitude is it?

2. What is very useful about the ionosphere?

3. Explain why the ionosphere has that name.

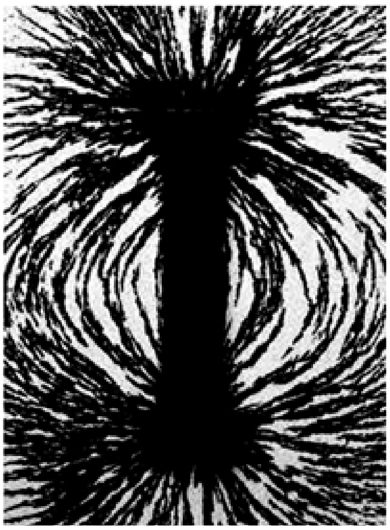
4. Give two reasons why humans could not survive for long in the ionosphere.

ANSWERS ON PAGE 130

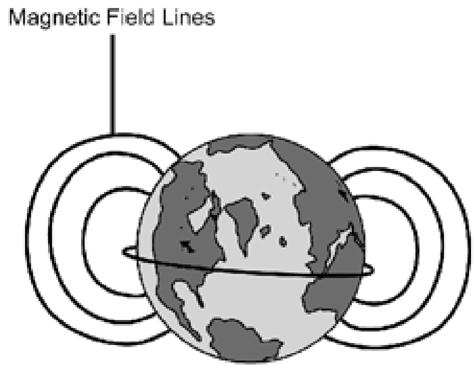
Earth's magnetic field

This section is not about the atmosphere, but it helps explain what comes next: the magnetosphere.

You can think of it as Earth being like a giant magnet that has a magnetic field around it. This photo of a bar magnet shows what a magnetic field looks like.



A simple bar magnet with iron filings around it showing the magnetic field



An illustration of Earth's magnetic field

The Earth's magnetic field is caused by convection currents within the outer core and the rotation of the earth. The outer core of Earth is composed of highly conductive molten iron. Convection currents in this liquid metal and Earth's rotation cause movement. This motion of the liquid metal, mainly iron, generates electric currents. You will know from learning about electricity, in Unit 3, that around any conductor, a magnetic field exists. This is why we can make electromagnets. It is the same with our planet.

COMMENT

Without the Earth's magnetic field there would be no life on Earth. Does this surprise you? The next section explains it.

ACTIVITY 4

Make an electromagnet.

You will need: a large nail, a long length of thin wire that is insulated with plastic or lacquer, a battery, some small iron objects like thin nails. It is important that the wire is insulated – if it is not you will get a short circuit.

1. Use the equipment and the diagram to help you. Make an electromagnet and use it to pick up the small nails.

   a. Wind the wire neatly around the nail: the more wire, the stronger the electromagnetic effect will be.
   b. Connect the two loose ends of the wire to a torch cell. You should now be able to use the tip of the nail as a magnet.
   c. Disconnect the electrical circuit. The objects you picked up should now fall down again.
   d. Do not leave your circuit connected.

2. Write a paragraph showing how the electromagnet has similarities to planet Earth.

ANSWERS ON PAGE 130

The magnetosphere and the solar wind

The Sun releases different rays like X-rays, gamma rays, visible light and radio waves. These are not the solar wind. The Sun also releases a stream of charged particles – mainly electrons and protons – that stream outwards from the Sun. This stream of charged particles is called the 'solar wind'. We use the word 'wind' here but it is not the same as wind on Earth, which is moving air. The solar wind is moving charged particles.

The magnetosphere

The magnetosphere forms in the region above the ionosphere and extends tens of thousands of kilometres into space. It forms from the interaction between the stream of charged particles of the solar wind and the magnetic field of the Earth. Look again at the diagram on page 4 to remind yourself where the magnetosphere is.

deflected:
turned away, something that is made to move away from the path it was on.

Earth's magnetic field extends outward from the Earth for several thousand kilometres and creates a protective bubble around the Earth. When the solar wind arrives at the Earth's magnetic field it gets **deflected** around and away from the Earth. This region protects the Earth from the dangerous radiation from the Sun and other parts of space.

If we did not have the outer core that generates our magnetic field, life on Earth would be very different. Without this field the solar wind would directly strike the Earth's atmosphere. This would very likely strip away our atmosphere and allow the dangerous rays from the Sun to reach Earth directly. Mars does not have a strong magnetic field so the solar wind has stripped away the Martian atmosphere. As a result most of the Red Planet is exposed to the full force of the incoming solar wind.

COMMENT

There are many reasons life should not be possible on Earth but because of certain features, it is. The existence of Earth's magnetic field is just one of these features.

The Aurora

Examples of the Aurora seen in the northern hemisphere, known as Aurora Borealis.

An aurora is a beautiful light that swirls in the sky close to the north pole or the south pole at certain times. Auroras are caused by the charged particles in solar wind. They collide with atoms and molecules in our atmosphere and cause energy to be released in the form of light (auroras). Auroras are more intense when the solar wind is stronger.

ACTIVITY 5

1. What is the solar wind?

2. What causes the magnetosphere to form?

3. In what way is the outer core of our planet critical for the survival of life here?

ANSWERS ON PAGE 130

Stratosphere

The stratosphere is the second layer in the Earth's atmosphere. It extends from about 10 to about 50 kilometres above the surface. The air here is very thin and humans could not survive because there is not enough oxygen. The top of the stratosphere at about 50 kilometres up is called the stratopause. Look again at the diagram on page 4 xx to remind yourself where the stratosphere is.

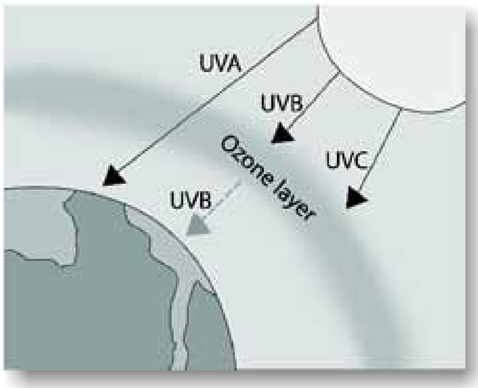
Jet aeroplanes fly in the lower parts of the stratosphere. This is because jet fuel burns well in the very low temperatures found there. The very thin air reduces the friction on the outside of the aeroplane, which reduces drag. At this level they can fly above most rough weather like thunderstorms and strong winds.

This passenger jet is cruising at 12 000 metres above sea level. Outside the temperature is around -50 ^{0}C.

The ozone layer

The ozone layer exists where it does within the stratosphere for a reason. At that height oxygen molecules (O_2) are not very plentiful and there is still a great deal of strong ultraviolet light from the sun. The UV light can split oxygen molecules into two oxygen atoms. These recombine with another oxygen molecule to form a molecule with three atoms this is ozone, or O_3. If there were many oxygen molecules around, the split atoms would simply join up with each other again to make normal oxygen molecules.

Although ozone represents only a small fraction of the gas present in the atmosphere, it is very important for protecting all life on Earth because it shields us from harmful ultraviolet light from the Sun. The ozone layer absorbs 9799% of the Sun's medium-frequency UV light (UVC) which potentially damages exposed life forms on Earth. UVA and UVB are less harmful.



The ozone layer prevents harmful UVC and some UVB from reaching us on the surface.

Air temperature increases as you go up in the stratosphere. This is because ozone absorbs sunlight, mainly UVC, which heats it up. About 90% of the ozone in our atmosphere is contained in the stratosphere. If all of the ozone were compressed to the pressure of the air at sea level, the layer would be only 3 millimetres thick.

COMMENT

Some industrial chemicals, known as CFCs (Chlorofluorocarbons), can attack and break apart the ozone molecules. In the past these were released into the atmosphere. The ozone layer started thinning as a result. However, most CFCs are no longer produced or used and the ozone layer is repairing itself. Imagine the destruction of life if we had continued with CFCs and caused the total removal of the ozone layer.

ACTIVITY 6

1. Why do jet aeroplanes cruise in the stratosphere?

2. Write a paragraph explaining why the stratosphere is very important for the protection of life on Earth.

3. Explain how ozone forms in the zone that it does and not at other altitudes.

4. Provide a statistic from this section that demonstrates just how thin and spread out the ozone layer is.

ANSWERS ON PAGE 130

Troposphere

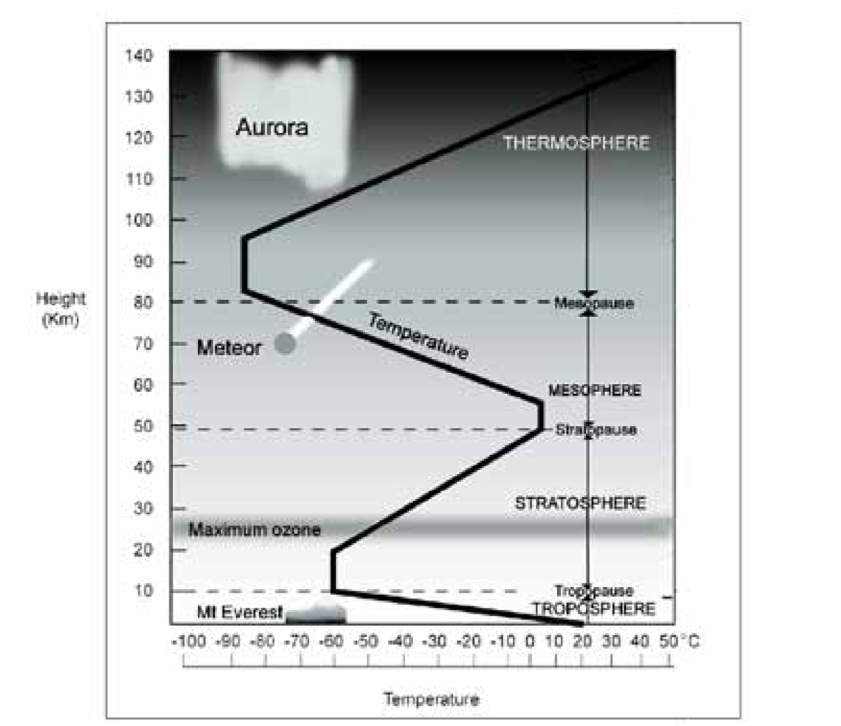
The troposphere is the lowest portion of the atmosphere. It is the bit we live in. The word 'troposphere' comes from the Greek word *tropos* which means 'turning' or 'mixing.' This tells us that air movement and mixing of air in the troposphere is important. It means that this is the layer where most of our day-to-day weather takes place.

When you see the top of a thunderstorm flatten out at the top it is usually because the updrafts in the storm have reached the top of the troposphere and because of temperature conditions there it can rise no further. We call the top of the troposphere the tropopause. Look again at the diagram on page 4 to remind yourself where the troposphere is.

The troposphere contains approximately 80% of the atmosphere's mass and 99% of its water vapour and dust particles. Air is warmest at the bottom of the troposphere near ground level. Higher up it gets colder. It gets colder at an average rate of 6.5°C per kilometre, unlike the stratosphere that gets warmer with height. Have you ever been up a mountain? It is colder there mainly because of this rate of cooling.

Temperature in the atmosphere

The graph shown here presents the temperatures of each of the atmospheric layers we introduced in this lesson.



The temperatures in the atmosphere

COMMENT

The temperature rises in the thermosphere. It can reach 2000 degrees centigrade there. But we cannot measure this with a thermometer because there are almost no particles of matter there. We would freeze there.

ACTIVITY 7

Use the graph and the information in this lesson to answer these questions.

1. What is the temperature shown for the surface of the Earth?

2. At what rate does it get cooler upwards in the troposphere?

3. Why does it warm up upwards in the stratosphere?

4. Passenger aeroplanes cruise in the lower stratosphere. Read from the graph what the temperature would be at this altitude.

5. What is the coldest temperature shown on the graph? In which layer or layers is it found?

ANSWERS ON PAGE 131

Summary

In this lesson you have learned that the atmosphere is structured in different layers or spheres and that it has a mix of gases in it that we call air. Although the atmosphere stretches upwards to about 100 kilometres, the majority of the air is concentrated lower down, 99% of it is below 31 kilometres. The ionosphere is an important layer because ionised particles in it can assist radio communication. Even more important for the survival of life on Earth is that Earth's magnetic field causes the magnetosphere to form, which deflects the dangerous solar wind away from and around our planet. The beautiful natural lights in the sky called the Aurora are created by the solar wind interacting with the magnetosphere. The ozone layer in the stratosphere is another feature of our atmosphere that makes it possible for life to survive on Earth because it restricts some of the dangerous ultra-violet rays from the Sun.

CHECKLIST

Are you able to:

- ❐ describe the main gases that make up the atmosphere and their abundance
- ❐ explain what each of the layers of the atmosphere is and their heights above sea level
- ❐ describe the key features of each of the layers, including the ionosphere and the magnetosphere
- ❐ explain how ozone forms and why the ozone layer is so important
- ❐ explain how the Earth's magnetic field is formed and why it is so important

NOTES

LESSON 2

On the Earth

About this lesson

This lesson focuses on water on planet Earth. It includes salt water and fresh water, lakes and rivers as well as glaciers and icecaps. The lesson goes on to explore the lithosphere and plate tectonics. It examines what causes crustal plates to move and how they fit together to make up Earth's crust and some of the features on it.

In this lesson you will:

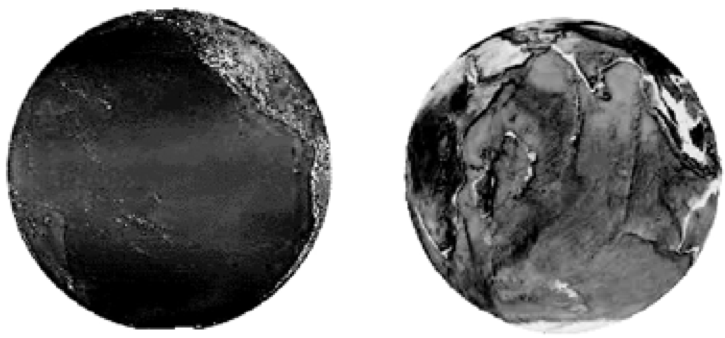
- learn about water on planet Earth (the hydrosphere)
- compare the amounts of salt and fresh water on the planet
- produce a graph of ocean depths, (actual and deepest depths)
- understand what groundwater is, including threats to groundwater
- examine glaciers and icecaps and find out about the important role of glaciers for water supply
- learn about the lithosphere, the rigid, solid outer shell of Earth
- examine the arrangement of continents on the planet and work out how they came to be this way
- understand the underlying mechanism for how Earth's crust moves
- find out about plate tectonics and why the different types of plate boundaries are important for understanding our planet.

The hydrosphere

The word **hydrosphere** means the zone around the Earth where there is water. This includes the oceans, lakes, rivers, groundwater, ice caps and glaciers.

Saline oceans

Most of the water on our planet is salty. This is what the word saline means salty. Seawater covers about 71% of our planet.



Pacific and Indian oceans. These photos help you see just how much of the planet is covered by seawater.

That is a lot of water. And not only do the oceans cover a lot of area, but they are also very deep. The average depth of all oceans together is about 3,800 metres. The deepest depth is in the Pacific – 11,033 metres! This means that about 97% of all water on the planet is salty.

	Surface Area ($km^{2)}$	Average depth (m)	Deepest depth (m)
Pacific Ocean	165,250,000	4,028	11,033
Atlantic Ocean	106,400,000	3,926	8,604
Indian Ocean	73,560,000	3,963	7,724
Southern Ocean	20,330,000	3,270	7,236
Arctic Ocean	13,990,000	1,205	5,450

ACTIVITY 1

ANSWERS ON PAGE 131

Use the information in the table to draw a bar graph showing the average and maximum depths of the five oceans of the world. Think of a way of showing the average depth of all oceans on the same graph.

Salt in seawater

Seawater contains about 35 grams of salt for every litre of water. That is 35 parts per thousand, or 3.5%. So, in all the oceans there is also a lot of salt! It has been estimated that if the salt in the oceans could be removed and spread evenly over the land surface it would form a layer more than 166 metres thick!

Just imagine – the entire land surface of Africa, North America, South America, Australasia, Eurasia, Antarctica – all covered in a 166 metre thick layer of salt!

Where did all that salt come from? It comes from the land. The elements that make up salts, such as chlorine and sodium, started out in rocks. Water and acids eroded the rocks, and rivers carried the elements into the sea. Over time, as water evaporated from the sea, the salt was left behind and the salinity levels rose until they reached 35 parts per thousand as they are today.

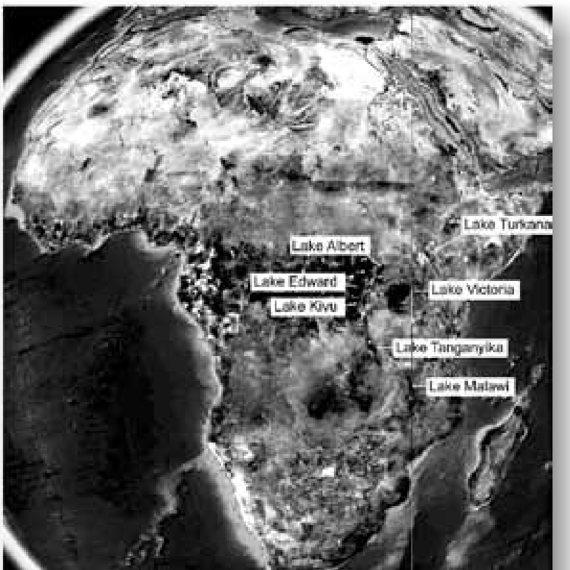
COMMENT

Continuous input of fresh water from rivers, rain, snow and melting of ice keep the ocean salinity at about 3.5%.

Freshwater rivers and lakes

We have seen that the majority of water on our planet is salt water. This means we have to be careful how we use it, and not waste or pollute it.

The source of almost all fresh water is precipitation in the form of mist, rain and snow. Very, very little of the water on Earth is fresh water available to us on the surface. In fact, less than 0.01% of water on the planet is surface water in lakes, wetlands and rivers. Freshwater lakes contain about 87% of this fresh surface water, including 29% in the African Great Lakes, 23% in Lake Baikal in Russia, 21% in the North American Great Lakes, and 14% in other lakes. Wetlands contain most of the remainder with only a small amount in rivers.



The African Great Lakes contain about 25% of all of the world's surface fresh water.

Caring about and for water

Fresh water is an important natural resource necessary for the survival of all life on our planet. It is renewable, but it is limited. Our use of water for activities such as irrigation and industry can have negative impacts. Chemical contamination of fresh water can also seriously damage eco-systems.

Fresh water can only be renewed through the process of the water cycle, where water from seas, lakes, rivers, and dams evaporates, forms clouds, and returns to water sources as precipitation. If more fresh water is consumed than is renewed by nature, the result will be less fresh water and lower quality of that water.

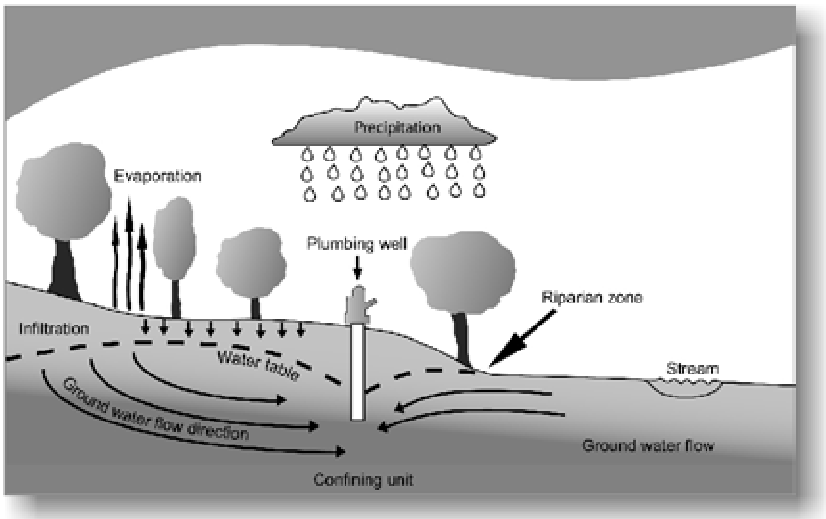
Groundwater

Groundwater is water that comes from the ground. Many people use groundwater but don't even know it. It is pumped up by the local authority, cleaned and piped to users. People living on farms and in dry areas use wind pumps (we often call them windmills) to get groundwater to the surface.

Where does groundwater come from?

infiltrate:
soak

Groundwater comes from rain, snow, sleet, and hail that **infiltrates** into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock until it reaches a depth where the ground is filled, or saturated, with water. The area that is filled with water is called the saturated zone and the top of this zone is called the water table. It is not flat like a wooden table, but it is the top level of the groundwater. The water table may be very near the surface or it may be hundreds of metres below. Water from the groundwater zone can flow out onto the surface, usually as springs.



Groundwater collects in aquifers (saturated zones) below the ground

COMMENT

Have you ever dug a hole in sand next to an ocean, lake or river? What happens? As you're digging, you eventually reach water. That water is groundwater.

A groundwater area that holds a lot of water and can be pumped up from a well is called an **aquifer**. We can pump groundwater from the aquifer, and then pipes deliver the water to cities, houses in the country, or to crops. In South Africa we use groundwater mostly in areas where there is very little surface water.

aquifer:
a large amount of groundwater that can be used as a water source

landfill:
a rubbish disposal site

Most groundwater is clean, but groundwater can become polluted, or contaminated. It can become polluted from leaky underground tanks that store petrol or diesel, leaky **landfills**, or when people apply too much fertilizer or pesticides on their fields or lawns. When pollutants leak, spill, or are carelessly dumped on the ground they can move through the soil.

Because it is deep in the ground, groundwater pollution is difficult and expensive to clean up. Sometimes people have to find new places to dig a well because their own well has become contaminated.

ACTIVITY 2

1. What is an aquifer?

2. Groundwater is usually pure and safe to drink. Explain why this is so.

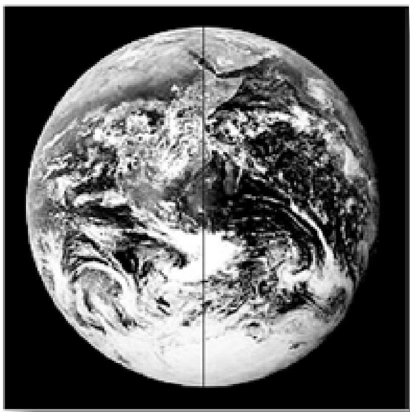
3. Describe some of the threats to groundwater.

ANSWERS ON PAGE 132

Ice caps and glaciers

A huge amount of the fresh water on our planet is frozen. Most of it is in the ice caps at the north and south poles, and some is in glaciers.

The photo shows the southern ice cap which covers Antarctica. It contains 1.7% of all water on the planet, and a massive 61% of all of our fresh water.



The Antarctic ice sheet contains 61% of all fresh water on the planet

Glaciers

A glacier is like a river of ice. Glaciers form when snow accumulates or collects quicker than it melts or is somehow removed. It builds up slowly and turns into thick sheets of ice. The weight of the ice causes it slowly to flow down slope. 99% of glacial ice is contained in the polar ice caps. The better known ones are in mountainous areas, for example, in the Himalayas, the Alps and the Andes mountains.

Glacier in Argentina. Notice the size of the trees in the foreground. How thick do you think this glacier is? Notice also the meltwater.

Glaciers can be as little as 15 metres thick or hundreds of metres thick. Deeper down there is more pressure from the weight of ice above. This means the ice, though solid, can bend without cracking. This helps the glacier flow over or around obstacles.

Glaciers move at different speeds, and some parts of glaciers move faster than others. A slow glacier might move just a few metres a year, whereas others can move hundreds of metres in a year. This depends on how much snow falls, the steepness of the slope and the kind of surface it is moving over.

Meltwater

A very important role of glaciers is as a store of fresh water. At the bottom end of a glacier where it is slightly warmer, the ice melts and feeds into rivers. Meltwater provides drinking water for a large proportion of the world's population, as well as providing water for irrigation.

COMMENT

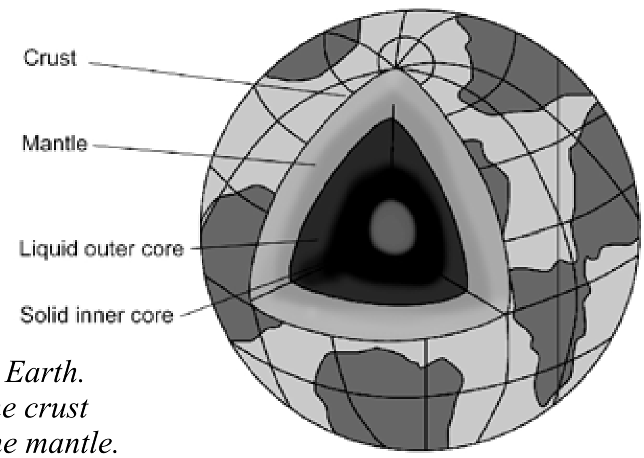
A major concern is what the impact of climate change will be. If glaciers melt quickly in the next ten to twenty years and the climate changes, those parts of the world that depend on glacial meltwater might go dry. This would be disastrous for many millions of people.

The lithosphere

There are four Earth 'spheres' that we learn about. You have already learned about two of them: atmosphere and hydrosphere. These are both fluid, which means that they flow (air and water both flow). The lithosphere is solid. The fourth sphere is the biosphere, that part of Earth where living things can be found. The biosphere is covered in Lesson 7 of this unit. In the eight lessons in *System Earth* we will cover only the non-living parts.

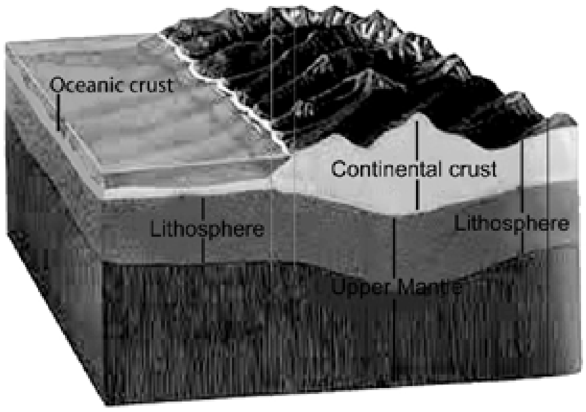
The Greek word *lithos* means stone, or rock. The lithosphere is the outer solid, or rocky, section of Earth. It includes the Earth's crust and the uppermost rigid part of the mantle. You will learn more about these Earth structures later on in this lesson.

The diagram identifying the main structures inside the Earth, shows the overall structure of the Earth. Note the liquid outer core that we learned about in Lesson 1 that is responsible for generating Earth's magnetic field.



The main structures inside Earth. The lithosphere includes the crust and the upper, rigid part of the mantle.

In this lesson we are interested in the outer, rigid section, which we call the lithosphere.



The lithosphere includes the crust and the upper section of Earth's mantle.

Notice how the lithosphere is thicker where the continent is and thinner where the ocean is. These thicknesses, combining both crust and upper mantle, are Oceanic lithosphere: 50-100 kilometres, Continental lithosphere: 40-200 kilometres.

COMMENT

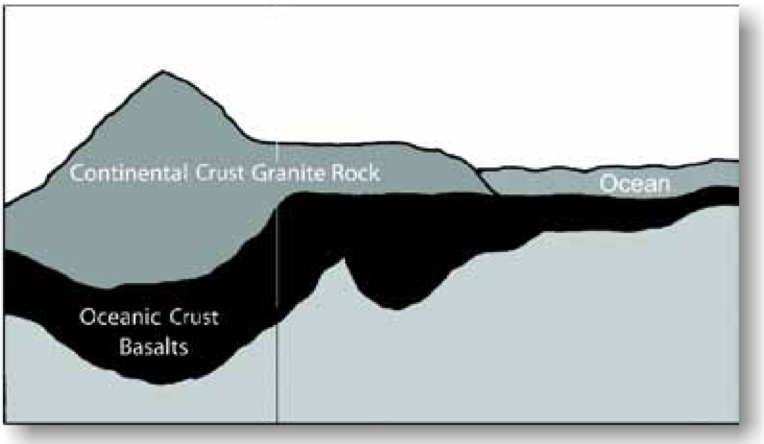
Many people have difficulty imagining that pressures in the Earth's crust can push up mountains as high as the Himalayas (which includes Mount Everest). This is because the time scales required are over many millions of years and this is too much for us to consider in a practical way.

Oceanic and continental crust

The Earth's crust is the solid rocky part around the outside of the planet. Deeper down it gets very hot and the material is molten or at least 'plastic', which means it is flexible, like tar. The crust is actually very thin compared to the rest of the Earth.

Under the oceans, the crust is only about 6 to 10 kilometres thick. The continental crust is about 30 to 50 kilometres thick. Compare that to the radius of the Earth, which is 6,371 kilometres.

The following diagram illustrates more clearly how the two types of crust fit together.



Oceanic and continental crust.

The crust is composed of two main rock types. Continental crust is mostly made of granite type rocks, while oceanic crust is mostly made of basalt. Basalt type rocks are made from volcanic lava rock. These rocks are normally darker in colour and are **denser** than the granitic rock of the continental plates. Because of this the less dense continents ride or 'float' on the denser oceanic plates. This is a very important idea that you will learn more about in the next section.

denser:
heavier

ACTIVITY 3

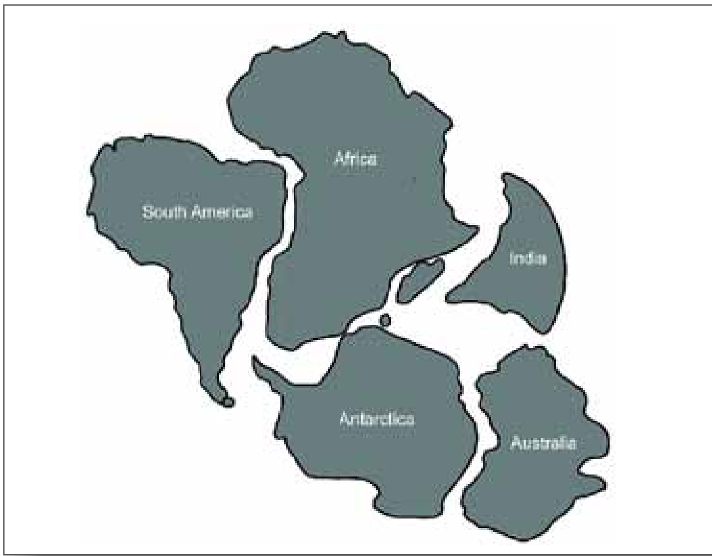
1. Name the two types of crust.
2. What are their thicknesses?
3. Why is continental crust normally found above oceanic crust?
4. Explain why mines get very hot the deeper they go. Do some research to find out how deep the deepest mines in South Africa are. Compare your findings with the depth figures provided in this section.

ANSWERS ON PAGE 132

Arrangement of continents

Have you ever noticed that the shapes of the different continents fit together quite well? Look, for example, at how well Africa and South America fit together in the diagram on the next page. This is no mistake. At one time, long ago, they were all actually one huge super-continent.

This super-continent was called Pangaea. Slowly Pangaea split up into two. The northern part was called Laurasia and the southern part was called Gondwanaland. Those two split up into the different continents that we have now. We were part of Gondwanaland.



Gondwanaland showing the continents that split off it.

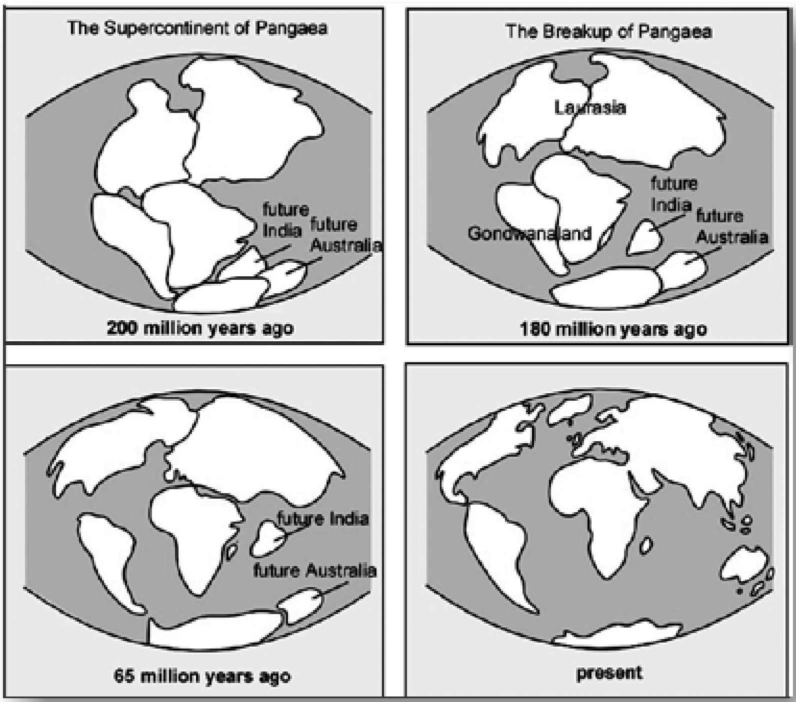
ACTIVITY 4

Use a globe or an atlas. Make a rough tracing of the shapes of the continents. Place these shapes on a table like a jigsaw puzzle and see if you can fit them all together. Make sure you use a map that shows the correct shapes of each continent, including Antarctica. On many maps Antarctica is stretched out to make it fit.

ANSWERS ON PAGE 132

The theory of continental drift

The idea that continents were together and then split apart is known as the theory of continental drift. It was very controversial when it was first suggested by Alfred Wegener in 1912, but now it is accepted as fact. Scientists' main concern was they did not know how the continents drifted apart. What was the mechanism? We now know very well how it works, and we call the mechanism plate tectonics. In Unit 4 you learned how this movement of continents affected the distribution of organisms over time. That information and the material here are directly related.



This graphic shows how Pangaea broke up about 200 million years ago and where the continents are now.

COMMENT

There is evidence that you could go and look at of glacial ice scratch marks (called striations) in Antarctica, South Africa, Australia and South America that line up according to how these continents were joined in Gondwanaland.

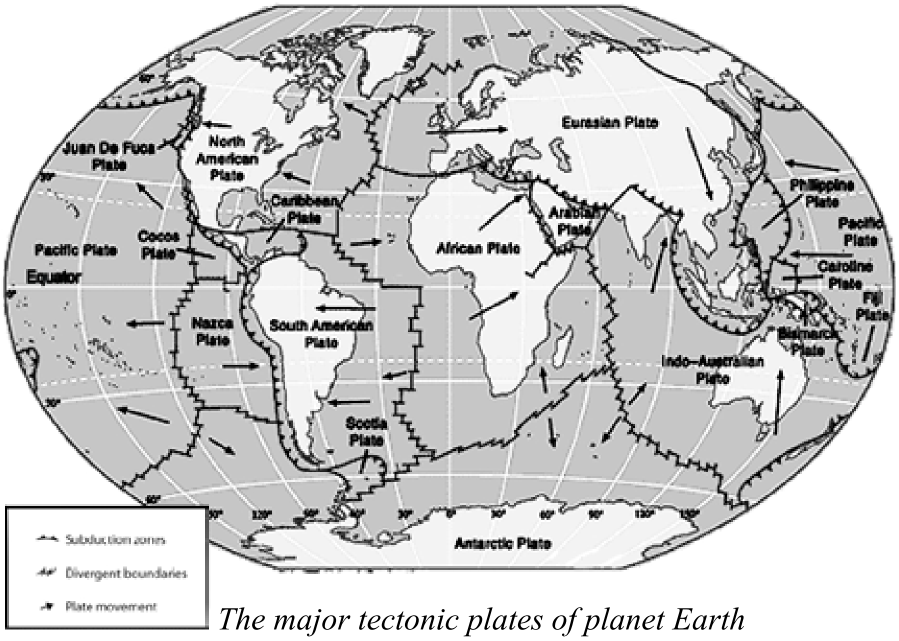
Plate tectonics

The mechanism that Alfred Wegener and other early researchers did not know about in the early 1900s is now called plate tectonics. The entire crust of the Earth is made up of 7 separate, large, rigid pieces called plates: the African, North American, South American, Eurasian, Australian, Antarctic, and Pacific plates. Several minor plates also exist, including the Arabian, Nazca, and Philippines plates. These plates move. The place where the two plates meet is called a plate boundary. Boundaries have different names depending on how the two plates move in relation to each other.

Some move towards each other (a convergent plate boundary), others away from each other (a divergent plate boundary). Some also slide alongside each other in opposite directions (a transform plate boundary). You can imagine when they rub against each other that it would cause some bumps and scrapes. This is why plate movement is a major cause of earthquakes and volcanoes, which you will learn more about in the next lesson.

ACTIVITY 5

Look at the diagram on page 25 showing the split-up of Pangaea into the continents today.



The major tectonic plates of planet Earth

1. Where would you cut Pangaea to make the new continents? Compare that with the jagged lines in the diagram above.

2. Where would you draw arrows to show these movements? Compare your arrows with the ones in the above drawing.

3. Where are the outer edges of Pangaea spreading outwards over the huge open spaces of that early single ocean. Compare those edges with the lines in this diagram.

4. That first huge single ocean became one of our oceans today. Which one is it?

5. Two new oceans were created when Pangaea and Gondwana split up. Which are they?

ANSWERS ON PAGE 132

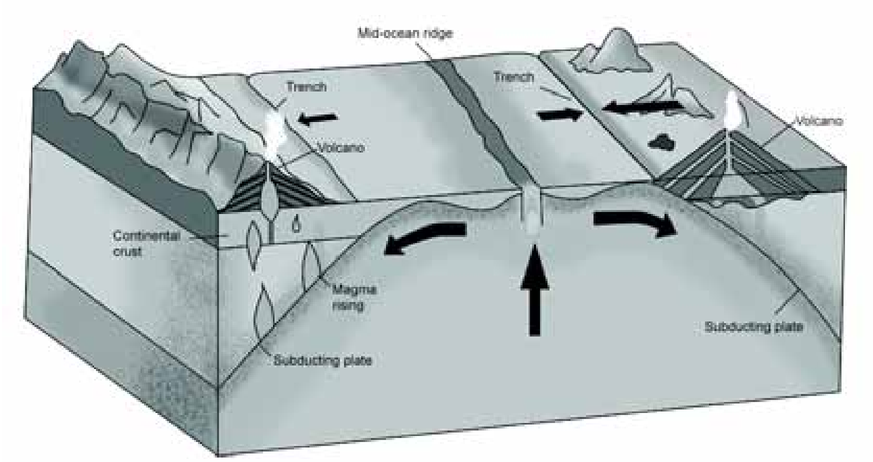
The mechanism of continental drift

The layer underneath the lithosphere is semi-fluid. That layer is, in fact, moving slowly, like a big conveyer belt. It carries the crustal plates with it. For example, rising convection currents of **magma** caused Africa and South America to split. This is still happening. As the currents reach the upper levels below the crust they separate and spread out sideways. This carries the crustal plates with them, spreading them apart. We call this is a **divergent plate boundary**.

> ***magma:***
> *molten rock under the Earth's surface. If magma comes to the surface we call it lava*
>
> ***divergent plate boundary:***
> *a zone where tectonic plates are moving apart, or diverging*

Divergent plate boundaries

Why isn't there a big gap between the two plates that are moving apart? As magma rises it cools and fills the gap between the diverging plates with new crust. This process makes new oceanic crust all the time.

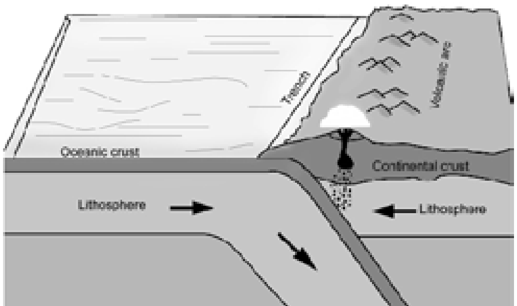


This divergence zone is where plates are moving apart and new crust is being formed from magma rising and cooling.

There is a major divergence zone in the middle of the Atlantic Ocean in a long line all the way from the Arctic Ocean in the north, almost to Antarctica in the south. Follow this line on the map of tectonic plates on page 26. This divergent plate boundary in the Atlantic is spreading at a rate of about 2.5 centimetres per year or 25 kilometres in a million years. This rate may seem slow by human standards, but because this process has been going on for millions of years, it has resulted in plate movement of thousands of kilometres. Seafloor spreading over the past 100 to 200 million years has caused the Atlantic Ocean to grow from a tiny strip of water between the continents of Europe, Africa, and the Americas into the vast ocean that exists today.

Convergent plate boundaries

Where plates are moving towards each other we call them convergent plate boundaries. Find examples of these on the map on page 26.



A convergent plate boundary. The more dense oceanic crust is pushed below the less dense continental crust.

> ***subduction zone:***
> *area where one plate is moving underneath another plate. It is being subducted or pushed beneath.*

All along the west coast of North and South America the Pacific Ocean crust is moving towards the American plates. Oceanic crust is denser than continental crust, so it dips below and slowly melts as it is pushed into the upper mantle of the Earth. The same is happening on the other side of the Pacific Ocean, all along south-east Asia (the Eurasian plate) and Australasia (the Australian plate). It should be no surprise that these areas have many earthquakes and volcanoes. We call this the 'Pacific Ring of Fire'. We call areas where plates are moving underneath others, a **subduction zone**.

COMMENT

Millions of people live in permanent risk in the Pacific Ring of Fire. The Ring of Fire has 452 volcanoes and about 90% of the world's earthquakes. 81% of the world's largest earthquakes have occurred along the Ring of Fire.

Where we have two continental plates converging, it is like a battle between elephants. Neither is more or less dense than the other. In cases like this they cause large mountains to form as the plate boundaries buckle. The best-known example is the Himalayas, where India (on the Indo-Australian plate) is crunching into the Eurasian plate. Look again at the diagram on page xx that shows the break-up of Pangaea. It shows the future India moving northwards towards Asia.

Transform plate boundaries

Where plates are sliding past each other they tend to hook up or get stuck for a while. The pressure builds and eventually they move suddenly and violently. Huge earthquakes are associated with transform plate boundaries. The south-west coast of the USA is well-known for this. People living in California are at great risk of a major earthquake taking place some time in the next 100 years!

Summary

In this lesson you learned about the hydrosphere and the lithosphere. The hydrosphere includes all water on Earth – salty, fresh, frozen and even underground water. We have mostly salty water, so we need to be careful how we use fresh water, and protect the natural resources that provide this water. The lithosphere includes the solid or rigid outer portion of the Earth – the crust and the upper part of the mantle. You learned why the continents are arranged as they are and the mechanism (called plate tectonics) that is responsible for this.

You learned about different plate boundaries and how some are building new plate material while others are being subducted and melted back into the mantle. In the next lesson we will continue this theme and explore earthquakes and volcanoes.

CHECKLIST

Are you able to:

- ❐ define and describe the different components of the hydrosphere
- ❐ explain why there is so little fresh water on the planet
- ❐ draw a bar graph from information in a table
- ❐ explain how the continents came to be arranged where they are
- ❐ use the terms lithosphere, continental crust and oceanic crust correctly and explain these terms
- ❐ explain the basic concept of plate tectonics

NOTES

LESSON 3

Inside the Earth

About this lesson

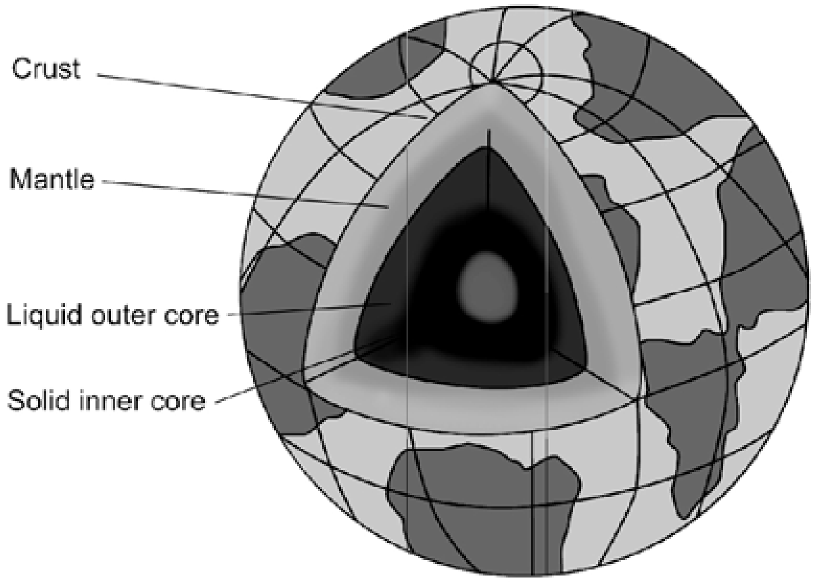
This lesson focuses on the internal structure of Earth and some of its characteristics. These characteristics are responsible for earthquakes and volcanoes in certain areas more than others. The lesson looks at different kinds of earthquakes and volcanoes and the reasons why we have different types. It also describes and explains two famous earthquakes.

In this lesson you will:

- learn about the core and mantle of the Earth
- describe the internal structure of the Earth and its features and characteristics such as temperature, depth and fluidity or rigidity
- learn what an earthquake is, the different types of earthquakes and their relationship with plate tectonics
- describe the features of at least two famous earthquakes
- examine what a volcano is, the different types of volcanoes and their relationship with plate tectonics.

The core and mantle

In the previous lesson you learned about the lithosphere and that it consists of the upper, rigid section of the mantle, and the crust. In this section we will continue with the mantle itself and the core of the Earth.



A cut-away of the Earth showing its internal structure

This diagram shows that the Earth has a three-part internal structure the core, the mantle and the crust. These are further separated into the inner and outer core, and we also sometimes refer to the inner mantle, which is plastic (flexible, like thick tar), and the outer mantle, which is rigid.

Earth's core

> ***seismic:***
> *related to or caused by an earthquake or a vibration of the Earth*

Although we have never been there, we know quite a lot about the core by measuring earthquake activity (we call it **seismic** activity) and how it echoes back from the interior of the Earth. There are monitoring devices all over the globe monitoring seismic activity. We have used these seismic measurements to show that the core is divided into two parts, a solid inner core with a radius of about 1,220 kilometres and a liquid outer core that has a thickness beyond the inner core of about 2,220 kilometres. This means that the core has an overall radius of about 3,440 kilometres.

The pressure and temperature of the earth increases as one moves closer to the centre. The outer core has a very high temperature and ranges from about 4,400 degrees Celsius to about 6,100 degrees Celsius. The temperature at the inner core of the earth is about 7,000 degrees Celsius.

The existence of the solid inner core was discovered in 1936. It is believed to be made mainly of iron and some nickel. In the early stages of Earth's formation about 4.5 billion years ago, melting would have caused denser substances to sink toward the centre of the Earth.

COMMENT

During the Earth's formation less-dense materials moved or floated upwards and formed the crust. We are standing on a thin layer of that surface material that floated to the surface, like scum in a pot of boiling food!

The liquid outer core surrounds the inner core and is believed to be composed of iron mixed with nickel and small amounts of lighter elements. As you learned in the previous lesson the outer core has **convection** and other circulation movements in it. This generates electrical currents and these have a magnetic field. It is this magnetic field that produces our magnetosphere that protects us from harmful charged particles in the solar wind.

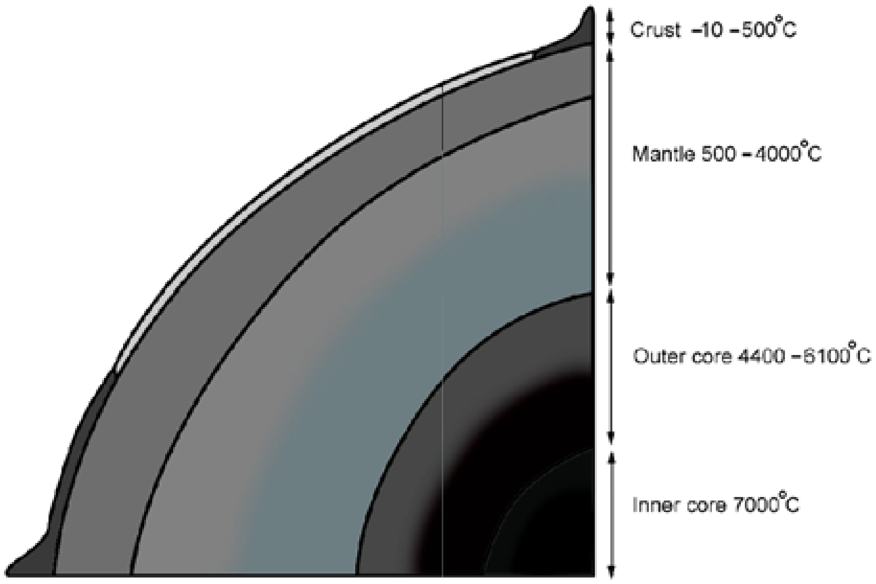
convection:
the transfer of heat by the movements of hot fluids such as air, water and magma

The mantle

The Earth's mantle lies above the core. The mantle has a thickness of about 2,885 kilometres, of which the lower mantle is about 2235 kilometres thick and the upper mantle is about 650 kilometres thick. The temperature of the mantle reaches about 4,000 degrees Celsius. This is hot enough for it to melt, but as you know, the lower mantle is solid. How can this be? The inner mantle is solid because of the enormous pressures exerted at that depth.

The mantle rock material has less iron and nickel in it and more magnesium and material based on silicon combined with other substances, which we call silicates. This means it is less dense than the material in the core, which is why it migrated or 'floated' above the core.

The diagram on the next page summarises some of the information provided in this section.



Schematic view of the interior of the Earth

ACTIVITY 1

1. Draw a diagram showing the following Earth structures:
   - inner core
   - outer mantle
   - crust
   - outer core
   - inner mantle

   and label each section with its temperature and radius or thickness.

2. Why is the inner mantle so hot yet still solid?

3. Describe the density of the different structures inside Earth and explain why they are arranged in this way.

ANSWERS ON PAGE 133

Earthquakes

Earth's crust is made up of tectonic plates. These plates move very slowly in relation to each other. There are three main types of plate boundaries – **convergent**, **divergent** and **transform**. These plate boundaries are associated with earthquakes and volcanoes, for example, the Pacific Ring of Fire is well-known for this kind of activity.

convergent:
when two plates move towards each other, they converge.

divergent:
when two plates move away from each other.

transform:
when two plates move in opposite directions alongside each other.

An earthquake is the sudden release of energy in the Earth's crust. We call this a seismic event. Earthquakes are caused mostly by the sudden slippage of geological faults (cracks in the rock underground), but also by other events such as volcanic activity, landslides, mine blasts, underground rockfalls and even nuclear tests.

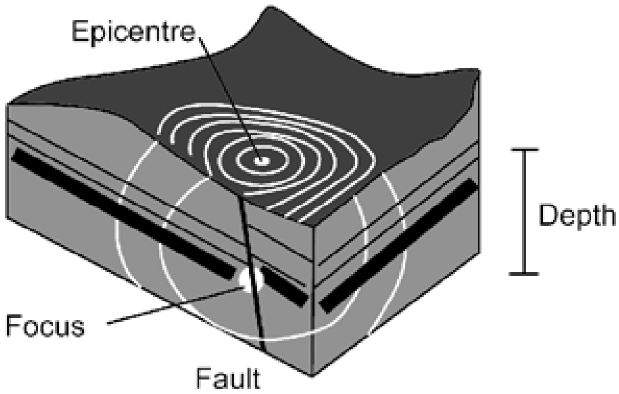


Diagram showing the main elements of an earthquake

An earthquake's point of release is called its **focus**. This is where the main slippage or sudden movement takes place. This can be at a fault – a crack between two sections of the Earth's crust that are moving in relation to each other. They might have become stuck for a while. During that time the pressure can build up, storing more and more energy. The longer this happens, the greater the release of energy and the more violent and damaging the earthquake can be.

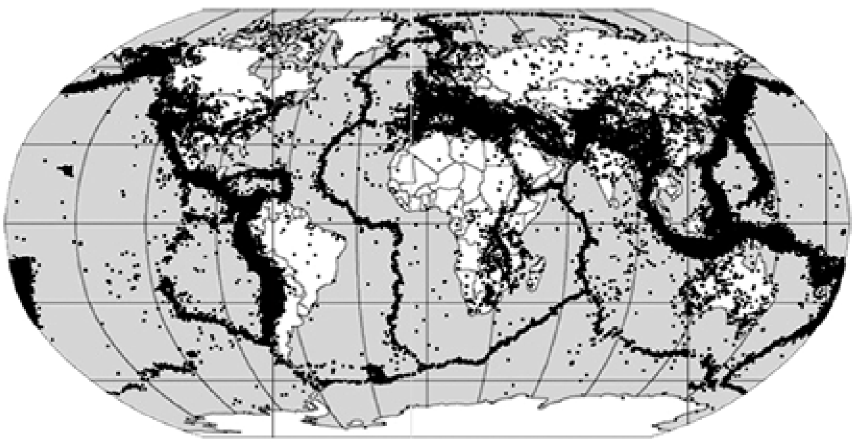
The **epicentre** of an earthquake is the point at ground level directly above the focus.

earthquake focus:
the place below the surface where the actual movement of rock takes place

epicentre:
the point at ground level directly above the focus of an earthquake

ACTIVITY 2

This image shows the epicentres of 358,214 seismic events between 1963 and 1998.



Preliminary determination of epicentres
358,214 seismic events 1963 - 1998.

1. Notice where these epicentres are. Compare this map with the diagram of tectonic plates on page 26 in Lesson 2? What do you notice?

2. In this diagram there are three types of plate boundaries and each type has produced earthquakes. Which ones are responsible for the most earthquakes?

3. Explain why you think this is the case using the ideas of plate tectonics to help you.

ANSWERS ON PAGE 133

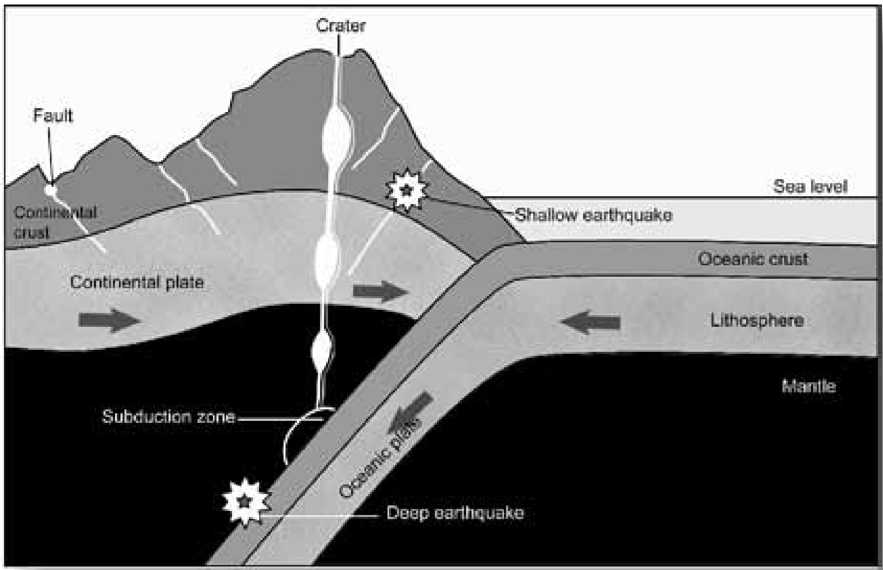
COMMENT

Many people live in hazardous regions where floods, earthquakes or volcanoes can cause immense damage. Even people who can afford to move to other places like those living in San Francisco, California, don't move. Why should this be?

Subduction zone earthquakes

subduction:
when one plate moves below another plate and melts into the mantle it is subducted.

This image shows a **subduction** zone. It is part of the Australian plate with the Pacific plate being subducted underneath it.



Earthquakes at a subduction zone

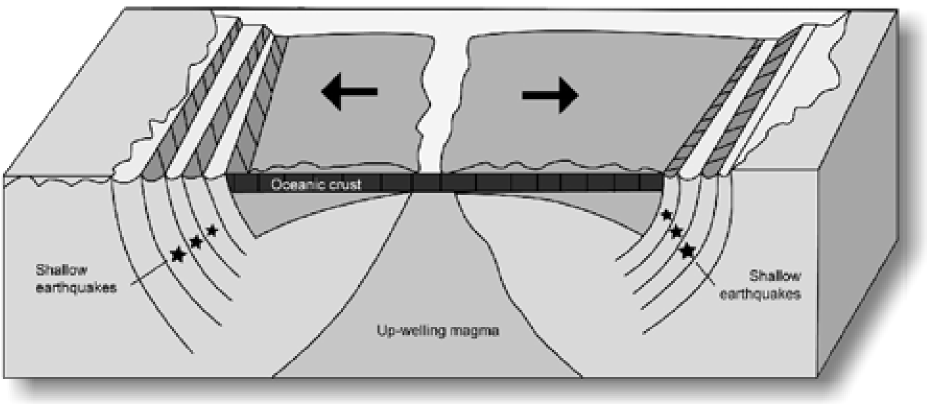
What happens at subduction zones is that the continental crust is pushed back or compressed sideways and as a result it bunches upwards. This causes coastal mountains to form. This has happened all the way down the west coasts of North and South America the Andes Mountains, the Rocky Mountains and the Coast Mountains, closer to the coast.

During this process of subduction and mountain building, immense forces are exerted and huge amounts of energy are released when the two plates shift. Earthquake focus points can occur all along the contact zone, from shallow to deep, until the rock becomes hot and less rigid. Something else that occurs is that the oceanic plate becomes **molten** and sometimes erupts at the surface as a volcano. This is also an important part of mountain building.

molten:
made soft by heat, either completely runny, or like tar.

Divergent zone earthquakes

When two plates such as the African and the South American plates start to move apart as a result of movements in the mantle beneath, a long crack occurs. This crack becomes filled with molten material. It does not normally erupt as major volcanoes, but simply plugs the gaps, cools and later cracks down the middle. This continues and builds the width of ocean floor over millions of years. If it did not, the ocean would leak down the crack and disappear wouldn't it? (Think about this.) The upward force of rising mantle material (we call this molten rock under the surface ‘magma’) pushes the oceanic crust upwards and so a long ridge forms. In the Atlantic this extends from Iceland in the north all the way almost to Antarctica. It is called the Mid-Atlantic Ridge. As the crust keeps moving apart, the sides of this ridge form cracks and slip downwards, causing mild and shallow earthquakes. This diagram shows what happens.



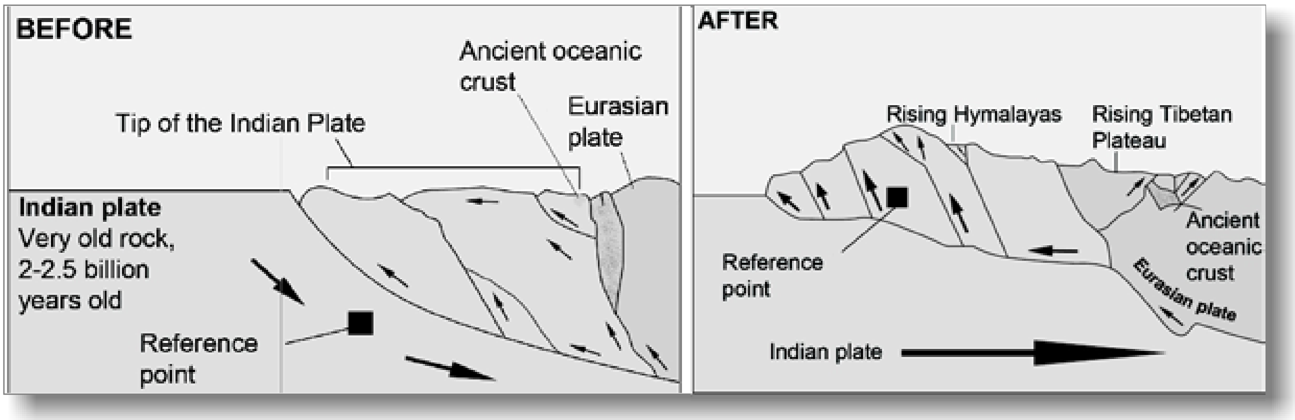
A diverging plate boundary. Shallow earthquakes occur when fault blocks slip.

Continental convergence

Sometimes two continental plates converge. This happened in the case of the Indian plate (which is now part of the Indo-Australian plate, because the two joined together) and the Eurasian plate.

This also happened relatively recently in the Earth's history, as the Indian plate had to move many thousands of kilometres northward before it collided with the Eurasian plate. It is believed to have travelled at a rate of about 20 centimetres per year.

These two diagrams show what happened.



How the Himalayas were formed.

When the Indian plate collided with the Eurasian plate the two were of similar density. Unlike the oceanic plate, the Indian plate did not easily find a way of subducting, although it eventually did. Some of the material at the leading edge of the Indian plate, including some oceanic crust left as the ocean between them closed up, was bull-dozed back and upwards by the Eurasian plate. This rose to become the Himalayas, which consist of some of the highest mountains in the world. Those mountains are still rising very slightly. The remainder of the Indian plate then began subducting under the Eurasian plate.

COMMENT

Mount Everest is just one of over 30 peaks in the Himalayas that are over 7,315m high. The Himalayas continue to grow, by about 2,4 centimetres each year! This is because of continental plate convergence.

This whole process of continental convergence caused immense pressure to build up and created lots of faults in the two sections of crust. As these slipped, so they released large amounts of stored energy, causing many large earthquakes. The map of epicentres on page 35 shows that earthquakes are still frequently experienced in this zone. However, the subduction zones of the world, particularly around the Pacific Ring of Fire, are some of the strongest, or most energetic of all earthquakes.

ACTIVITY 3

1. Explain why continental plate convergence could be described as 'accidental'.

2. Why does the formation of the Himalayas involve very old sections of Earth's crust?

3. Why do you think subduction zone earthquakes are more violent, or energetic, than earthquakes in the Himalayan region?

ANSWERS ON PAGE 134

Some famous earthquakes

San Francisco Earthquake of 1906

San Francisco is on the San Andreas fault which is a transform plate boundary. It is close to the boundary between the Pacific (oceanic) plate and the North American (continental) plate. The Pacific plate is moving towards North America, so there is a subduction zone along parts of the west coast, but it is also moving north-westwards, along the coast. It is moving at a rate of between 33 to 37 millimetres per year across California. The Pacific plate moves alongside the North American plate, but most of the time it is stuck in one position. When it releases, earthquakes are caused.

Although the earthquake itself caused a lot of damage in San Francisco, it was the resulting fire that had a more devastating impact. This is mainly because gas pipes were broken and gas fires erupted throughout the city.

The devastation of the 1906 earthquake in San Francisco

tsunami:
a huge wave of sea water caused by an earthquake.

seismograph:
an instrument that is designed to measure and record seismic activity.

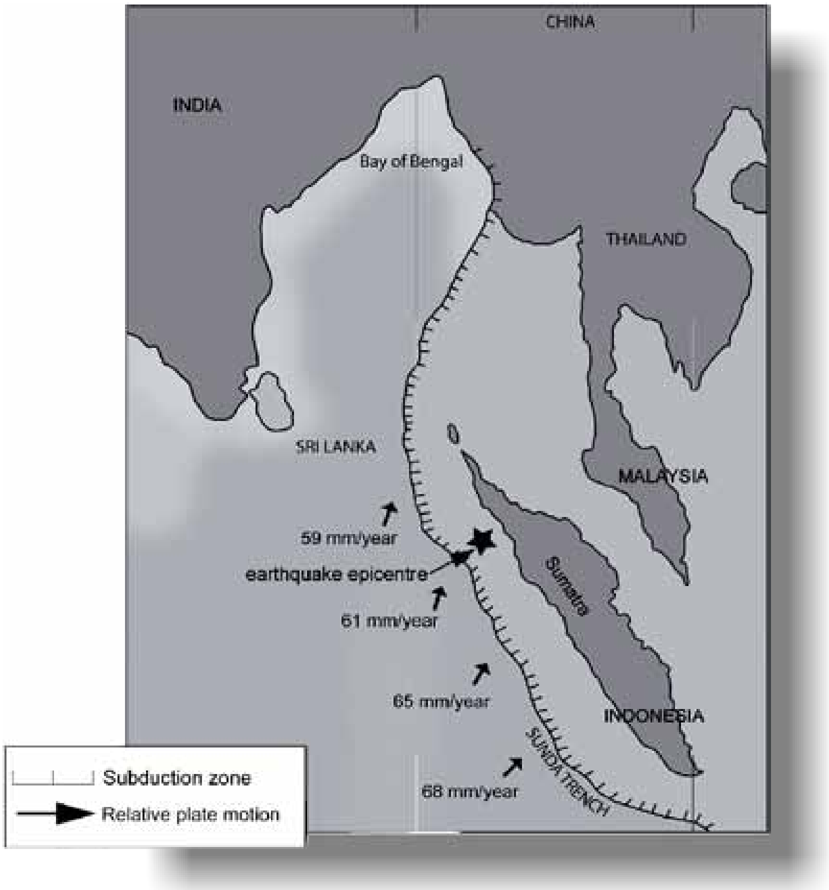
Indian Ocean Earthquake of 2004

The Indian Ocean earthquake took place on 26 December 2004. The epicentre was off the west coast of Sumatra, Indonesia. It is the third largest earthquake ever recorded on a **seismograph**. It also had the longest duration ever observed in an earthquake between 8 and 10 minutes. However, just as in San Francisco, it wasn't the earthquake itself that caused most damage. The **tsunami** caused by the earthquake killed 230,000 people and its 30 metre-high waves destroyed virtually everything in its path.

The devasting tsunami in the Indian Ocean earthquake of 2004.

Causes of the 2004 earthquake

Sumatra is close to a subduction zone between the oceanic Indo-Australian plate and the Eurasian plate. The two plates meet on the ocean floor at the plate boundary about 200 kilometres off the western shore of Sumatra. This plate boundary is called the Sumatran Subduction Trench.



A map showing Sumatra and its location close to the subduction zone and earthquake epicentre.

Volcanoes

Most volcanoes in the world are also associated with tectonic plate boundaries. There are some interesting exceptions that you will also learn about.

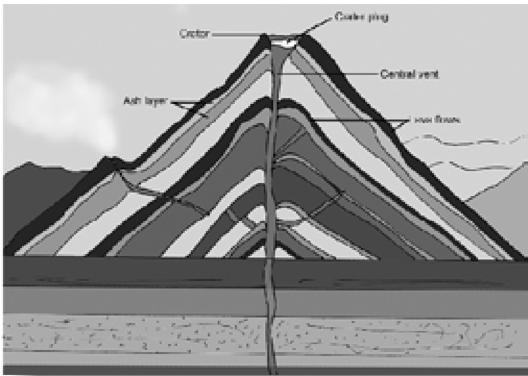
There are many different types of volcanoes, depending on where they are and what kind of lava is coming from them. Some are relatively small, for example cinder cones, that are small mounds or cones of ash and cinders thrown out of a volcanic vent. However there are two main types that are large and of great interest.

Cone volcanoes or stratovolcanoes

The typical volcano is one of those beautiful cone-shaped volcanoes that one normally thinks of. Examples are Mount Fuji in Japan, Mount Vesuvius in Italy and Kilimanjaro in Tanzania.

Mount Kilimanjaro, a typical cone-shaped volcano

The reason that some volcanoes are called stratovolcanoes is because they are made of layers of ash and lava that allow them to build up to great heights. The word *strato* or *strata* means layers. They are also known as 'composite cones' because they are not made of one type of material but a composite of different types.



A typical cone-shaped stratovolcano

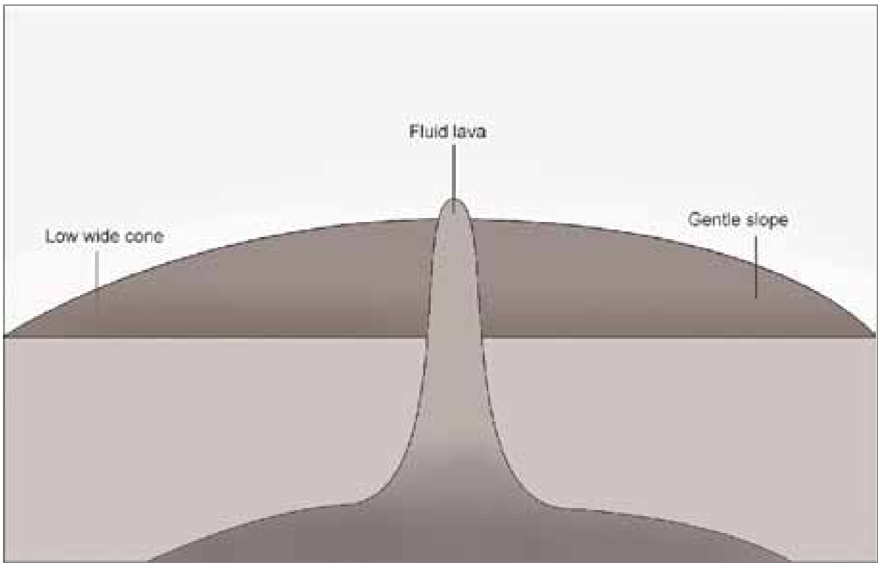
A stratovolcano is one of the most destructive types of volcano. The fact that it can build up into a huge cone shape explains why. The lava that erupts from a stratovolcano is thick in consistency because of its chemical composition (it has a high percentage of Silica). The lava forms a plug so that pressure builds up under and inside the volcano, but cannot easily be released. When the pressure gets too great, the volcanic plug in the cone, and sometimes a section of the cone itself, is shot out in a huge explosion. Gas, lava and ash can erupt. Ash can eject high into the sky and fall over the surroundings, smothering nearby towns, covering houses and trapping people. This is what happened when Vesuvius erupted and covered Pompei. The entire town was covered and preserved. Excavations there revealed, for example, people in their houses, meals on tables and dogs curled up in kitchens.

Shield volcanoes

A shield volcano is a low but widespread volcano. Imagine a circular shield placed on the ground. They have this shape because they are made of quite runny lava that is mostly **basalt** type rock, which has a low percentage of silicate material. The fluid nature of the lava means that it runs out over the ground rather than erupting into the sky. Shield volcano lava travels a longer distance than lava of other volcanic types, resulting in larger and thinner sheets of lava, often just 1 metre thick. Over long periods of time, the gradual build-up of thousands of these flows slowly builds up the broad profile of a mature shield volcano.

An example of what can be seen in the Pompei excavations

basalt:
a type of rock that is dark in colour, rich in minerals and produces good soil. Basaltic lava is low in silicates and is runny.



A shield volcano has very fluid, basaltic lava that spreads out.

Mature shield volcanoes are the largest volcanoes on Earth. Shield volcanoes often measure 5 to 6 kilometres in diameter and can be up to 610 metres high. The largest shield volcano in the world is Mauna Loa in Hawaii. This still-active volcano reaches 4,169 metres above sea level and is over 97 kilometres wide.

Hotspots

The Hawaiian shield volcanoes and some others are not located near any plate boundaries. Instead they form a chain of islands in the sea. This is because, as the crust moves, a feature called a hotspot punctures the crust like a sewing machine punching holes in moving fabric. A hotspot is an up-movement of magma in the mantle while the oceanic crust moves over it. This usually results in a string of volcanic islands.

ACTIVITY 4

1. Describe the main types of volcanoes, their shape and explosiveness and the reason for this.

2. Explain why some types of volcanoes are found in certain places on the planet.

3. Why is a hotspot volcano associated with plate movement, but not plate boundaries?

ANSWERS ON PAGE 134

Summary

In the previous lesson you learned about the Earth's crust and outer mantle. In this lesson we continued with the inner mantle and the core and some of their properties. The remainder of the lesson covered earthquakes and volcanoes. These are almost always associated with tectonic plate boundaries, and thus we are usually able to predict where earthquakes will happen, even if we don't know precisely when they will happen. Subduction zone earthquakes are the most common, and the most energetic and destructive. You also learned about continental convergence zone earthquakes and the much milder divergence zone earthquakes.

There are various sorts of volcanoes, also depending on where they are in relation to tectonic plates. Those near subduction zones or under oceanic plate are normally made of fluid lava and form shield volcanoes. The more explosive stratovolcanoes are made of more viscous (less runny) lava and ash and so they build up steeper mountains that get plugged. These plugs resist pressure and then explode violently.

CHECKLIST

Are you able to:

- ❐ describe the internal structure of the Earth and its features and characteristics such as temperature, depth and fluidity or rigidity
- ❐ explain what an earthquake is, the different types of earthquakes and their relationship with plate tectonics
- ❐ describe the features of at least two famous earthquakes
- ❐ explain what a volcano is, the different types of volcanoes and their relationship with plate tectonics

NOTES

LESSON 4

Biogeochemical cycles

About this lesson

This lesson focuses on the way nature recycles materials in biogeochemical cycles. We examine the water cycle, rock cycle, Carbon and Nitrogen. Each of these is critical for the healthy functioning of the planet and the living systems that are part of it.

In this lesson you will:

- learn about biogeochemical cycles, particularly the water cycle, the rock cycle and the Carbon and Nitrogen cycles.
- discover the importance of the water cycle as a water purifier
- find out why the biogeochemical cycles are critically important for the functioning of our planet and life on the planet
- discover more about the importance of these cycles in recycling essential chemical compounds through life systems

Nature recycles almost everything. Living things die and the energy in them, the chemicals in them, everything, eventually goes back into nature and returns in another form. Almost the only thing that does not get recycled is the energy that comes from the Sun. That is a one-way supply of energy, and eventually it leaves Earth as heat energy radiating way from us. Energy is taken in by plants, the plants grow, animals eat the plants or they die and rot away, and those materials and the Sun's energy enter into a recycling process until the energy is radiated away from Earth again.

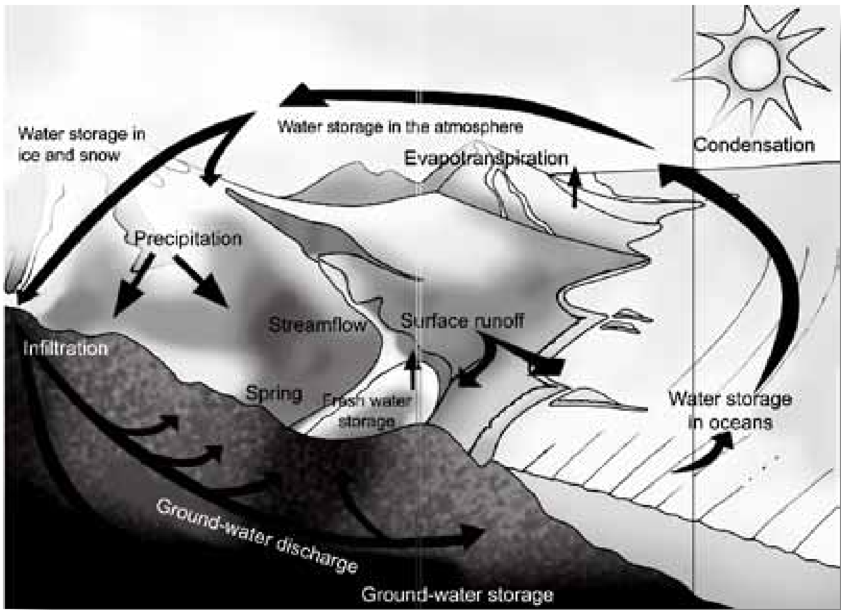
precipitation:
all forms of water falling to Earth or forming on Earth rain, snow, mist, dew, hail.

biogeochemical cycles:
the recycling of living matter, chemicals and earth materials by nature.
transpiration: water that is used in plants and released as water vapour from leaves.

The term 'biogeochemical' in the title of this lesson tells us that biological, geological and chemical factors are all involved. The circulation of chemical nutrients such as Carbon, Oxygen, Nitrogen, Phosphorus, Calcium, and water through the biological and physical world are known as **biogeochemical cycles**.

The water cycle

Water is always recycled through the water cycle, as you can see in the diagram below. The water undergoes evaporation, condensation, and **precipitation** and then falls back to Earth clean and fresh. This is all driven by energy from the Sun, which is free and abundant. Water is stored for some of the time in glaciers and ice caps as a solid (ice), lakes, oceans or the groundwater zone as liquid, or in the atmosphere as a gas (water vapour). Later in this lesson you will learn the word 'reservoir' which means the same as 'storage'.



The water cycle

This illustration of the water cycle summarises some of what you learned in the previous lesson about the hydrosphere. What you can see in the water cycle is that water falls as rain, hail, mist or snow. We call all of these 'precipitation'.

COMMENT

Water treatment plants treat waste water mainly from homes. They cost a lot of money to build and operate and the amount of water we can treat is limited. Yet nature does this free of charge, and the amounts of water are huge by comparison.

How the water cycle works
Water is continuously being recycled. Rain and other precipitation like snow, fall to the ground. The water runs along the ground. Some soaks into the soil, some seeps into the groundwater, and some runs into wetlands and rivers. Plants use water and also release some of it into the air through transpiration. Other amounts of water flow into lakes and eventually into the sea. Water in rivers, lakes and the sea evaporates and joins water that is transpired from plants. We call evaporated and transpired water **evapo-transpiration**. In the air, water becomes part of weather systems and eventually falls back again as precipitation. And so the recycling of water continues.

evapo-transpiration: *the combined total of water that evaporates from the ground, from plant leaves and other sources and water that is transpired as water vapour from plants.*

ACTIVITY 1

1. Explain why we call the water cycle 'Nature's great and free water purifier'.

2. Draw a schematic diagram of the water cycle and label it using the following labels: evaporation, transpiration, water storage, condensation, precipitation, groundwater flow.

3. Write a paragraph of about 8 lines explaining the importance and value of the water cycle.

ANSWERS ON PAGE 135

COMMENT

Imagine if there was no water cycle. All water on the planet would ultimately end up in the sea and be salty, while everything above sea level would be bone dry and lifeless.

The rock cycle

weathered, weathering:
rocks are weakened and begin decomposing because they are weathered by physical and chemical changes

igneous:
rock formed from lava or magma

sedimentary:
rock made from sediments that were deposited in layers by wind or water

metamorphic:
rock that is in existence and then is changed into a different kind of rock by heat, pressure or both

sediment:
particles of rock that are carried away and deposited somewhere

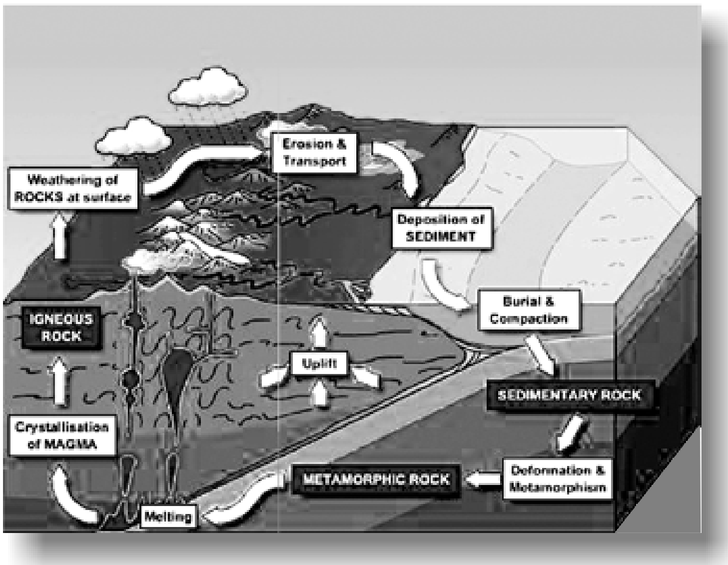
Our world is constantly changing. This is true of rock as well. Rock is constantly being **weathered**. All rock is being weathered, whether it is igneous rock that might have been formed from lava, or sedimentary rock that was laid down as layers of sediment (sand, mud, pebbles). Rock that might have been **igneous** or **sedimentary** rock, and has been changed by intense pressure or heat, called **metamorphic** rock, is also being weathered.

Once rock has been weathered, its particles can be carried away by wind or washed away by water, or they might simply fall off and be moved later. When these particles are deposited somewhere else, we call them **sediment**. The sediment might stay there, be covered over by other sediment and slowly turn into sedimentary rock.

COMMENT

Planet Earth is around 4.54 billion years old. Yet the oldest rock that we can find on or near the surface is slightly over 4 billion. Where is the missing half a billion years? Those older rocks are all gone, thanks to the rock cycle.

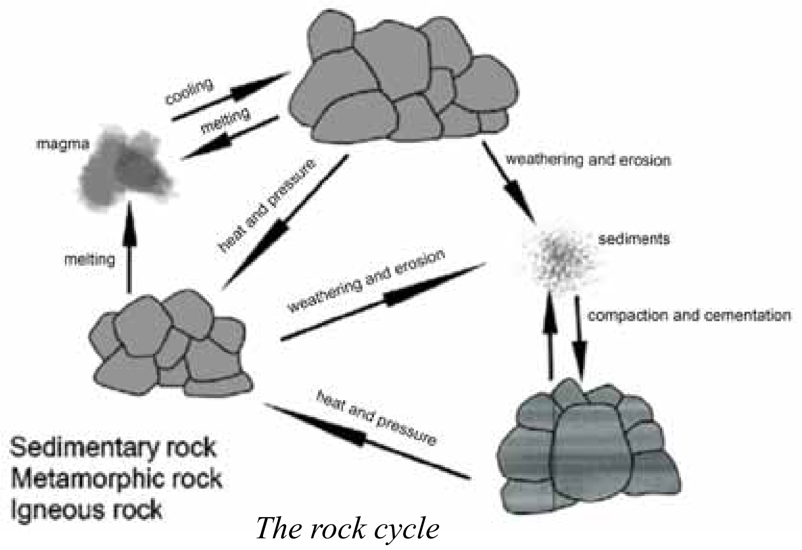
Millions of years later that same sedimentary rock that formed, perhaps on the ocean floor, might be subducted under a section of continental plate and melt into the magma. It might then erupt as lava from a coastal volcano. The diagram shows how the rock cycle works.



The rock cycle

ACTIVITY 2

1. Look carefully at this diagram. We have removed the labels from the three piles of rock. Use the other information in the diagram to link the labels back correctly.



The rock cycle

2. Write a sentence for each label explaining why you put it where you did.

3. Write sentences explaining how each of these rock types becomes the second rock type in the pair, and where in or on the Earth this usually happens.
   a) Sedimentary → Igneous
   b) Igneous → Sedimentary
   c) Igneous → Metamorphic

4. Why do we call the rock cycle a 'cycle'?

ANSWERS ON PAGE 135

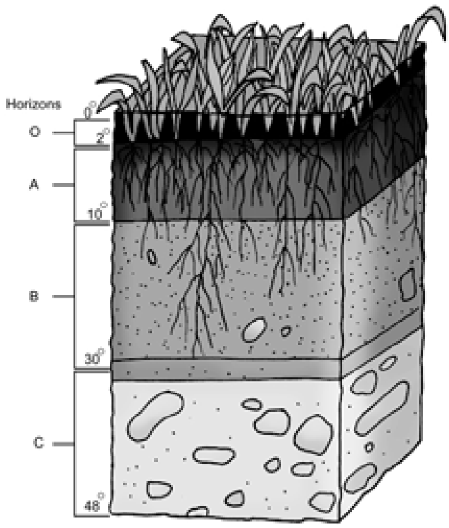
Importance of the rock cycle

The rock cycle has been shaping Earth's surface for 4.5 billion years. The crustal movements (plate tectonics) you have learned about have been responsible for the formation of continents, mountain ranges and ocean basins. Over time the Earth's crust has been altered, reformed and eroded to form many different landforms and features.

Formation of Soil

Rock is rich in minerals, which are important for plants. When rock weathers it combines with other matter, for example organic matter from once-living things, and forms soil. Soil gains minerals from the parent rock, which is why we have many different soil types.

If it were not for the rock cycle and the processes that it involves, particularly weathering, we would not have soil. And without soil there would be no plants or any other life.



Parent rock below weathers and causes soil to form

Minerals for Life

Movements of the Earth's crust release life-sustaining minerals such as Sodium, Iron, Potassium and Calcium into the biosphere. Sodium and Potassium are crucial for the nervous system, while calcium is an essential component for the synthesis of bones. If it were not for these minerals, our food would not be as nutritious for us.

Energy

The rock cycle helps us know where to search for different kinds of natural resources. For example, fossil fuels like coal and gas are found in sedimentary rock environments. Diamonds are found in certain types of igneous rock, called Kimberlite. Once Kimberlite is weathered and the weathered material is transported from its origin, diamonds can be found in rivers downstream from that area, and even on the sea bed where those rivers enter the sea. A good example of this is the Orange River.

Building Materials

Rock material has different properties, depending on its composition and how it was formed. This makes it useful for different purposes. Iron, limestone, marble, granite and basalt have been used as building materials for thousands of years. The structures of cities depend on them.

The carbon cycle

Carbon is stored in living things until they die, then it is released and moves into the soil or some other living thing.

Carbon is one of the elements in the Periodic Table (see Unit 2). It has the chemical symbol C. It is one of the most important chemicals on the planet, because it is the building block of almost all living matter. This is because it has four valence electrons. This allows it to bond with elements such as Oxygen, Hydrogen and Nitrogen and also to bond with itself, allowing it to form the long chains of molecules that living matter is made of.

The characteristics of Carbon mean that there is no other element that comes close to it for being able to support and build life processes. Carbon is indeed, the stuff of life.

The same Carbon atoms in your body today have been used in countless other molecules since time began. The wood burned just a few decades ago could have produced Carbon Dioxide which, through photosynthesis, became part of a plant. When you ate that plant, the same Carbon from the wood which was burnt became part of you. This is how the Carbon cycle works.

Carbon reservoirs and pathways
Carbon moves through a huge and complex cycle. It is stored in what are called **reservoirs** that are connected by what we call Carbon pathways.

reservoir:
a storage place for natural substances such as Carbon, for example

These are the major carbon reservoirs:

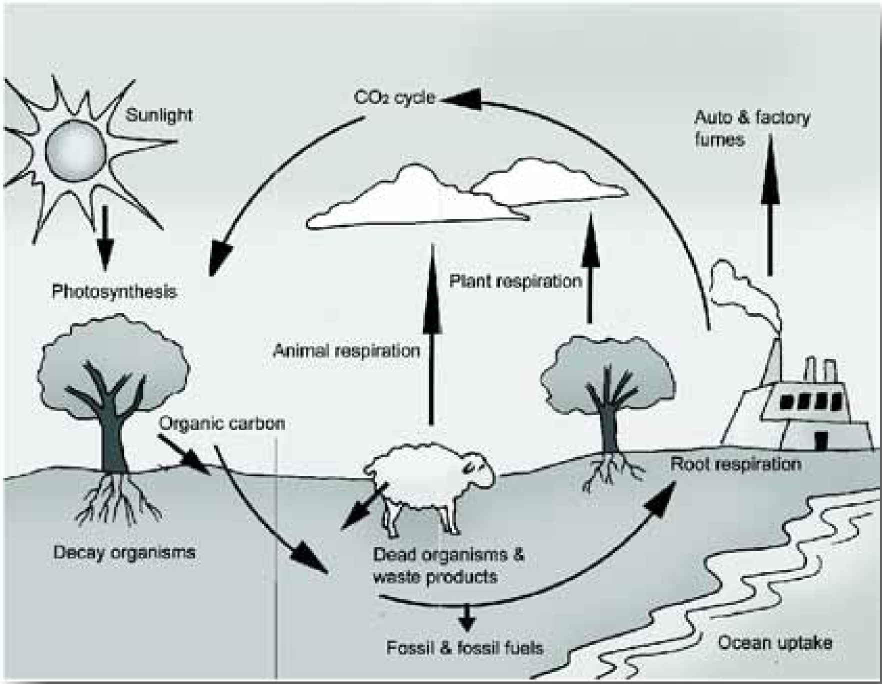
- the atmosphere
- the biosphere
- the oceans, both living and non-living components
- sediments, including fossil fuels like coal, oil and gas
- the Earth's interior – Carbon stored in crust and mantle material.

The major Carbon pathways are:

- photosynthesis absorbs Carbon from the air into the biosphere
- industry releases Carbon from fossil fuels into the atmosphere
- Carbon enters the soil when living things die
- the ocean absorbs Carbon from the air
- living things consume Carbon when they eat food

ACTIVITY 3

1. Look at this diagram.



An overview of the Carbon cycle

a. How many reservoirs of Carbon can you find? Name them.
b. How many Carbon pathways can you find? Name them.
c. You ate something that came from a plant today. Where did the Carbon come from that was in that food?
d. Name the main places where the Carbon will go.

ANSWERS ON PAGE 136

The importance of the Carbon cycle

The Carbon cycle is vitally important to life on earth. Through photosynthesis and respiration, it is the way the earth produces food and other resources. Without the Carbon cycle food production would stop.

Through decomposition, the Carbon cycle serves as the earth's waste disposal system. The decomposed material is recycled into the soil, and in this way it maintains the fertility of soil. Some Carbon from decomposition ends up in sediments and is stored or locked up in sediments and eventually in rock. It might take millions of years before this Carbon is released again.

The Carbon cycle is an important part of the Earth's temperature control system. The atmosphere is a very important reservoir of carbon in gas form (for example CO_2 or CH_4). These gases work as a kind of insulation for the Earth. Without it Earth would get very cold. But if too much Carbon-based gas gets into the atmosphere it will cause the temperature of the Earth to increase. This increase in heat energy is called global warming. It causes major changes in climate. So we can expect more violent storms, more rain in some places, less rain in others and higher temperatures generally. This is why humans need to reduce the amount of Carbon we burn (mainly in the form of fossil fuels) because it increases the amounts of Carbon in the atmosphere.

The Nitrogen cycle

Nitrogen is a very abundant substance. It makes up about 79% of the atmosphere. This means the atmosphere is the largest reservoir of Nitrogen. However, this gas is not very reactive. It is not a fuel, nor does it help things to burn. In air Nitrogen is diatomic, which mean that two atoms of Nitrogen are linked together to form the N_2 molecule. The reason why Nitrogen is inactive is that it takes so much energy to pull these linked atoms apart. Atmospheric Nitrogen is thus not readily available for life processes. Biologically useful Nitrogen needs to be in the form of organic Nitrogen compounds like Ammonium (NH_{4+}), Nitrite (NO_{2-}) and Nitrate (NO_{3-}) compounds.

The amazing thing about the Nitrogen cycle is the way atmospheric Nitrogen is converted into organic Nitrogen compounds. We call this 'fixing'. This does not mean 'repairing' something that is broken, but capturing or holding onto something. Nitrogen that is floating around in the atmosphere and cannot be used by plants is not captured or secured for them. It needs to be 'fixed'.

There are two ways that Nitrogen fixing happens in nature.

- Lightning
- Nitrogen-fixing bacteria

Lightning fixes a small quantity of Nitrogen by making it combine with water in the air. From here it washes down into the soil, where it becomes accessible to plants.

Most Nitrogen-fixing is done by bacteria. These bacteria have an enzyme that combines gaseous Nitrogen with hydrogen to produce ammonia. Some Nitrogen fixing bacteria are free-living and live in the root nodules of legumes (such as peas or beans). Nutrient-poor soils can be planted with legumes to enrich them with Nitrogen.

Manufacture of ammonia in chemical factories now produces about 30% of the total fixed Nitrogen.

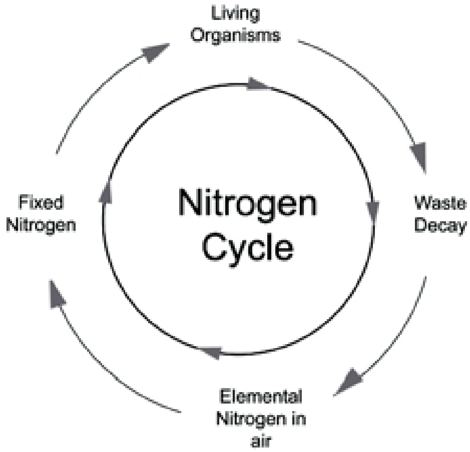
COMMENT

Possibly the most important group of living organisms on the planet are bacteria that can 'fix' Nitrogen. This means that they change Nitrogen from inorganic N_2 to a chemically active organic form. Without these bacteria, life on Earth would not be possible.

Putting the Nitrogen cycle together

Nitrogen is everywhere present in this scene and is being recycled

The picture shows Nitrogen in a 'real-life' situation. The diagram below provides a helpful overview of how it works.



An overview of the Nitrogen cycle

Look at the picture on the previous page and at the diagram as you read the next two paragraphs.

The atmosphere is a major reservoir of Nitrogen. Atmospheric Nitrogen is fixed into Nitrogen compounds that plants can use in various ways. Nitrogen-fixing is a pathway between reservoirs. Plants take Nitrogen from the soil by absorption through their roots, in the form of either nitrate ions or ammonium ions. Animals eat plants; animals are eaten by other animals; and this process continues up the food chain. All Nitrogen obtained by animals can be traced back to the eating of plants at some stage of the food chain. The biosphere is a reservoir of Nitrogen in the form of plant and animal protein.

The waste from the bodies of living organisms as well as dead matter from these organisms decays and releases this organic form of Nitrogen (all that work by Nitrogen-fixing bacteria is undone!) The decay process is another pathway between reservoirs. Most of the organic Nitrogen is converted back into atmospheric (inorganic) Nitrogen. Some is also stored in the soil or rock reservoirs until it is released at a later time.

Importance of the Nitrogen cycle

Nitrogen is essential for many processes and is crucial for any life on Earth. It is a component in all amino acids, a critical component of proteins and DNA and RNA. In plants, much of the Nitrogen is used in chlorophyll molecules, which are essential for photosynthesis and further growth.

ACTIVITY 4

1. Explain why, in spite of the fact that Nitrogen makes up almost 79% of the air around us, that it is actually quite a scarce resource for life processes.

2. Define the term 'Nitrogen-fixing'.

3. Draw a schematic diagram of the Nitrogen cycle and label it with the following: reservoir, pathway, Nitrogen-fixing, decay, and any other labels you think might be needed.

ANSWERS ON PAGE 136

Summary

In this lesson you learned about different biogeochemical cycles the water cycle, rock cycle, Carbon and Nitrogen cycles. Each is critical for the functioning of the planet and life on the planet.

The water cycle acts as a huge and free water purifier, the rock cycle changes rock into different forms and shapes the Earth, and the Carbon and Nitrogen cycles recycle essential chemical compounds through life systems. Perhaps the most surprising thing you have learned is the importance of bacteria in fixing Nitrogen.

CHECKLIST

Are you able to:

- ❒ describe biogeochemical cycles, explain how they work and say why they are important
- ❒ explain how the water cycle is nature's great and free water purifier
- ❒ explain how rock types can change into other rock types though the rock cycle
- ❒ explain how soil relates to the rock cycle
- ❒ define a reservoir and a pathway in a biogeochemical cycle
- ❒ describe the Carbon cycle
- ❒ describe the Nitrogen cycle, and in particular what fixing means

Seasons

About this lesson

This lesson focuses on seasons and why we have them. It uses diagrams to explain seasons in relation to the positions of the Earth and the Sun, in particular, the role played by the tilted axis of the Earth. It presents the names and dates of certain seasons. The lesson then changes focus and examines the way in which seasons affect living things, including humans.

In this lesson you will:

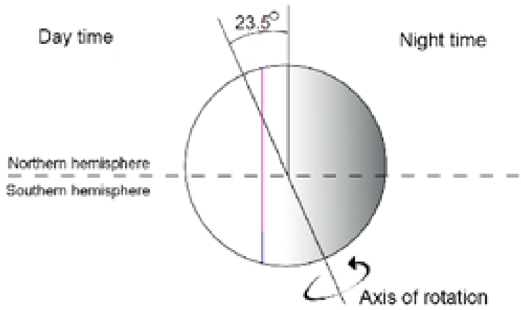
- learn about seasons and why we have them
- draw diagrams to explain the positions of the Earth and Sun in relation to the seasons
- discover why, when it is winter here it is summer in the northern hemisphere, and vice versa
- find out why our days get longer towards summer and shorter towards winter
- find out about the names solstice and equinox and what they mean
- find out some interesting facts about how seasons affect living things.

Orientation of the Earth on its axis

If I ask you where up is, you will probably point above your head. If I ask someone standing on the other side of the planet where up is, she will also probably point above her head. But you can't both be right can you? Up is away from the centre of the planet you are standing on at the moment. There is no one place that is 'up'.

The Earth's axis is tilted

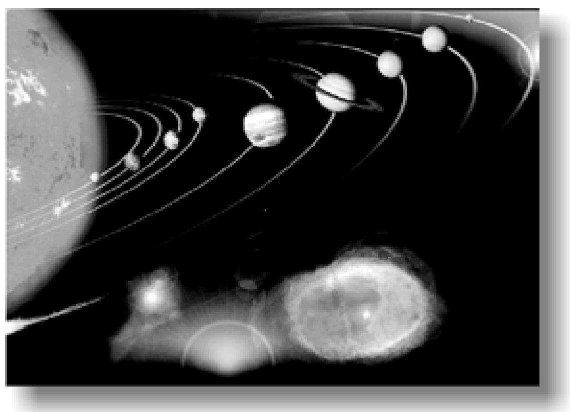
The question about 'up' is similar to asking about the tilted axis of the Earth. Where is it tilted from or towards?



Earth's axis in inclined from the plane of the Ecliptic

Look at the image of the Solar System. Of course, there are no lines drawn in space, but in this diagram there are lines showing the orbits of the planets. The Earth is the third planet from the Sun. The next one outwards is Mars, which has a red colour. Notice that the orbits of all the other seven planets are lined up on almost the same plane or level as Earth's. They lie on that plane because during the Solar System's formation, the planets formed out of a disk of dust and gas that surrounded the Sun (a bit like a fried egg). Because that disk of dust and gas was all in one **plane**, all of the planets formed in the same plane.

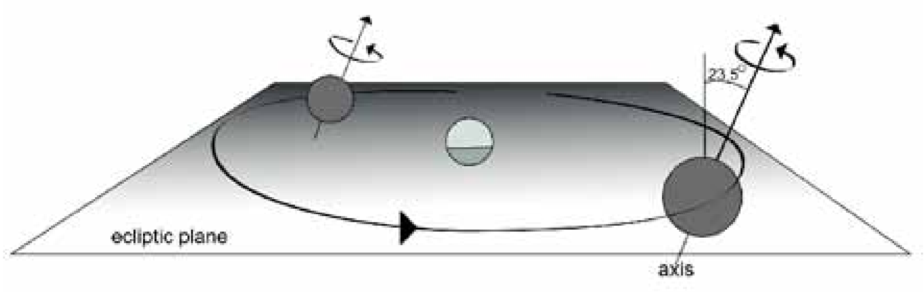
plane:
a flat surface



The Solar System. This is not to scale!

We call the plane of Earth's orbit the 'plane of the **Ecliptic**'. The Ecliptic is actually a line that might be drawn on the sky (if one could do such a thing) in line with the centres of the Sun and Earth as Earth revolves around the Sun during one year.

ecliptic:
an imaginary line made by the path of the Sun around the sky during one year



Earth orbits the Sun on a plane and is tilted away from that plane by 23.5 degrees

This diagram shows what we mean when we say the Earth's axis is inclined. It is inclined away from the plane the Earth follows around the Sun by 23½ degrees.

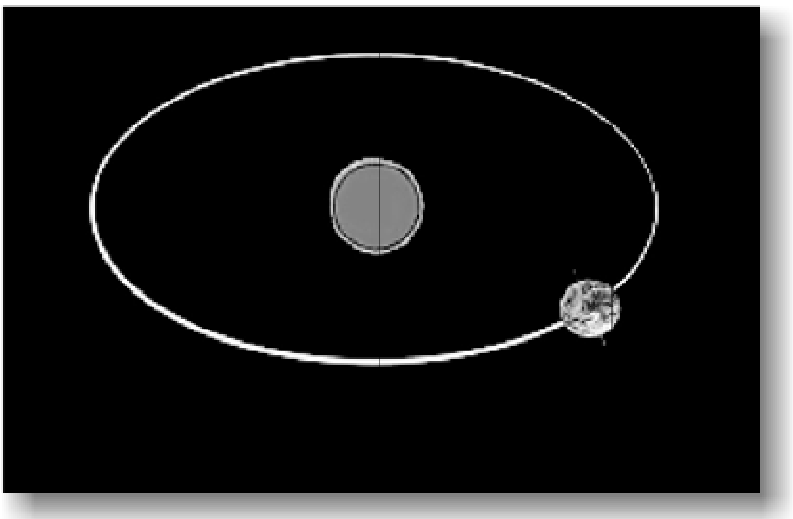
COMMENT

The inclination of Earth's axis is why we have seasons: spring, summer, autumn and winter. If there wasn't an inclination, there wouldn't be any seasons!

Earth's orbit around the Sun

Once a year the Earth completes one orbit around the Sun.

hemisphere:
half of a globe or sphere. For example, if you cut an apple in two equal parts you would have not one sphere, but two hemispheres.



Earth's orbit around the Sun takes one year to complete

Notice that Earth's axis is tilted away from the plane of Earth's orbit. This is important to remember when we explain seasons.

ACTIVITY 1

1. Draw and label a diagram showing Earth's orbit round the Sun.

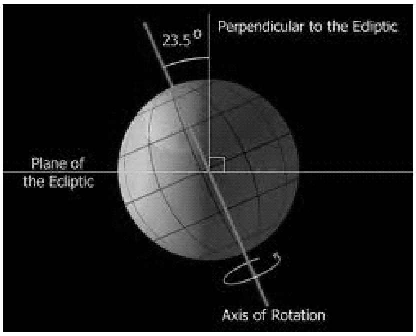
2. Where is the Sun in the diagram on the previous page?

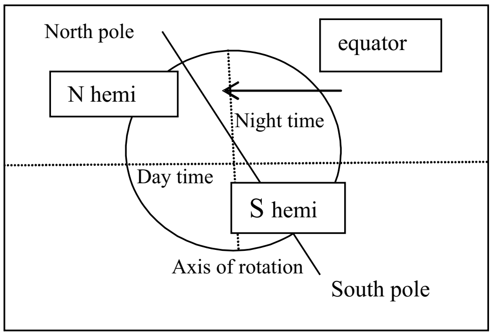
3. Note where the plane of the Ecliptic and the angle of Earth's axis are. Which hemisphere is tilted towards the Sun – the northern or the southern hemisphere? Give a reason for your answer.

ANSWERS ON PAGE 137

COMMENT

The equator divides the Earth into two parts called the Northern and Southern Hemispheres. We live in the Southern Hemisphere.





Earth's axis is inclined from the plane of the Ecliptic

ACTIVITY 2

Use a ball and a torch or lamp to model the Sun and the Earth.

1. Set up your lamp and ball to match the diagram above. Draw an axis line on the side of the ball. Write an 'N' for the North Pole at the top of the ball and an 'S' for the South Pole at the bottom of the ball.

2. Tilt the axis so that the North Pole is more in the sunlight. The South Pole will be in shadow.

3. Which hemisphere do you think is getting more sunlight?

4. Take the lamp around to the other side of the ball, but keep it tilted exactly the same as before (this is important!)

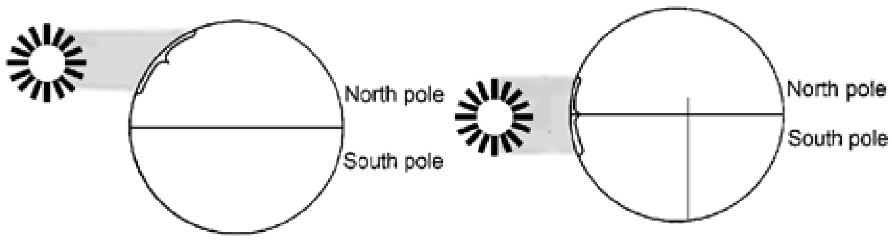
5. Which hemisphere do you think is getting more sunlight now?

ANSWERS ON PAGE 137

Why temperatures change in winter and summer

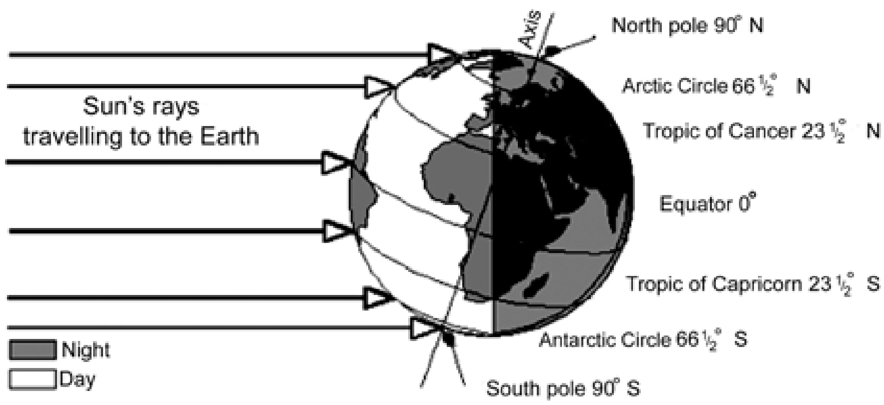
We have said that less light falls on a hemisphere in winter than in summer. Let us look at what 'less light' really means.

The amount of energy received by different parts of the Earth's surface is not the same. At the equator, the Sun's rays are almost perpendicular to the Earth's surface. So the equator receives more energy per unit area than the regions north or south of the equator. The Polar Regions receive the least amount of energy. Look at this diagram (we will not tilt the Earth for now).



Sunlight in the first diagram is striking the Earth near the poles. It is more spread out. Sunlight in the second diagram is striking the Earth's surface near the equator. It is more concentrated.

We know that the Earth is tilted at 23,5 degrees. So the amount of solar energy per unit area reaching the Southern Hemisphere in summer is greater than the amount of solar energy reaching the Northern Hemisphere. Look at the figure below.



Solar energy is more concentrated on the southern surface in summer than on the northern surface. This is because of the tilt of the Earth.

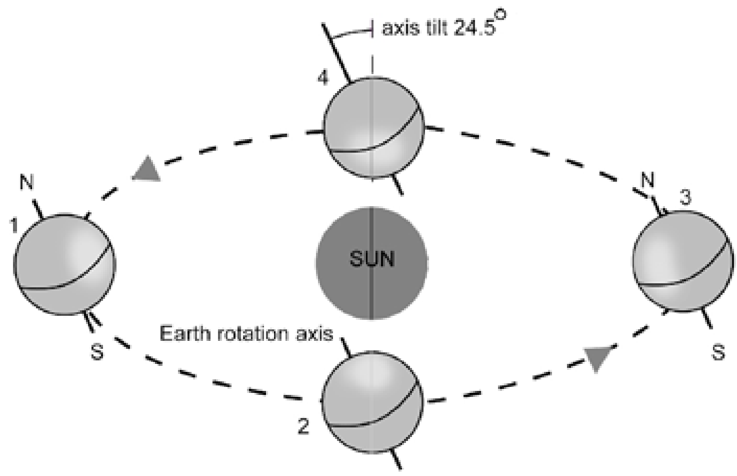
In summer the situation in the Northern Hemisphere is reversed. The north tilts towards the sun, as you can see in the drawing. So the amount of solar energy per unit area is more in the north than in the south.

Seasons

> ***maximally:***
> *the most possible*

The Earth's tilt with respect to the plane of the Ecliptic is the reason we have seasons. If there was no tilt and the Earth was totally upright we would have no seasons. Around June the northern hemisphere is tilted **maximally** towards the Sun, so it is warmer there and they have summer. At the same time the southern hemisphere is tilted maximally away from the Sun so it is colder here and we have winter.

At that time of year our days are short and the northern hemisphere's days are long. Six months later, in our summer, our days are long and the northern hemisphere's days are short. During summer the Sun is also higher in the sky (it is more overhead) and in winter it is lower in the sky (being more overhead in the other hemisphere). So longer days and the Sun being higher in the sky make summers hotter than winters.



Earth shown in four different positions during its one year orbit around the Sun

COMMENT

Some people think it gets warm in summer because the Earth moves closer to the Sun. But then why does it get colder in the northern hemisphere at the same time? This diagram could make you think Earth's orbit is egg-shaped. But it is not – this is just a drawing and is not to scale.

ACTIVITY 3

1. Look at Earth in position 1. Which part of the planet is getting more sunlight, the northern hemisphere or the southern hemisphere? Give a reason for your answer.

2. Now look at Earth six months later, in position 3. Which part of the planet is getting more sunlight, the northern hemisphere or the southern hemisphere? Give a reason for your answer.

3. Draw a diagram similar to the one on the previous page.
   a. At position 1 label summer for the hemisphere that gets more sunlight and winter for the hemisphere that gets less light.
   b. Do the same for position 3.
   c. What about positions 2 and 4? Notice that the axis is tilted sideways, but **not** towards or away from the Sun. Which hemisphere is getting more sunlight in these positions, the northern or the southern? Label positions 2 and 4 with their correct seasons (both hemispheres).
   d. Write the months December, March, June and September in the correct places.

solstice:
the time when it is mid-summer or mid-winter. The meaning of the word comes from sol = sun, stice = stopping point.

equinox:
the time when it is equal day and night for southern and northern hemispheres. The meaning of the word comes from
equi = equal,
nox = night.

ANSWERS ON PAGE137

The Earth orbits around the Sun from position 1 (where it is summer for us) towards position 2. Here, and in position 4, the Sun is not providing more light for one hemisphere or the other. So these seasons are autumn and spring. We have names and dates for each of these positions (note that the exact date varies slightly from year to year):

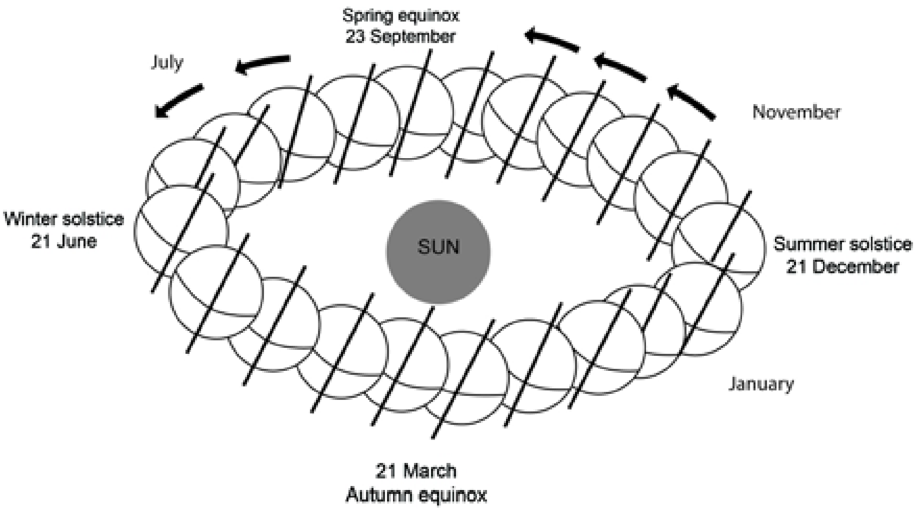
Position	**Name**	**Approximate date**
Position 1	**solstice** (summer solstice for us, winter solstice for the northern hemisphere)	21 December
Position 2	**equinox** (autumn for us, spring for northern hemisphere) (meaning: equi = equal, nox = night)	21 March
Position 3	solstic e (winter solstice for us, summer solstice for the northern hemisphere)	21 June
Position 4	equinox (spring for us, autumn for northern hemisphere)	21 September

Every day between these four main positions, the position of the Earth changes very slightly, the place where the Sun is most overhead changes very slightly, and so the seasons change, almost unnoticeably each day. The length of day also changes slightly each day. From our summer to our winter the days get shorter and shorter, and then for the next six months they get longer again.

COMMENT

Seasonal changes happen too slowly for us to notice daily differences, but we certainly notice it when it is mid-winter and mid-summer!

Look closely at this diagram. It has many more positions of Earth drawn in an orbit around the Sun than just the four we have seen so far.



The seasons change gradually during the entire year

Effect of seasons on living things

deciduous:
a deciduous tree drops its leaves in winter

In some climates there is very little difference between the seasons. Mostly these places are close to the equator because there the sun is more directly overhead for most of the year. In the tropical areas there are very few **deciduous** trees.

Deciduous trees lose their leaves mainly when water is less available in the soil. In cold climates this happens in winter and in warmer climates it is in the dry season, which is usually also winter. Further away from the equator you will see from the previous diagram that the sun is higher in the sky in one hemisphere of the planet while the other side has much less sunlight. So winters are usually much colder than summers. This is when trees drop their leaves and re-grow fresh new leaves during spring.

The same tree and scenery in different seasons

We are also affected by the seasons. In English we use the term 'spring cleaning'. This is the time of year when it is warming up, the Sun rises earlier and people feel energetic and happy. So they start being more active, including cleaning out the house and throwing away old stuff that might have collected during the cold, dark winter.

In colder climates where the daylight time is short during winter, levels of depression are known to be higher. People actually get depressed by the cold and dark. This affects people in all of the far northern countries. It is called 'Seasonal Affective Disorder', or SAD. There are many countries in these high latitudes in the north. In the southern hemisphere, these higher latitudes are mostly ocean, so it is not so much of an issue here.

Breeding behaviour

Living creatures tend to breed mostly in spring. This is mainly because life is tough during winter – there is less food available, conditions are harsh and many animals tend to **hibernate**. As it warms up there is more food and conditions are usually easier. Breeding takes place early in spring so that by the time eggs hatch or babies are born there is still plenty of summer left for a good season of raising young ones and giving them time to mature enough to look after themselves the next winter.

hibernate:
when animals slow down their body processes and become inactive during winter

A weaver bird building a nest in early spring and trying to attract a partner to breed

Seasonal migration of birds

> ***migrate:***
> *move from one area to another usually because of seasonal changes*

Birds **migrate** from areas where the food resources are decreasing to areas of high or increasing resources. The migration usually takes advantage of rapidly increasing insect populations, budding plants and an abundance of nesting locations as spring arrives. As winter approaches, and the availability of insects and other food resources drops, the birds migrate back again. Some birds migrate thousands of kilometres between the northern and southern hemispheres each year.

When do birds know that the time is right to migrate? Migration can be triggered by a combination of changes – day length, lower temperatures or changes in food supplies. The main trigger is the changing length of day. This is why migrations begin on almost the same day each year.

ACTIVITY 4

1. Write down three examples of how humans are affected by seasons.

2. Write a short paragraph about the effect of seasons on animal behaviour, but as far as possible use examples that you know about that were not provided here. If necessary conduct research or talk to people to get ideas.

ANSWERS ON PAGE 137

Summary

In this lesson you learned about seasons and why we have them. This is mainly related to the fact that the axis of the Earth is tilted with respect to the plane it orbits around the Sun. This means that around June the northern hemisphere is tilted towards the Sun so people in the northern hemisphere have summer, while around December the southern hemisphere is tilted towards the Sun so we have summer. The other seasons are spread out between these times. As the seasons change so also do day lengths and the position of the Sun in the sky. You also learned about how seasons affect living things, for example breeding and migration.

CHECKLIST

Are you able to:

- ❒ explain why we have seasons
- ❒ draw diagrams to explain the positions of the Earth and Sun in relation to the seasons.
- ❒ explain why, when it is winter here it is summer in the northern hemisphere, and vice versa
- ❒ explain why our days get longer towards summer and shorter towards winter.
- ❒ explain how living things are affected by seasons.
- ❒ say why one can predict fairly accurately when birds will start their annual migration

NOTES

LESSON 6

The Earth as a System

About this lesson

This lesson focuses on a fascinating concept, namely that Earth operates as a system and has its own regulatory mechanisms that mainly serve to keep different factors such as temperature and chemical balances in the soil, atmosphere and water in balance. We will examine the different components and regulatory mechanisms in the Earth system, in particular what might have been happening in recent times as human activities have put additional pressure on some components of the system. This section includes a detailed coverage of the concept of boundaries. An example is your body temperature. How high can your temperature go before the body system can no longer cope? How far can we change different components of the Earth system before they can no longer cope and no longer support life? And how long will it take before we reach these tipping points?

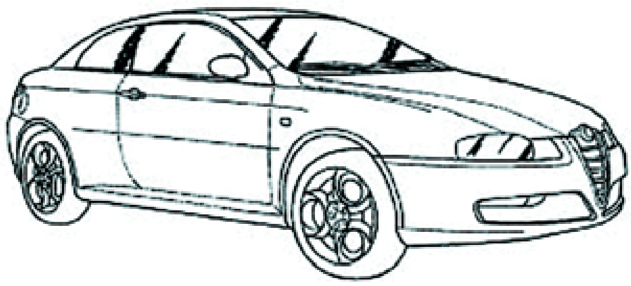
In this lesson you will:

- find out what a system is and how its components relate to each other
- consider the idea that Earth is a system
- examine the concept of equilibrium (balance) in Earth's different components and the Earth system as a whole
- learn how systems are regulated through different feedback mechanisms
- examine how human-induced changes are driving some changes through positive feedback mechanisms, and how these might represent tipping points for the planet.

What is a system?

interdependent: *separate parts depend on each other; they are mutually dependent*

A system is a collection of interacting parts. We say they are **interdependent** as they all depend on each other. However, those interacting and interdependent parts also form a whole. For example, a motor car is a set of interacting and interdependent systems; a human body is a set of interacting and interdependent systems, but the important thing is that the car and the body are a whole machine or organism.



A car is a system

ACTIVITY 1

1. Look at the photo of the car.
   a. Make a list of as many of its sub-systems as you can.
   b. Which ones can fail and still allow the car to operate properly?
   c. Which ones cannot fail if the car is to continue operating correctly?
   d. What does this teach you about systems?

ANSWERS ON PAGE 138

Let us look at the system that is the human body. The body consists of many different parts that all depend on each other. The liver cannot do the work of the heart, and vice versa. But if the heart stopped working, the liver would also soon stop working. A system often also has sub-systems. The body system has sub-systems: circulatory system, the nervous system, the endocrine system and so on.

The same is true of the Earth system. The parts of the Earth system interact in complex ways. You already know some of the Earth system's components from the first three lessons in this Unit:

- lithosphere
- hydrosphere
- atmosphere
- biosphere

Within each of these are other systems. For example, you know from Lesson 4 on biogeochemical cycles that there is a system for transferring Carbon along pathways amongst and between living organisms. There are also non-living physical components that often act as reservoirs, such as water, air and soil.

Systems have certain common features:

- structure: they have components (for example lithosphere, atmosphere and biosphere) that are related to each other (or heart, liver, lungs in your body or battery, starter motor, alternator in a car – there are many examples)
- interconnectivity: the parts and processes are connected by pathways such as decomposition, evaporation and Nitrogen-fixing
- regulation: feedback mechanisms, such as forests absorbing carbon dioxide, that help keep them in balance (e.g. you sweat when you get hot).
- boundaries: these are not only physical boundaries such as the edge of the atmosphere, but, more importantly, boundaries such as temperature, or levels of a certain chemical which, if exceeded, can cause major changes in the system. Rising CO_2 levels, for example, can cause major climate change.

You will learn more about these features in relation to the Earth system as you work though this lesson.

A new way of thinking about Earth as a system

There is a new awareness that solutions for the world's big problems cannot be found within separated disciplines like atmospheric science, soil science, microbiology and many others on their own, important as these are, but rather by integrating them and finding new ways of thinking and finding solutions to the big issues. A systems-way of thinking is now being followed rather than a discipline-based way of thinking.

What does this extract from a Florida International University brochure tell you about how different subjects have been combined?

More recently a theory called the 'Gaia Hypothesis' was developed that suggests that the Earth is like an organism that can regulate and heal itself, just as your body does. At first people were critical of this – 'How can our planet be a living organism?' But, while we know it is not a living thing, it could almost be, because it is a self-regulating system and reacts to changes. It does this by making another change that controls the first change. For example, you sweat or breathe harder when you exert yourself. When there is more Carbon Dioxide in the air, plants grow faster and absorb it.

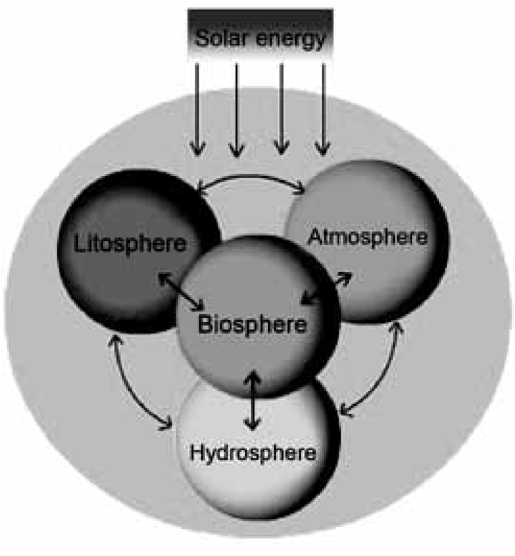
The Gaia Hypothesis is becoming more widely accepted as it is a very good way of thinking about the planet. The problem arises when human activities cause change to be so rapid that the Earth system cannot respond quickly enough, or is too severely damaged. Then permanent changes can take place. Earth is no longer able to regulate things and 'heal' itself. Similarly, if you become extremely dehydrated there is a danger that you could die of heat stroke.

The rest of this lesson follows a systems approach – systems are not separate and separated things, but integrated parts of the whole.

Components of the Earth System

The Earth system is a complex functioning system that includes all the components of the various 'spheres':

- lithosphere – the rocks of the crust and upper mantle
- atmosphere – the layer of air surrounding earth
- biosphere – all living organisms
- hydrosphere – all water on the planet (and in the atmosphere and below the surface).



The Earth system diagram on the previous page, shows arrows representing flows of energy and mass that connect the four spheres. At the top, solar energy drives many of the environmental processes operating in the four spheres. Heat from inside the Earth provides additional energy to drive some Earth systems (you know about this from an earlier lesson – think of some examples!) There is a constant cycling of energy and matter between the hydrosphere, lithosphere, atmosphere, and biosphere as indicated by the arrows.

For example, Nitrogen is found mostly as a gas in the atmosphere, where it does not react chemically. But when it is converted into active chemical form like Nitrates (NO_3) or Ammonia (NH_4) in the soil it is a major natural fertiliser for plants. Plants take up this Nitrogen and store it in their bodies. Animals eat plants and take up this Nitrogen into their bodies. When living things die the Nitrogen is released back into the soil or the atmosphere.

There are many other substances that have such cycles in nature – Carbon, Phosphorous, water, Oxygen, Sulphur and others. Rock also has its own cycle. It changes over long periods of time from igneous to sedimentary to metamorphic rock, and so on. Energy from inside the Earth, weathering, and erosion change the rock and move it from one place to another.

In Lesson 4: *Biogeochemical Cycles* you learned about pathways for substances such as Carbon and Nitrogen. The arrows in the Earth systems diagram represent those pathways.

ACTIVITY 2

1. Review Lesson 4: Biogeochemical Cycles, looking specifically at reservoirs and pathways. Now re-draw the diagram of the Earth system as a rough sketch on a large piece of paper. Make annotations and labels on or alongside the diagram giving information about and examples of reservoirs and pathways.

ANSWERS ON PAGE 138

The concept of equilibrium

All systems have some kind of regulation mechanism. The example we have used so far is of sweating when you get hot, or breathing faster and deeper when you exert yourself. You don't consciously tell your body to do these things.

Your system is made in such a way that it can monitor conditions and trigger sub-systems when certain conditions change or move closer to limits (in this example it is temperature limits and Oxygen and Carbon Dioxide limits.)

The Earth system is exactly the same, except that most of it (excepting the biosphere) is non-living.

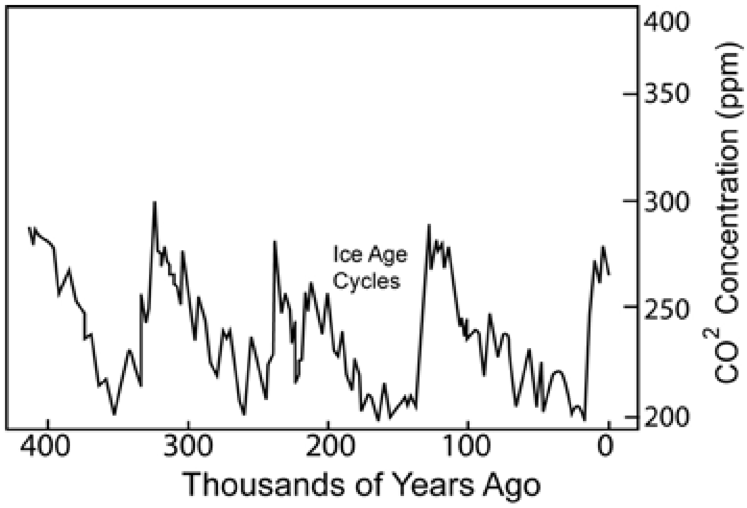
Equilibrium

__equilibrium:__
a state of balance

__ppm:__
parts per million, which in our case is how many parts of carbon dioxide there are per million parts of other gases in the atmosphere

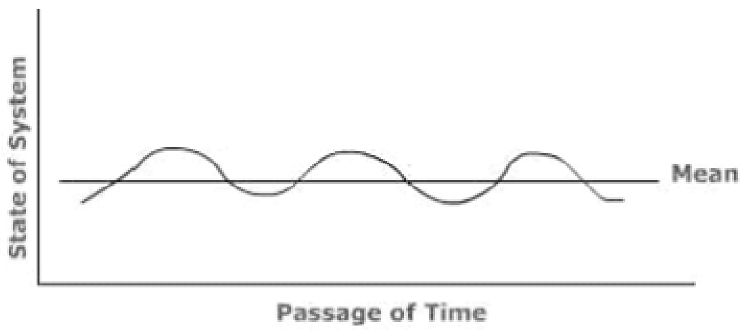
__dynamic equilibrium:__
equilibrium that fluctuates and usually stays within certain limits fairly closely

Most systems tend toward a state of **equilibrium**, or balance. For example, for 20 million years the levels of carbon dioxide in the atmosphere were in equilibrium, at between 280 **ppm** to 300 ppm, although the level of Carbon Dioxide has increased over the last fifty years. So, although it has fluctuated during this time it has been fairly steady. The graph below shows only the last 400 thousand years, but it is a perfect example of this kind of fluctuating equilibrium. We call this **dynamic equilibrium**.



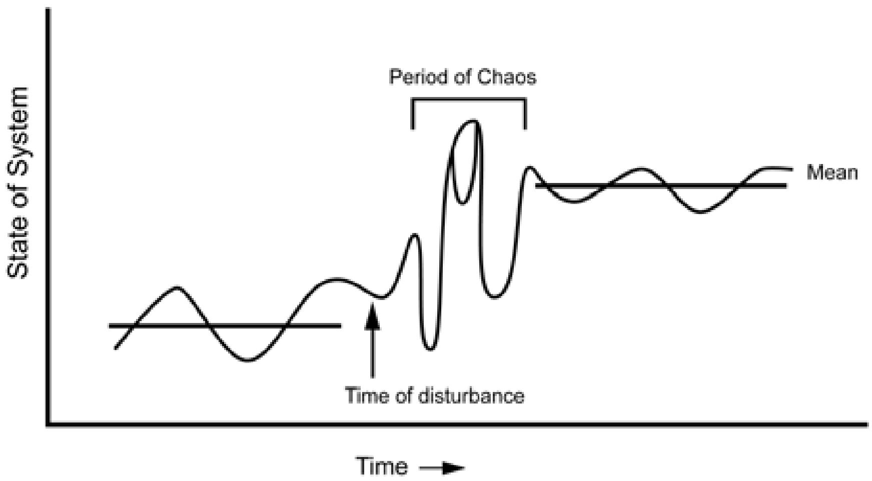
This graph shows CO2 concentrations of the last 400 thousand years

Although natural systems change over long periods of time, on the scale of a human lifetime they appear to be static, fluctuating slightly between certain limits. For example, the Earth's atmospheric temperature has remained fairly constant through long periods of time, even though at shorter time intervals, the temperature has risen or fallen. This concept of dynamic equilibrium is shown in the graph.



If a system is disturbed in some way it will initially have some big changes and even some chaotic things happening, but eventually it will settle down at a new level or in a new condition and will reach a new dynamic equilibrium, as shown in the graph. For example, a stream might be very stable in terms of organisms in it, water chemistry, water temperature and so on. But if a factory starts releasing coolant water upstream (let's say for now that it is clean water) and causes a slight increase in the average water temperature of the stream, dissolved Oxygen levels in the water will decrease, growth rates of some plants will increase, some temperature-sensitive organisms will die, others might increase in number and so on. But after a few years (assuming the factory keeps releasing the same amount and temperature of water at all times) then the stream will likely settle down into another steady-state of equilibrium.

That graph might look like this:



A system is controlled or influenced by feedback mechanisms between its components. When there is equilibrium such as described here, then the feedback mechanisms cause the movement up or down to move back to the middle again. This is **negative feedback**. However, if a change in a system is because of **positive feedback**, that change will get larger and the rate of change will probably increase. The next section deals with both of these types of feedback.

negative feedback:
a response to a change that tends to keep the system stable and at the same state as before

positive feedback:
a response to a change that tends to push the system away from its average state and become unstable

Feedback

We have already discussed the idea of feedback and that two types, positive and negative feedback exist. In this section we will look at some examples to further explain these concepts.

Negative feedback mechanisms

A negative feedback mechanism tends to keep a system stable and in the same state as before.

Some systems need to stay in a very stable state – we call this steady-state equilibrium. Their feedback mechanisms act quickly and are very sensitive. A good example of this is the water balance that needs to be maintained by cells and organisms. These systems must excrete water at about the same rate that they take it in or they suffer damage.

Others vary quite considerably, but over time remain stable, such as the predator-prey relationship (for example, lions hunting antelope such as Impala, Bushbuck and Duiker). If there are more lions there will be a reduction in the population of antelope. That will lead to starvation for lions and some will die. Fewer lions imply more antelope, leading to more food for lions, allowing the lion population to increase. This leads to a condition of dynamic equilibrium. Moreover, this state also interacts with other systems. When there are more antelope, they will reduce the amount of vegetation in the area. This might lead to hardship for the antelope, and some might die off or move to another area. This might cause hardship for the lions, but at least the vegetation will recover. This is an example of how negative feedback mechanisms tend to maintain a balance.

ACTIVITY 3

The photo shows extensive damage to vegetation by elephants.

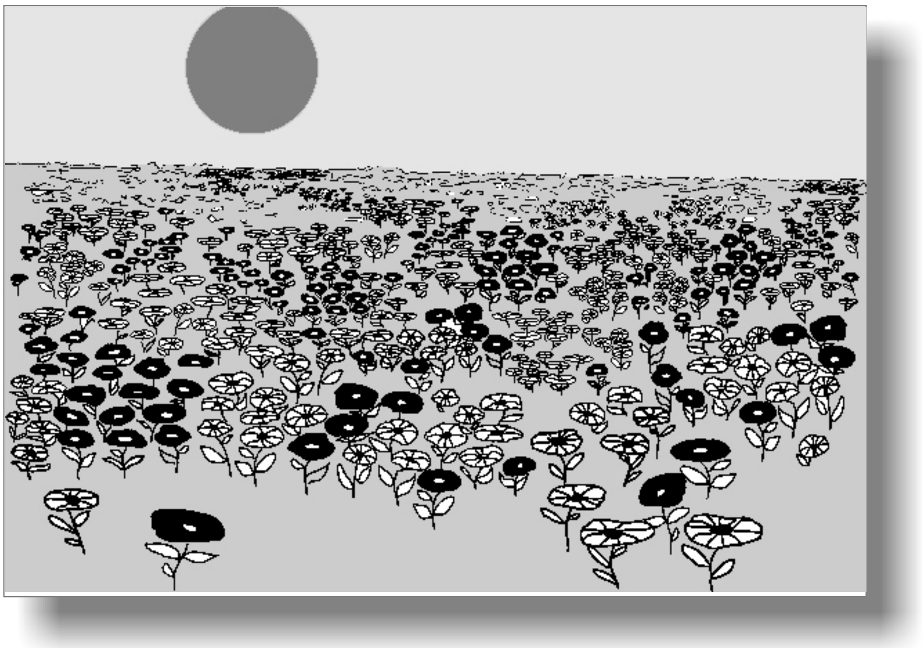
Bush damage caused by elephants

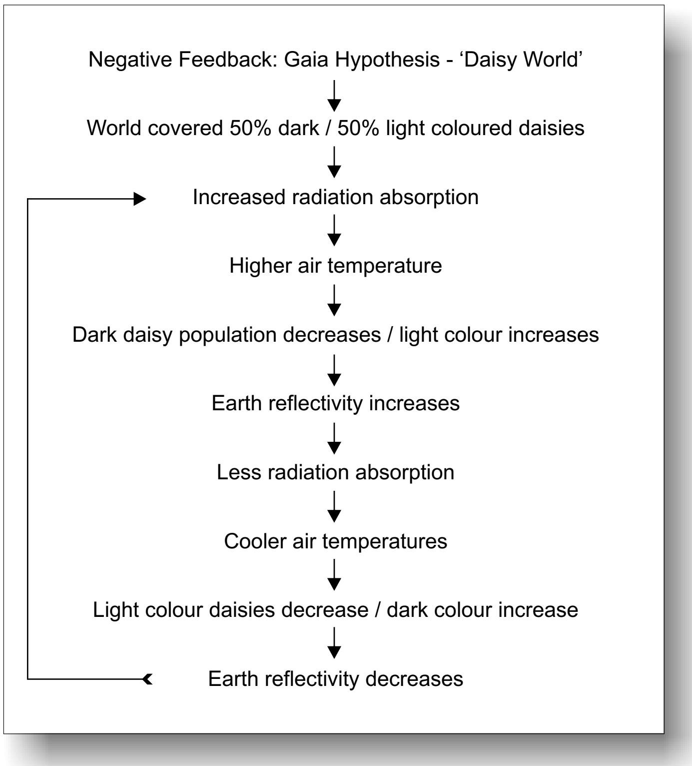
1. From what you know about feedback mechanisms, explain what will happen to the population numbers of different living things in this area.

ANSWERS ON PAGE 139

The relatively stable conditions in recent times (the last 20 million years is recent!) on Earth might be due to the **regulatory influence of the biosphere over the atmosphere** (you will have learned about this in Unit 4). According to this theory, if something causes environmental conditions to shift, activities of the biosphere bring them back into balance. A simple model called 'Daisy World' illustrates this. We know that more solar radiation has been reaching the earth through time, but the air temperature has not changed all that much. How can that be?

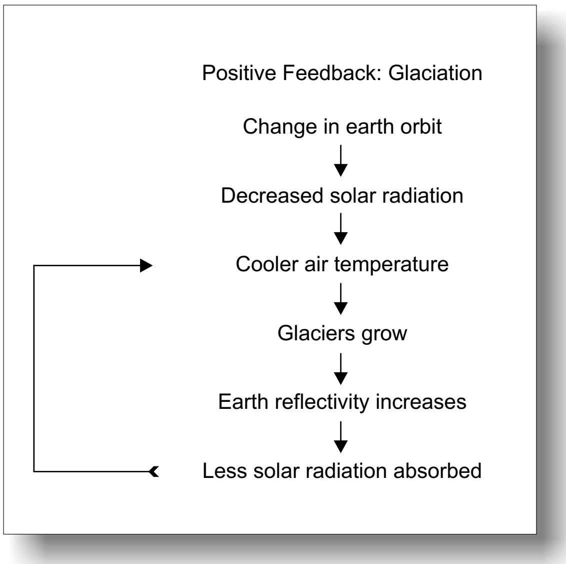
The Daisy World model shows how. Let us begin with a world that is covered with 50% dark and 50% light coloured daisies (for now we will not have any other plants, just light and dark daisies). The darker daisies absorb more sunshine than the light coloured daisies because of their colour. As energy from the Sun increases, the dark daisies absorb more of the Sun's energy, and eventually the energy gets too intense and they begin to die off. Meanwhile the light coloured daisies reflect more light and can thus endure higher temperatures, so the light coloured daisies flourish and they cover more of the land surface. The reflectivity of the surface thus increases, energy is reflected and the air temperature begins to go down again. If it gets too cold, the dark daisies begin to flourish, causing the cycle to begin again. These two scenarios represent negative feedback that causes the system to reach and maintain equilibrium.





Positive feedback mechanisms

An example of positive feedback is that of glaciation (the start of an ice age). You will learn more about ice ages in the next lesson. An ice age can be triggered by a reduction in the amount of solar radiation reaching the earth. This causes the air temperature to decrease. With colder temperatures more snow falls and less melts. The snow and ice are light in colour and are reflective. This means less solar radiation is absorbed and temperatures decrease further, glaciers grow, and more sunlight is reflected. This positive feedback mechanism is illustrated in the diagram.



The glaciation positive feedback mechanism

The opposite is also true. Once ice starts melting it exposes the darker surface underneath. This absorbs more solar energy and warms up, causing the ice to melt faster, and so on. This begins a cycle whereby the effect of a small rise in temperature can be amplified to have effects far beyond its actual scale.

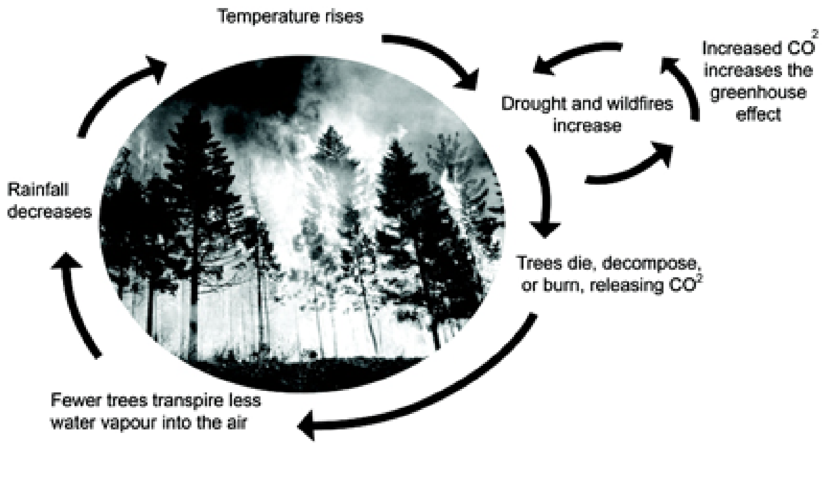
Feedback driving human-induced environmental changes

Recently, scientists have warned of positive feedback mechanisms that may drive the Earth system past safe limits towards a new state of equilibrium. In so doing, climates and ecosystems may be irreversibly altered and a new set of balances in the Earth system will develop. These may or may not suit human and many other life forms.

Feedback driving global climate change

Rising temperatures are expected to cause increased evaporation of water into the atmosphere, most of which will originate from oceans. The additional water vapour in the atmosphere increases air temperatures (water vapour is a greenhouse gas). This is a positive feedback. The increased warmth will, in turn, promote more evaporation, and so one condition reinforces another.

However, the addition of water may cause an increase in cloud cover, resulting in a higher atmospheric reflectivity, leading to cooling. This effect contradicts the positive feedback mentioned above and makes it difficult to determine what actually will occur in the future.



Removal of forests and land clearing

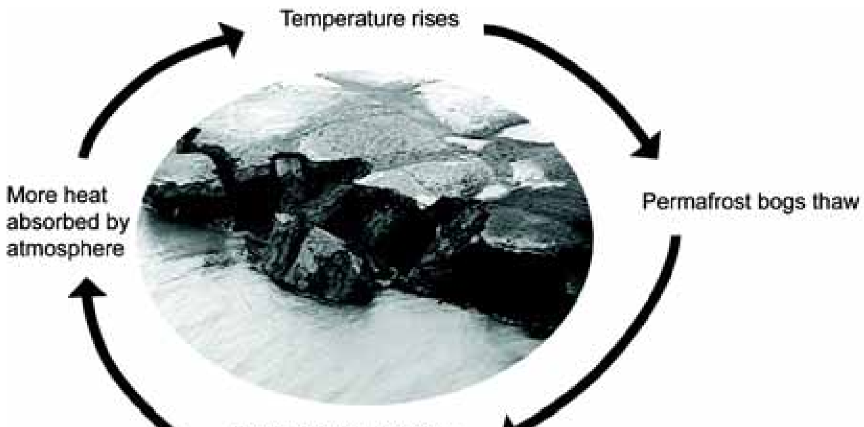
Throughout history, we have cut forests to build structures, warm our homes, cook our meals, and clear the land for agriculture. Removing forests and other soil cover does a number of things:

- soil is dark and absorbs more energy than forest and other vegetation cover
- vegetation is a good reservoir for Carbon (from CO_2)
- this leaves more CO_2 in the atmosphere, which is a greenhouse gas
- hotter temperature conditions may be too warm to support healthy forest ecosystems.

These are all positive feedback mechanisms that drive the Earth system toward warmer conditions.

Loss of permafrost

Permanently frozen ground called 'permafrost' lies beneath much of the land surface in the Arctic. The uppermost 'active layer' experiences seasonal thawing. Recent studies indicate that climatic warming may result in a 12 - 15% reduction in the area covered by permafrost and a 15 - 30% increase in the thickness of the active layer. As temperature rises permafrost melts, releasing stored Carbon, but just as importantly, Methane. Increased warming results in more permafrost melting. This is a positive feedback mechanism that is also driving the Earth system toward greater warming.



Tipping points and environmental change

Positive feedbacks can drive different components of the Earth system through a **tipping point** and past a **system boundary** towards new states. There are now several examples of Earth systems reaching or nearing a tipping point. A 'point of no return' is reached when unstoppable and irreversible change occurs. Each component of the Earth system has its own point at which irreversible change will occur. For example, the Greenland ice cap could disappear if global temperature rises by more than 2^0C above current temperatures, but for Arctic sea ice it is between 0.5^0C and 2^0C.

tipping point:
a point at which a change moves faster and becomes irreversible, leading to a new equilibrium level

system boundary: *a point in a system (e.g. a temperature, a chemical balance, a concentration of CO_2) beyond which that system will change irreversibly and go through a potentially chaotic period as it re-adjusts.*

Given the current amount of global warming, Arctic sea ice may have reached its tipping point. Once ice disappears, the reflectivity decreases as the sea or soil beneath is exposed, leading to greater absorption of energy and further temperature increases. This is a very dangerous tipping point.

What and where are the boundaries of the Earth System?

An international group of researchers looked at the idea of boundaries and proposed using a set of nine Earth System boundaries as a way of monitoring how safe the planet is for humans to live on. They call it a 'safe operating space for humanity'. This is based on scientific research that indicates that since the Industrial Revolution, human actions have gradually become the main driver of global environmental change. This means that we need to monitor what is happening to the planet so that we can take action where needed.

The scientists identified nine' planetary life support systems' essential for human survival that we need to monitor. Some of these systems' boundaries have already been crossed because of human activities, while others are close to being crossed. Beyond these boundaries there is a risk of 'irreversible and abrupt environmental change' which could make Earth less habitable. Estimates indicate that three of these boundaries climate change, biodiversity loss, and the biogeochemical flow appear already to have been crossed.

The nine boundaries

An Earth system boundary is that place or condition at which all it takes is a small change to produce a large, possibly catastrophic, change in the response variable (global warming).

A well-known example is Carbon Dioxide and its role in causing climate change. This table summarises how we are doing with this specific Earth system.

Earth-system process	Control variable	Boundary value	Current value	Boundary crossed	Pre-industrial value
Climate change	Atmospheric Carbon Dioxide	350 ppm	393 ppm	Yes	280 ppm

The table on the following page summaries all nine earth systems.

Earth-system process	Controlling variable	Boundary crossed?
1. Climate change	Atmospheric carbon dioxide concentration	yes
2. Biodiversity loss	Extinction rate of species	yes
3. Biogeochemical	Nitrogen removed from the atmosphere to make reactive chemicals and fertilisers	yes
	Phosphorus going into the oceans	no
4. Ocean acidification	Global mean saturation state of aragonite in surface seawater	no
5. Land use	Land surface converted to cropland	no
6. Freshwater	Global human use of water	no
7. Ozone depletion	Ozone concentration in the atmosphere	no
8. Atmospheric aerosols	Overall concentration of dust and other particles in the atmosphere	Not enough data yet
9. Chemical pollution	Concentration of toxic substances in the environment	Not enough data yet

ACTIVITY 4

1. Write down a simple definition of a ‘tipping point’.

2. Explain why the idea of tipping points is so important when we discuss the future of life on the planet.

3. Which of the Earth system processes have moved or are in danger of moving into positive feedback?

4. Make a list from this lesson or other sources of five human-induced environmental changes that are creating positive feedback mechanisms.

ANSWERS ON PAGE 140

Summary

In this lesson you learned about the Earth and how it operates as a system that has its own regulatory mechanisms. These serve to keep different factors such as temperature and chemical balances in the soil, atmosphere and water in equilibrium. We examined the different components and regulatory mechanisms in the Earth system. We also considered what might have occurred in recent times, as human activities have put additional pressure on some of these components of the system.

We also examined the concepts of boundaries and tipping points and asked questions whether human-induced environmental changes might have already pushed or might in the future push the Earth system beyond a tipping point so that it can no longer support life.

CHECKLIST

Are you able to:

- ❒ describe what a system is and how its components relate to each other
- ❒ describe the Earth system, its main components and some of its regulatory mechanisms
- ❒ explain the concept of equilibrium in Earth's different components and the Earth system as a whole
- ❒ describe and give examples of how Earth systems are regulated through different feedback mechanisms
- ❒ explain how human-induced changes are driving further changes through positive feedback mechanisms, and how these might represent tipping points for the planet

NOTES

LESSON 7

Climate Change

About this lesson

There has been a lot of concern and discussion recently about climate change. There have been unusual changes in our weather, and weather events have been more extreme than usual. Researchers have presented evidence that suggests that our climate is indeed changing rapidly.

This lesson examines climate changes on planet Earth, and we will find that climate has been changing all the time. We will look at the causes of climate changes and their consequences.

We conclude with a discussion around human-induced causes of climate change, extinctions, and whether we are heading for a major extinction period in the future.

In this lesson you will:

- describe how the Earth's climate has changed over time
- examine evidence for these changes
- identify possible causes of climate change
- explain the consequences of climate change

What is climate?

Climate can be defined as the average temperature and rainfall a region experiences, measured over a long time. Climate is different from weather. Weather is what you experience at a particular time. For example, it may be raining at the moment, but over a whole year the town you live in may receive very little rain. So the climate is dry, not wet.

The climate of a region is a result of interactions in the atmosphere, hydrosphere and lithosphere (See Lessons 1 and 2 in this Unit). Climate is also affected by where a region is on the planet.

ACTIVITY 1

Weather or climate?

Does this photo show weather or climate?

ANSWERS ON PAGE 141

1. Look at this picture.
   a. What kind of climate do people usually experience in a place like this?
   b. What sort of weather is being experienced in the picture?
   c. Write simple definitions of weather and climate.

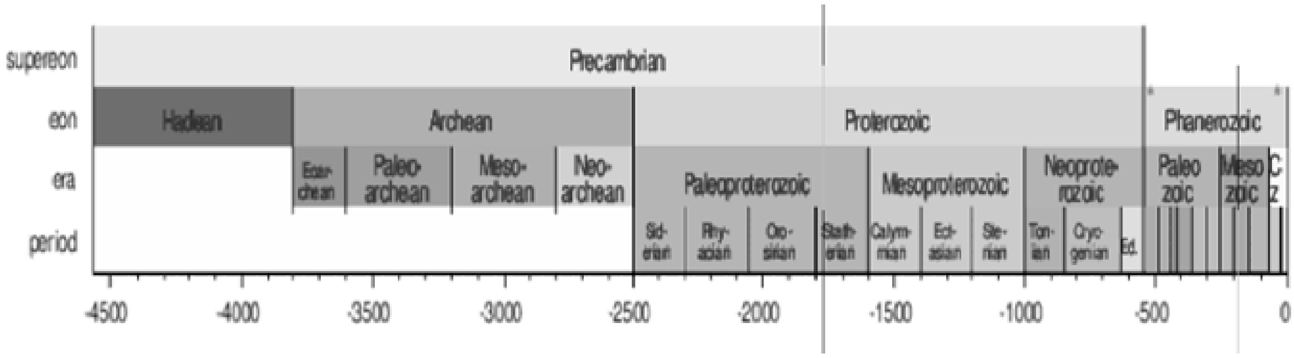
People have been recording data about weather in different places around the world for more than 100 years. This means we have a very good idea about the average rainfall and ranges in temperature. We can describe the climate for different regions of the Earth using this recorded data.

Based on this information, scientists are asking some very important questions.

- Has the climate on Earth as we know it today always been the same?
- Is the climate changing?
- Will future climates be different from what they are today?

To measure and identify special geological and climate events scientists have developed a timescale called the geological timescale. This was covered in detail in Unit 4, Lesson 3. It is important that you understand the geological timescale, so we will revise it in the next section.

The geological time scale revised



The geological timescale covering the 4,600 million years of Earth's existence

We are able to think about time in relation to our own scale of life and history. But the human timescale is like a few seconds compared to the length of time Earth has existed. We call Earth's timescale the **geological timescale**. We will refer to the geological timescale in the rest of this lesson, so here is a quick revision activity.

> ***geological timescale:*** *the time of Earth's existence over about 4.6 billion years (4,600 million years)*

ACTIVITY 2

1. Look closely at the geological timescale and then read the paragraph that follows and find what the text is referring to on the timescale.

2. Name all four eons.

3. Write down the names of the eras in the most recent eon.

ANSWERS ON PAGE 141

eons:
the second largest unit of time in the geological timescale, typically lasts around 600 to 2000 million years

eras:
the third largest unit of time in the geological timescale, typically lasts around 200 to 900 million years.

period:
the fourth largest unit of time in the geological timescale, typically lasts around 50 to 150 million years

epoch and age:
the fifth and sixth largest units of time in the geological timescale

glacial:
a cold period in Earth's history

interglacial:
a warmer period between glacials

The largest unit of the geological timescale is the supereon, but we will ignore that and start with the second largest one the **eon**. An eon lasts for half a billion (500 million) years or more. There are four eons on the geological timescale. Eons are divided into **eras**, which are in turn divided into **periods**, **epochs** and **ages**.

A history of climate change

Throughout much of its 4.6 billion year history, Earth's climate has alternated between periods of warmth and cold, each lasting for tens to hundreds of millions of years. During the warmest periods, the polar regions of the world were completely free of ice. During the cold times Earth experienced ice ages. These were periods lasting for millions of years during which ice sheets advanced and retreated many times over portions of the globe. During the most extreme cold phases, snow and ice covered the entire globe. We sometimes call this phase of Earth's history 'Snowball Earth'.

But there are no accurate measurements of temperature or rainfall that are older than 200 years. So how can we be so sure about Earth's climatic history so far back in time?

Information about the Earth's climate millions of years ago comes from a variety of different sources. Scientists have pieced together a picture of Earth's climate, dating back hundreds of thousands of years, by analyzing a number of indirect measures of climate such as ice cores, tree rings, glacier lengths, pollen remains, and ocean sediments, and by studying changes in Earth's orbit around the sun.

Earth's five main ice ages

There is evidence that there has been a cycle of climate change. These are referred to as the Ice Ages. Earth has known five main ice ages. Each ice age and its related climate changes, lasts for millions of years. Within each ice age there are periods when the global temperature decreases and water freezes to form ice. This is known as a **glacial** period. After some time, the global temperature increased. This is known as an **interglacial** period.

Tabulated on the next page are the names of each of the five main ice ages in the history of Earth, the time span of each ice age in Millions of years (Ma – short for mega–annum) and the names of each geological era and period in which the ice age took place. You will need to compare these era and period names and times with the geological timescale on page 89.

	Name of the Ice Age	Time span in Ma (Millions of years ago)	Name of the era	Name of the period
5th	Quaternary	258 - present	Cenozoic	Neogene
4th	Karoo – there were extensive glaciations during this ice age	360 - 260	Paleozoic	Carboniferous and Permian
3rd	Andean-Saharan	450 - 420	Paleozoic	Ordovician and Silurian
2nd	Cryogenian – this is believed to be the worst ice age	800 - 635	Neoproterozoic	Cryogenian
1st	Huronian	2400 - 2100	Paleoproterozoic	Siderian and Rhyacian

ACTIVITY 3

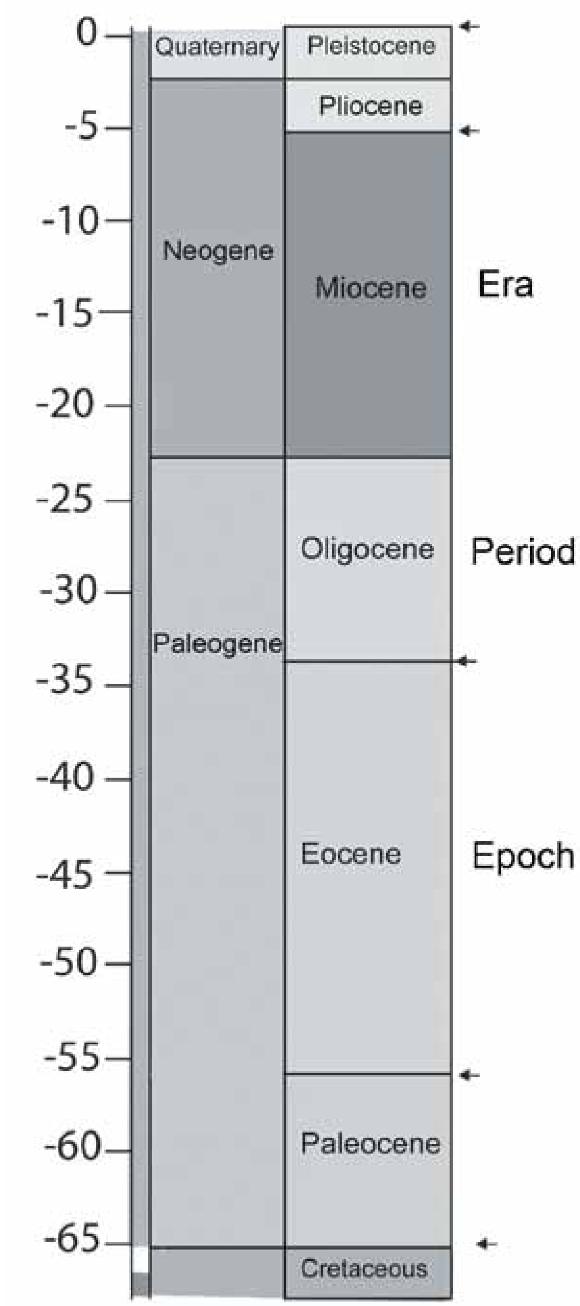
1. Use a pen or pencil to mark off on the geological timescale on page 89 the era and then the period in which each of the five ice ages occurred. You can also refer to Unit 4, Lesson 3 for information.

2. Look carefully at the section of the geological timescale on the right.
   a. Which era in the geological timescale does it show?
   b. Find this era on the geological timescale on page 89.

3. 65 million years ago something major happened. Find out, or read the first few pages of this Lesson or Unit 4 and work out what event marked the start of the Cenozoic Era. ANSWERS ON PAGE 141

The five major ice ages are usually named after places where evidence of these ice ages is clearest or where they were first discovered. Outside these ages, the Earth seems to have been ice-free even in high latitudes.

The Huronian Ice Age is based on evidence first collected near Lake Huron in North America, where three separate layers of glacial deposits covering a large area were found and studied.



The most recent 65 million years of the geological timescale

The Cryogenian Ice Age is named after the word Greek word *cryo* which means cold. This was the most severe ice age and was one time where 'Snowball Earth' occurred the entire planet was covered in snow and ice. The Andean-Saharan Ice Age is named from major erosion marks on underlying rocks that can be seen in many places, mainly the Andes in South America and the Sahara.

The Karoo Ice Age uses our own South African place name because of well-known glacial deposits in the Karoo Basin and other parts of the world when the continents were still joined together as part of Gondwanaland. In the Karoo those deposits formed rock now know as the Dwyka Tillite.

Finally, the Quaternary Ice Age is named after the Quaternary (meaning fourth) period, which followed the Tertiary (meaning third) Period. Although there are now new names for the first three periods, we still use the name Quaternary.

COMMENT

What is interesting about the Quaternary Ice Age is that scientists consider that it still continues today because at least one permanent large ice sheet – Antarctica – still exists and has existed continuously ever since the ice age began. We are living in an ice age!!

Glacials and interglacials

glacial periods:
colder periods in an ice age when snow and ice cover advance

interglacials:
warmer periods in an ice age (such as at present) when snow and ice cover retreat.

inter:
between

The current ice age (the Quaternary Ice Age) started about 2.58 million years ago when the spread of ice sheets in the Northern Hemisphere began. Since then there have been cycles of glaciation with ice sheets advancing and retreating. These happen over 40,000 to 100,000 year cycles. The colder periods are called **glacial periods** and the warmer periods **interglacials.**

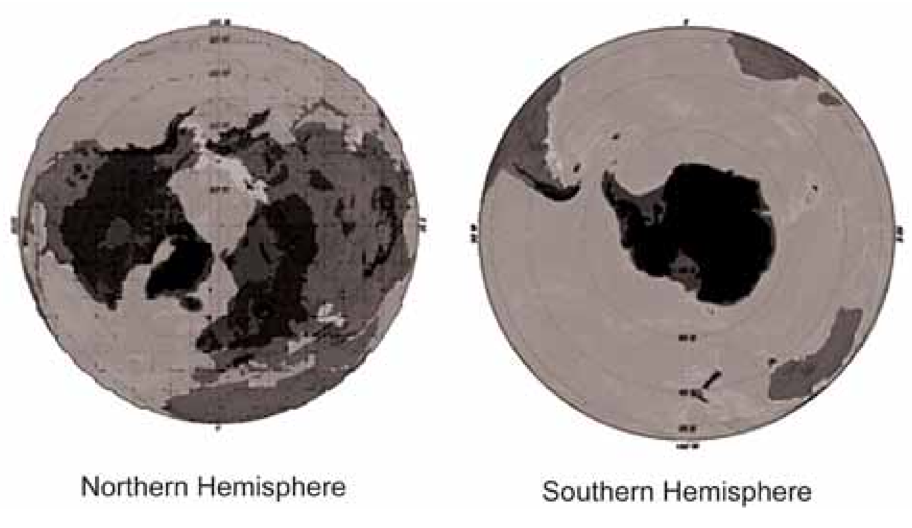
COMMENT

We are living in an inter-glacial period of the current ice age. Will the next glacial affect us? Will human activities delay it? Is there anything we can or should do about it?

The current ice age glacial maximum in the northern Hemisphere

The earth is currently in an interglacial. The last glacial period ended about 10,000 years ago. All that remains of the ice sheets of that time are the Greenland, the Antarctic ice sheets and various smaller glaciers.

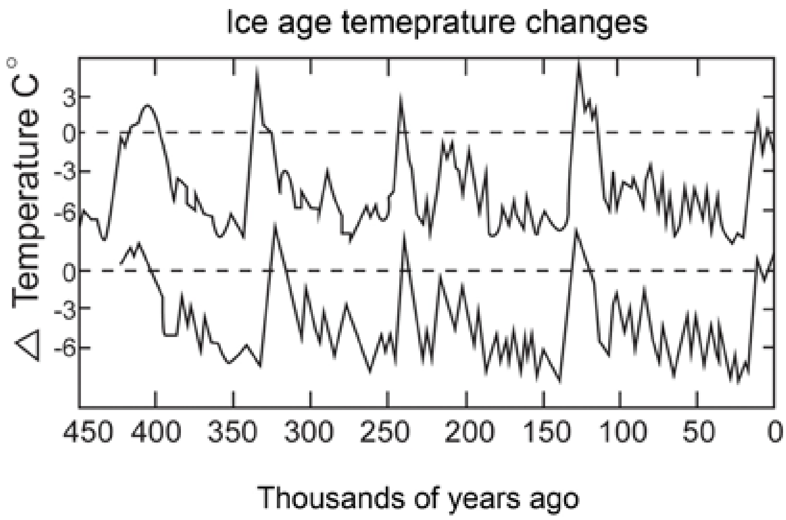
Glacials are characterized by cooler and drier climates over most of the Earth and large land and sea ice masses extending outward from the poles. Mountain glaciers spread down to lower levels.



Ice cover in the Quaternary Ice Age showing glacial and interglacial spreading and receding of ice

ACTIVITY 4

This graph shows changes in average world temperature in the last 450 000 years. The numbers on the left are not actual temperatures, but just changes up or down from a set middle point.



Patterns of glacials and interglacials over the last 450 000 years. These are based on ice cores drilled in Antarctica

1. In the last 450 000 years, what is the lowest drop in average temperature from the middle point (zero on the Y-axis?)

2. What is the highest rise from the middle point?

3. What is the largest range of temperature shown on these graphs?

4. What does this tell you about how much change in temperature would be needed to bring about major climate change?

ANSWERS ON PAGE 142

When will the next glacial happen?

The Earth has been in an interglacial period for more than 11,000 years. Although most interglacial periods last about 12,000 years, the present interglacial is likely to be much longer. Predictions for our interglacial have been about 28,000 years. But new predictions based on the shape of Earth's orbit around the Sun suggest that the current interglacial could last another 50,000 years.

There is another factor that is expected to influence the onset of the next glacial. This is the release of large amounts of carbon dioxide (CO_2) into the atmosphere by human activity. You learned about the role of CO_2 as a greenhouse gas in the previous lesson. New reports now suggest that future CO_2 emissions might be enough to delay the next glacial cycle for as long as 500 000 years. It seems as if human-induced climate change will play a significant role in when the next glacial will start.

Human-induced climate change

Up until now all the climate changes and ice ages we have seen since the beginning of Earth's history have been natural. Human-induced changes mainly occur because we are using fossil fuels very quickly and are changing the composition of the atmosphere rapidly. We are already approximately 2^0C warmer than we were before the Industrial Age. It is expected that human-induced climate change could cause a steady increase of average global temperatures beyond the existing 2^0C increase by another 3 or 4 degrees. Look at Activity 4 again and work out what a total of 5 or 6 degrees temperature increase in a few hundred years would do to this planet, and in particular life on the planet.

Climate change in the future

You will now realise that climate change is part of Earth's natural cycles and will continue as surely as it has happened in the past. So why are so many people concerned about climate change induced by the carbon dioxide we are releasing into the atmosphere? The reason is that the changes will cause major environmental destruction and suffering for human life in too short a time for us and nature to do much about it and adapt. You will learn more about this in the next section.

Causes of climate change

There are a few main factors that are responsible for most of the past episodes of climate change. These include:

- variations in the Earth's orbit.
- variations in solar output.
- volcanic eruptions
- atmospheric carbon dioxide variations.

Variations in Earth's orbit

Changes in the earth's orbit affect the amount of sunlight reaching earth's surface. There are three main factors that affect Earth's orbit:

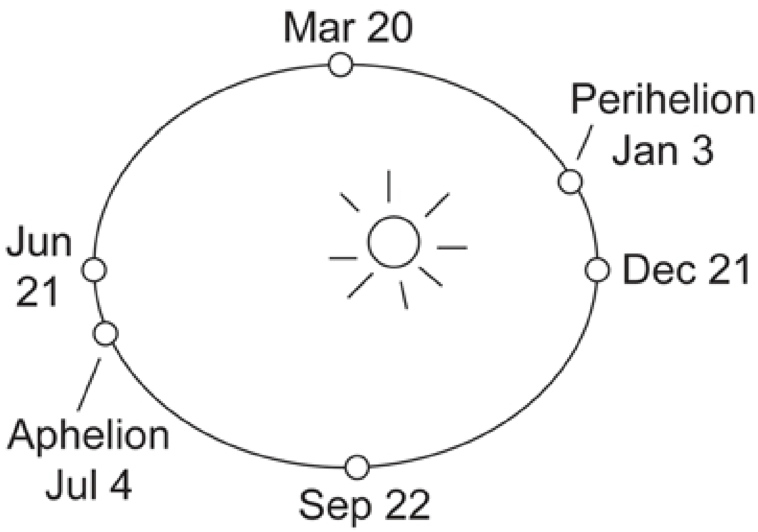
Shape of the orbit:

__elliptical:__
not circular, egg-shaped.

__aphelion:__
the point in Earth's orbit around the Sun when Earth is closest to the Sun.

__perihelion:__
the point in Earth's orbit around the Sun when Earth is furthest from the Sun.

Earth's orbit is not circular. It is egg shaped, or **elliptical**. So we are slightly closer to the Sun at some time during the year and slightly further away at another time in the year. The furthest point of Earth's orbit from the Sun is called the **aphelion**. This occurs around 4 July each year. The closest point in Earth's orbit to the Sun is called the **perihelion**. This occurs around 3 January each year.



Earth's orbit showing aphelion and perihelion and the dates of the equinoxes and solstices

When the difference in distance from the Sun between perihelion and aphelion is at its maximum the difference in solar energy received is about 20%. This can easily trigger a glacial or interglacial. But you also need to know that the orbit gradually changes from being elliptical to being nearly circular and then back to elliptical in a period of about 100,000 years. Earth's orbit is currently close to circular. This means that if this were the only driver of glacials, we would not be moving into a glacial any time soon. We might have to wait 50,000 years for that. But there are other drivers.

The wobbling Earth

The angle of Earth's rotation changes very slightly over the centuries. This causes the dates of the seasons to change. In the diagram on page 96, aphelion is close to June 21 (mid-summer/winter) and perihelion is close to December 21 (midwinter/summer). But because of Earth's rotational wobble, in about 13,000 years the opposite will be true and the Earth will be closer to the Sun (perihelion) in July. This means that our southern hemisphere summers will be cooler and our winters will be warmer. In the northern hemisphere they will have hotter summers and cooler winters. This could trigger another glacial in about 13,000 years' time.

Changing tilt of Earth's axis

During a 41,000 year cycle the tilt of Earth's axis can change from approximately 22.5° to 24.5°. It is presently 23.5°. A larger tilt causes less snow and ice to accumulate during winters, and more melts during summers. A lesser tilt allows more snow to build up in the high latitudes (the polar regions) and there is more extensive formation of glaciers. As we are moving towards a lesser tilt (22.5 degrees) this factor could take us into another glacial in about 20,000 years' time.

These three factors are presently not aligned or synchronised, so the next glacial might not happen in 13,000 years' time, or even in 20,000 years, or it might be weak. When the three Earth orbit factors line up, however, they are a powerful driver of glacials and climate change.

COMMENT

The person who discovered these Earth orbit cycles (called the Milankovitch Cycles) was called Milutin Milankovitch who was a Serbian geophysicist and astronomer. He worked on his theory while he was imprisoned during the First World War.

Variations in Solar Output

The sun is the source of energy for the Earth's climate system. So changes in the sun's energy output would cause the climate to change. Scientific studies demonstrate that solar variations have performed a role in past climate changes. For instance a decrease in solar activity was thought to have triggered the Little Ice Age between approximately 1650 and 1850, when Greenland was largely cut off by ice from 1410 to the 1720s and glaciers advanced in the Alps.

Measurements made during the early 1980s showed a decrease of 0.1 percent in the total amount of solar energy reaching the Earth over just an 18 month time period. If this trend were to extend over several decades, it could easily influence global climate change, leading to a cooler period.

Volcanic Eruptions

The main reason volcanoes cause a cooling is not the one most people think of – ash clouds blocking out sunlight. This is because ash falls back to the ground within a few weeks or months. The main reason volcanoes can cause climate change is because of the sulphur dioxide gas they release. This gas spreads across most of Earth's surface and lasts in the atmosphere for up to three years.

One of the coldest years in the last two centuries occurred the year following the Tambora volcanic eruption in 1815. Accounts of very cold weather were documented in the year following this eruption in a number of regions across the planet. Several other major volcanic events also show a pattern of cooler global temperatures lasting 1 to 3 years after their eruption.

Researchers believe that the Pinatubo eruption in the Philippines in June 1991 was the main cause of a 0.8 degree Celsius drop in global average air temperature in 1992, with a peak effect in late 1993. The satellite data indicated that the Sulphur Dioxide plume from the eruption caused an increase in the amount of sunlight reflected by the Earth's atmosphere back to space causing the surface of the planet to cool.

Other eruptions, like that of Mount Montserrat in the West Indies, have produced huge clouds of ash and dust and produced Sulphur Dioxide gas.

Ash column generated by the eruption of
Mount Montserrat between October 2009 and February 2010

Carbon Dioxide variations in the atmosphere

Studies of long term climate change have shown a connection between the concentration of Carbon Dioxide in the atmosphere and average global temperature. Carbon Dioxide is one of the more important gases responsible for the **greenhouse effect**. This was introduced in Lesson 6 and is described in more detail in Lesson 8. Certain atmospheric gases, like Carbon Dioxide, water vapour and Methane, are able to alter the energy balance of the Earth by keeping the planet warmer. We call this the greenhouse effect. Without the greenhouse effect, the average global temperature of the Earth would be a cold −18° Celsius rather than the present 15° Celsius.

greenhouse effect: *the effect of certain gases in the atmosphere that retain energy and prevent it from escaping into the atmosphere.*

Temperature variations over Earth's recent history have been closely linked to the concentration of carbon dioxide in the atmosphere. Carbon dioxide levels were about 30% lower during colder glacial periods.

The evolution of land plants during the Devonian period (see the geological timescale on page 89) is believed to have caused a long-term increase in planetary oxygen levels and reduction of CO_2 levels. This reduced the greenhouse effect and eventually resulted in the Karoo Ice Age.

In addition to the factors that are responsible for the past episodes of climate change, there are also human-induced causes of climate change.

ACTIVITY 5

ANSWERS ON PAGE 142

Analyse the four main causes of climate change described in this section. Rank them in order from most likely to cause the next phase of climate change to least likely and explain your reasoning.

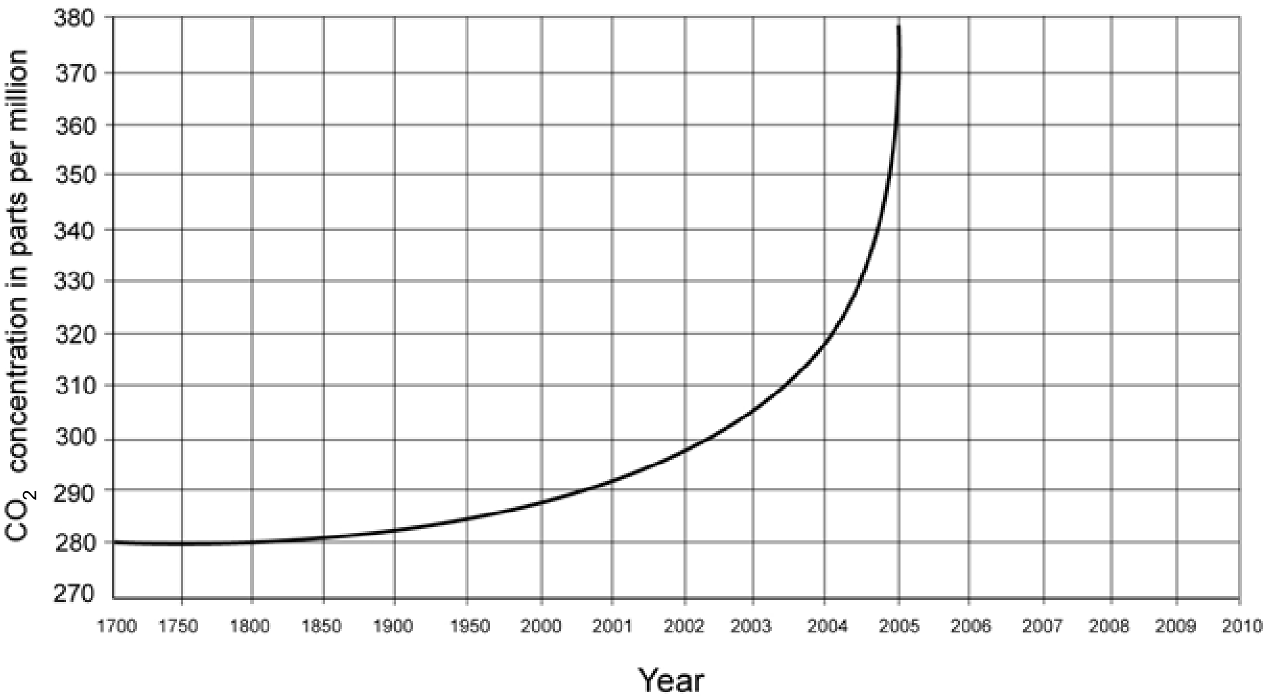
Human-induced causes of Climate Change

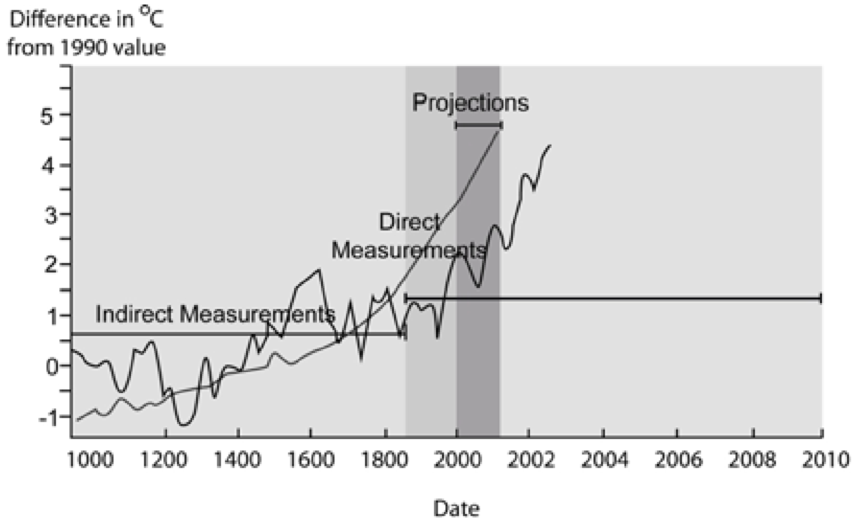
> ***extinctions:***
> *the end of an organism or of a group of organisms, normally a species*

Emission of greenhouse gases

Carbon Dioxide is the most important greenhouse gas in the atmosphere. Changes in land use pattern, deforestation, land clearing, agriculture, and other activities have all led to a rise in the emission of Carbon Dioxide. Methane is another important greenhouse gas in the atmosphere. It is released from animals such as dairy cows, goats, pigs, buffaloes, camels, horses and sheep. Methane is also emitted during the process of oil drilling, coal mining, leaking gas pipelines, landfills and waste dumps.

From the early 1700s, Carbon Dioxide has increased from 280 parts per million to 380 parts per million in 2005 (see graph below). Higher concentrations of Carbon Dioxide in the atmosphere will enhance the greenhouse effect making the planet warmer. Most computer climate models suggest that the globe will warm up by 1.5 - 4.5° Celsius if Carbon Dioxide reaches the predicted level of 600 parts per million by the year 2050.





Global climate change has caused changes in the habitats of some plants; extreme weather conditions; dramatic change of the polar caps; the shrinking of the Arctic ice cap and the melting of the Antarctic ice shelf.

Putting it all together

Earth orbital changes, solar output changes and carbon dioxide levels in the atmosphere are the most likely causes of the next phase of climate change. If all these factors occur simultaneously, would we be heading for a cataclysmic event?

ACTIVITY 6

1. Examine all of the data we have presented in this section.
   a. Predict whether global temperatures are likely to increase or decrease in the next tens of thousands of years. Explain your answer.
   b. Based on your understanding, do you think that global temperatures are likely to increase or decrease over the next 1000 years? Explain your answer.

ANSWERS ON PAGE 142

The biggest shifts are actually happening very fast. Human activity seems to be the most powerful driver of climate change. Are we likely to be the cause of possible major extinctions on Earth? The next section examines the five major extinctions we know about in Earth's history and a predicted sixth extinction.

Consequences of Climate Change

Changes in a climate often trigger other changes or 'feedbacks' in the climatic system. For example, heating or cooling of the earth's surface changes the greenhouse gas concentration in the atmosphere.

If the temperature of the Earth's surface increases, the Carbon Dioxide that is dissolved in the oceans will enter the atmosphere. This in turn will increase the temperature of the atmosphere.

nutrients:
a substance that an organism needs to live and grow

Changes in the ocean currents drive climatic change. Heating or cooling of the earth's surface causes changes in the currents. Currents play a significant role in distributing heat around the earth and so currents have a significant impact on local climate from region to region. The upwelling of the cold currents bring **nutrients** to the surface of the ocean, feeding fish and maintaining the eco-balance. If the currents are too warm, the climate is warm and the marine life is not fed.

Ice ages and the glacial and interglacial conditions associated with them are part of earth's climatic history. These have led to some of the major extinctions that have taken place. Given these concerns the future of our planet is far from secure. The next section looks at the major extinction events in Earth's history.

Major extinction events

Five mass extinctions have been identified, although there have been may other smaller extinctions.

Cretaceous Paleogene extinction event

The most recent extinction event is also the most famous and most extensively studied: the event that killed the dinosaurs about 65 million years ago. The trigger for this extinction was an asteroid that crashed into the planet, leaving a crater near the present-day Yucatan Peninsula of Mexico. Devastation at the site would have been massive, but it was the indirect, climatic effects of the impact that killed species across the globe.

Dust kicked up by the asteroid became trapped in the atmosphere, blocking and reflecting sunlight. As well as causing a dramatic, short-term cooling, the lack of sunlight reaching the Earth inhibited photosynthesis, so many plant species became extinct. This effect was carried up the food chain, as first herbivorous, then carnivorous, species became extinct. Dinosaurs, the dominant life form during the Cretaceous Period, completely died out, while insects, early mammals, and bird-like reptiles survived, as their small size and scavenging habits made it easier to find food.

Triassic Jurassic extinction event

This extinction took place about 205 million years ago. It is not entirely clear what caused it, but the most widely accepted cause is widespread volcanic eruptions associated with the breakup of Pangaea, mainly in the area where the Atlantic Ocean now is. The release of large amounts of lava would have released Carbon Dioxide or Sulphur Dioxide and other particles. This would have had a major impact on climate.

The event led to the extinction of about 23% of all families, 48% of all genera and 70% to 75% of all species. Most non-dinosaurian animals were eliminated, leaving the way clear for dinosaurs to begin to dominate the terrestrial environment.

Permian Triassic extinction event

The largest extinction in the Earth's history, the Permian-Triassic extinction, occurred about 250 million years ago, right before the time of the dinosaurs. Up to 95% of all species on Earth were killed in this event, and life in the oceans was particularly hard-hit. It took 100 million years for the remaining species to recover from this extinction, nicknamed 'The Great Dying', and we are fortunate that life recovered at all.

The trigger for this extinction is quite disturbing, given our current situation global warming from greenhouse gases. In the late Permian, a huge expanse of active volcanoes existed in what is now Siberia. Over the years, these volcanoes pumped out massive quantities of Carbon Dioxide, increasing the average temperature of the planet. However, as the warming continued, a positive feedback kicked in: ice and permafrost melted, releasing Methane that was previously frozen and trapped in the ice. Methane is a far stronger greenhouse gas than Carbon Dioxide. Consequently, the warming became much more severe.

Earth's largest extinction killed 57% of all families, 83% of all genera and 90% to 96% of all species, including insects.

The Permian-Triassic extinction is one reason why a warm planet tends to be less favourable to life than a cold one. An examination of 520 million years of data on fossils and temperature reconstructions found that high global temperatures correlated with low levels of biodiversity (the number of species on Earth) and high levels of extinction, while cooler periods enjoyed high biodiversity and low extinction.

anoxia:
a condition in which there is a total depletion of oxygen

When the temperature of the planet increases in a relatively short period of time, a condition known as **anoxia** can develop in the oceans. Anoxia means that there is a total depletion of oxygen in the water. This kills most living things in the water. This is why there is lower biodiversity during warm periods. As a result of this oxygen depletion, bacteria in the ocean begin to produce Hydrogen Sulphide (H_2S). That's what makes rotten eggs smell bad, and it's actually poisonous in large enough quantities. This is a possibility if we cause global warming. The next section deals with human-induced causes of climate change.

Late Devonian extinction

This event took place around 375360 million years ago over as long as 20 million years. This prolonged series of extinctions eliminated about 19% of all families, 50% of all genera and 70% of all species. The causes of these extinctions are unclear. Leading theories include changes in sea level and ocean anoxia, possibly triggered by global cooling or oceanic volcanism.

Ordovician Silurian extinction event

This event took place around 450440 million years ago. Two events occurred that killed off 27% of all families, 57% of all genera and 60% to 70% of all species. Together the two events that make up this extinction event are ranked as the second largest of the five major extinctions in Earth's history in terms of percentage of genera that went extinct.

The sixth extinction?

Not only is the climate changing, but it's changing in a way which could be the least favourable to life. We don't have volcanic activity anywhere near the scale of those that caused some of the five extinctions, but we have a source of carbon dioxide that could be just as devastating: ourselves. We could, however, prevent much of the coming damage if we wanted to, but political will is disturbingly low. How bad will it get? Only time, and our decisions, will tell. A significant number of the world's species will probably become extinct.

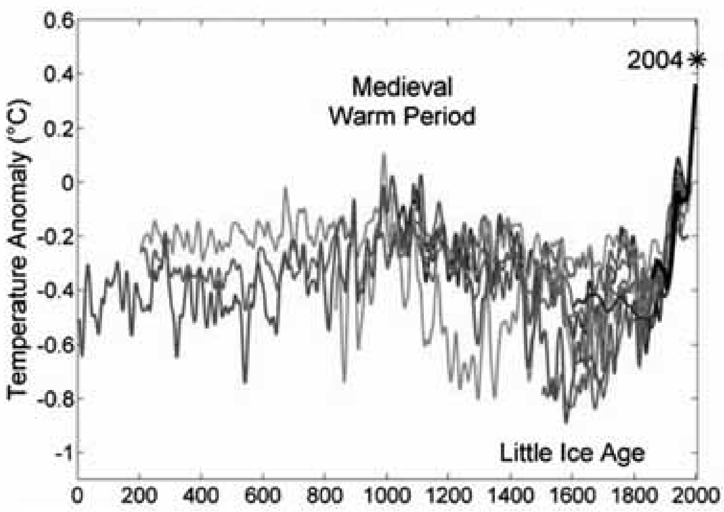
It's conceivable that we could cause anoxia in the oceans, if we are both irresponsible and unlucky – we are currently being irresponsible in the way we are producing so many greenhouse gases, mainly Carbon Dioxide, and if factors combine and result in positive feedback we will also be unlucky and experience major increases in global temperature.

It wouldn't be too hard to melt most of the world's ice, committing ourselves to an eventual sea level rise of tens of metres. These long-range consequences would take centuries to develop, so none of us has to worry about experiencing them. Instead, they would fall to those who come after us, our children, who would have had no part in causing – and failing to solve – the problem.

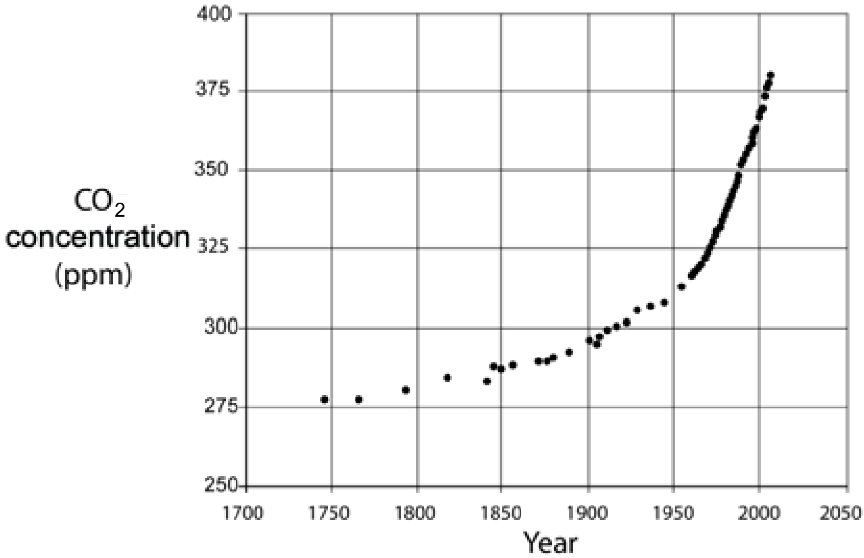
Species can adapt to gradual changes in their environment through evolution, but climate change often moves too quickly for them to do so. It's not the absolute temperature, then, but the rate of change that matters. Put simply, if climate change is large enough, quick enough, and on a global scale, it could be the perfect ingredient for a mass extinction. This is worrying, as we are currently at the cusp of a potentially devastating period of global warming, one that we are causing. Will our actions cause a mass extinction in the next few centuries? We can't tell the future of evolution, but we can look at the past for reference points.

ACTIVITY 7

Study the two graphs. You will notice a number of lines in the first graph that represent various reconstructed temperatures. Try to see the average through the graph.



Reconstructed Temperature



Atmospheric concentration of carbon dioxide (1744 - 2005)

1. From what you have discovered in this lesson and using these graphs:
   a. When did global temperatures start rising during the last 2000 years?
   b. What is the main cause or causes of that temperature rise?
   c. Which major 'advance' in human civilisation has led us to talk about a possible sixth extinction?
   d. Why did we use quotation marks around the word 'advance' in the previous question? Are we being too critical?
   e. What needs to be done about climate change in the human timescale? Explain.
   f. Is climate change something to worry about in the geological timescale? Explain.

ANSWERS ON PAGE 142

Summary

In this lesson we have covered the main episodes of climate change in Earth's history. In order to understand where things fit into that history you first learned about the geological timescale. We looked at the causes of climate change, including human-induced causes, and some of the consequences of climate change. The major consequence that we examined was extinctions, of which there have been five major ones, and then we asked questions about the possibility of a sixth extinction, and whether human activity might be responsible for that.

CHECKLIST

Are you able to:

- ❐ describe the geological timescale and explain its different components
- ❐ identify and explain the main causes of climate change
- ❐ describe the main periods of climate, with reference to the five ice ages
- ❐ discuss human-induced causes of climate change and place that in the context of the geological timescale

NOTES

The enhanced greenhouse effect

About this lesson

In this lesson you will learn more about the greenhouse effect and how human-induced increases in Carbon Dioxide levels in the atmosphere have enhanced this effect. The focus is on human-induced changes in particular during the last century. We examine observed climate changes during the last century and draw the conclusion that climate change due to human activity is happening and that it is likely to continue into the future. As a result we also look at the consequences, both environmental and social, of such changes and what can be done to reduce or moderate this impact and how societies might adapt to what is coming.

In this lesson you will:

- learn what causes the greenhouse effect and how it works
- see how human activity has enhanced Earth's greenhouse effect
- observe how the enhanced greenhouse effect has brought about changes in climate in recent times
- learn how climate changes are likely to continue into the future, with possibly severe consequences for the environment and for people
- learn what mitigation and adaptation means and some examples of mitigation and adaptation measures that are being taken and can be taken.

The greenhouse effect

You will read in the news every now and again that a child had to be rescued from a locked car suffering from dehydration or even heat stroke while the owner went shopping. Often, this can happen in a short space of time – 30 minutes in a car parked in the sun can be enough. This is incredibly negligent and can kill the child. How can this be? Apart from massive stupidity and even criminality on the part of the person who leaves a child like that, the mechanism for how the car gets hot so quickly is called the greenhouse effect.

A greenhouse

The greenhouse in this photo is from a cold climate. It allows people to grow vegetables and flowers even when it is cold outside. It works by allowing energy from the sun to enter the greenhouse, but not to escape. A greenhouse, like a car, has a high surface area of glass. This allows lots of solar energy to enter.

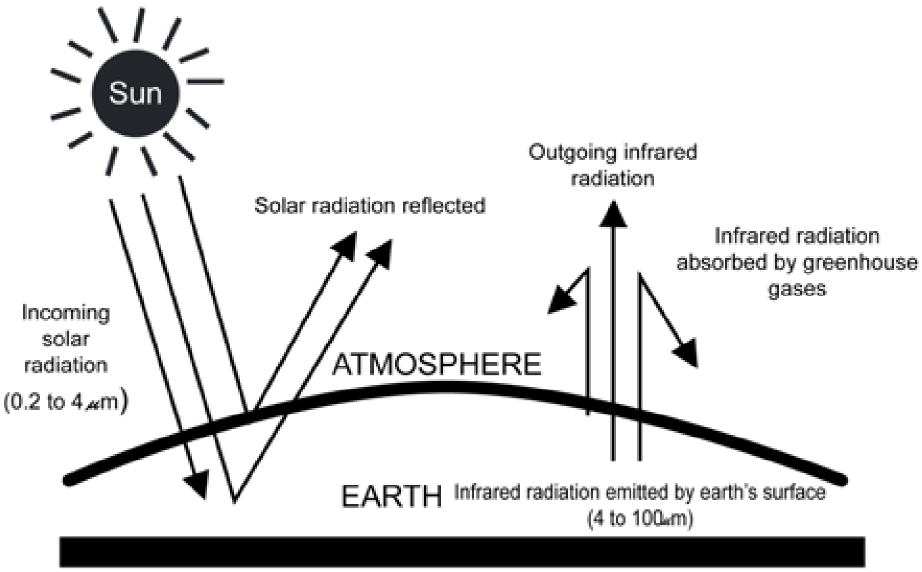
micrometre: *one-millionth of a metre*

Solar radiation is shortwave radiation. Shortwave radiation has wavelengths from about 0.2 **micrometres** to about 4.0 micrometres. Because solar radiation has a short wavelength and high energy radiation, it can easily pass through glass. When it gets inside the greenhouse, it heats up the objects and the air inside. The important point is that the heat energy that radiates away from the objects inside the greenhouse is longwave radiation, from about 4.0 micrometres to about 100 micrometres.

Longwave radiation cannot easily pass through glass because it is low energy radiation, so it remains inside the greenhouse. This is how it works in a car parked in a car park and also why planet Earth is relatively warm, with an average temperature of 15 degrees Celcius.

Earth's greenhouse effect

The greenhouse effect refers to the short wavelengths of visible light from the sun that pass through the atmosphere and are absorbed, but the longer wavelengths of the re-radiation from the heated surface are not all able to pass out again. The atmosphere is like the glass of the car and the greenhouse. The trapping of the long wavelength radiation leads to heating of the atmosphere. The greenhouse effect is a natural feature that has been enhanced, in recent centuries, by human-induced increases in the concentration of carbon dioxide in the atmosphere.



Simplified diagram illustrating the greenhouse effect

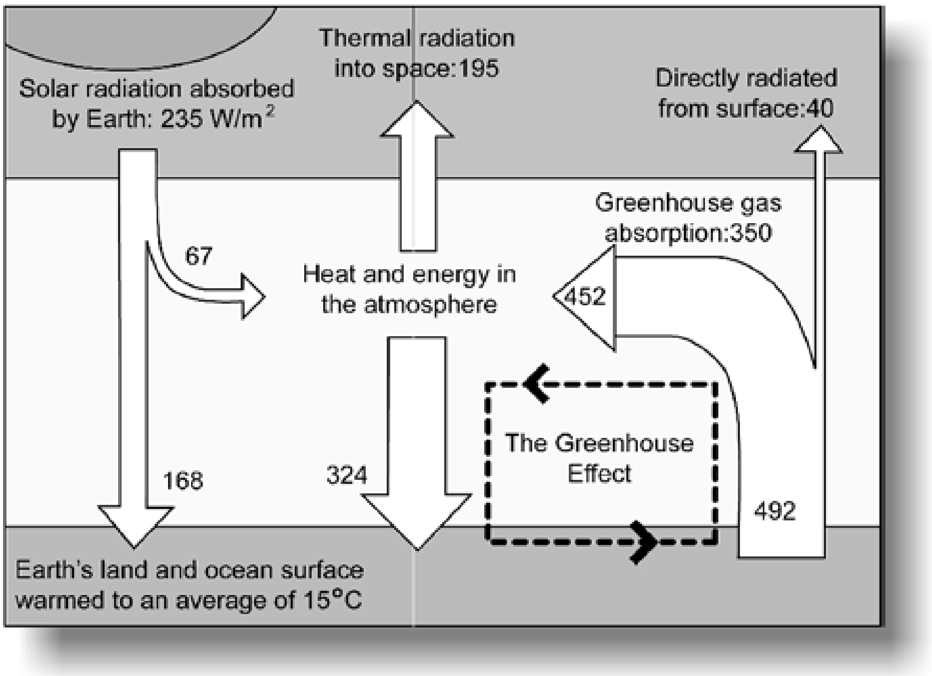
COMMENT

In the early days of Venus, which is much closer to the Sun than we are, the water on the planet heated up and released water vapour into the atmosphere. This caused a greenhouse effect that heated the oceans further until they all evaporated. This process is called a runaway greenhouse effect. Venus still has a strong greenhouse effect due to the dense carbon dioxide in its atmosphere.

Earth's energy budget

Earth's energy budget is a bit like your own financial budget. If you spend all the money you earn, you will have no money left. In your budget you would have the same amount in the income column as in the expenditure column. The important thing is what you are doing with that money while you have it. If you give it all away, there will be no benefit to you. If you invest some, and buy quality things with the rest, then that money is working well for you. The same is true with energy reaching Earth – if all energy from the sun were re-radiated immediately, Earth would be extremely cold. Even though there is, eventually, the same amount of energy arriving as leaving, it's what happens with that energy while it is here that is important. And it is why we have an average temperature of 15°C.

This diagram shows how the incoming energy is used, or where it goes. The units are watts per square metre.



Earth's energy budget

ACTIVITY 1

1. In what way is the thermal mechanism of a car parked in the sun similar to the thermal mechanism of planet Earth?

2. Explain how the greenhouse effect works.

3. Examine the thermal budget diagram on the previous page. Find all of the values of incoming radiation and all the outgoing values. Show the calculations to demonstrate that the budget is balanced.

4. What would be the result if the thermal budget was not balanced?

5. Explain how the simple feedback mechanism that keeps the thermal budget balanced works.

ANSWERS ON PAGE 143

Effects of human activity on carbon dioxide in the atmosphere

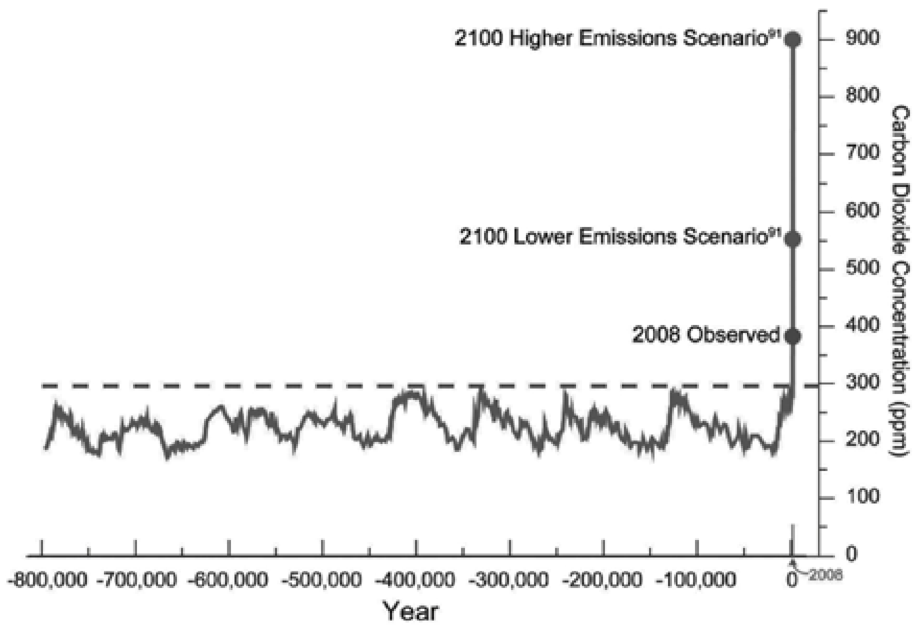
The Earth's climate depends on the functioning of greenhouse gases in the atmosphere. Carbon Dioxide and Methane are two of the most important greenhouse gases. Without this natural greenhouse effect, the average surface temperature of the Earth would be about 15°C colder. However, human activities since the Industrial Revolution have been releasing additional greenhouse gases, intensifying the natural greenhouse effect, thereby changing the Earth's climate.

Human activities have increased the levels of atmospheric Carbon Dioxide. The smoke you see is air pollution, not necessarily a greenhouse gas, but it shows combustion of something and therefore release of Carbon Dioxide is taking place.

The increase in the Carbon Dioxide concentration has been the principal factor causing warming over the past 50 years. Its concentration has been building up in the Earth's atmosphere since the beginning of the industrial era in the mid-1700s, primarily due to the burning of fossil fuels (coal, oil, and natural gas) and the clearing of forests. Human activities have also increased the emissions of other greenhouse gases, such as Methane and Nitrous Oxide. These emissions are thickening the blanket of heat-trapping gases in Earth's atmosphere, causing surface temperatures to rise.

Carbon Dioxide concentration has increased because of the use of fossil fuels in electricity generation, transportation, and industrial and household applications. It is also produced as a by-product during the manufacturing of cement and other products. In addition, deforestation provides a source of Carbon Dioxide by reducing its uptake by trees and other plants. Globally, over the past several decades, about 80 percent of human-induced Carbon Dioxide emissions came from the burning of fossil fuels, while about 20 percent resulted from deforestation and associated agricultural practices. The concentration of Carbon Dioxide in the atmosphere has increased by roughly 35 percent since the start of the industrial revolution.

This graph provides information for the last 800 000 years. Of course, this includes the last century, but the detail of that short time cannot be shown on this graph. We will examine the last century further on.



The graph on the previous page shows an analysis of Carbon Dioxide levels in the atmosphere using evidence of bubbles trapped in ice cores in Antarctic ice. It shows that until recently, Carbon Dioxide levels fluctuated between about 170 ppm and 300 ppm (parts per million). These fluctuations were kept in dynamic equilibrium by various negative feedback mechanisms (see Lesson 6). Since the Industrial Revolution human activities have caused a rapid increase in CO_2 levels to around 393 ppm at the end of 2011. This is approximately 30% higher than its highest level over the last 800,000 years, and it has taken place in about 250 years (or 0.03% of that time).

The two points marked 2100 Higher Emissions Scenario and 2100 Lower Emissions Scenario are estimates by the Intergovernmental Panel on Climate Change (IPCC) of where CO_2 levels might be in 2100 if we do nothing and allow high levels of CO_2 emissions, or do something positive and reduce the levels.

ACTIVITY 2

1. What are the projected CO_2 levels in 2100 according to the two scenarios?

2. Compare these with figures provided for the last 800 000 years.

3. The last 800 000 years include an interglacial (a warm period). What do the 2100 projections say about possible climate change?

4. Explain how human activities and greenhouse gases have a role to play in the above.

ANSWERS ON PAGE 144

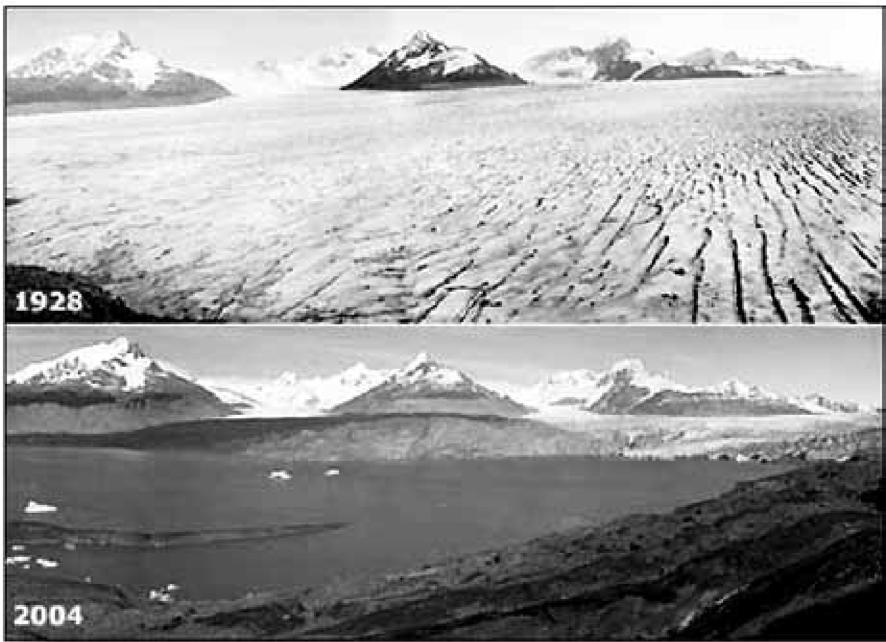
Observed climate change in the last century

In the last century many major climate changes have been observed. In many cases it is not possible to say that they are part of climate change, or just random events. However, when the bigger pattern is observed, and all the events and changes are put together, a compelling picture begins to emerge. Members of the scientific community are in no doubt that human-induced climate change is happening, that it is happening fast, and that it poses major challenges to the planet and to the human race.

The IPCC published a report called Climate Change 2001: The Scientific Basis. In addition, the U.S. National Research Council (NRC) issued a report on Climate Change Science: An Analysis of Some Key Questions. These two reports include a summary of observed or measured changes in climate during the last century and in particular, towards the end of that century. Some of these include:

Temperature

- Surface temperature data for Earth as a whole, including readings over both land and ocean, show an increase of about 0.8°C over the period 1901–2010 and about 0.5°C over the period 19792010 (the era for which satellite-based temperature data are routinely available).
- All of the 10 warmest years in the global temperature records up to 2011 have occurred since 1997. The year 2010 was globally the warmest since records began in the late 1800s, with 19 countries setting new national temperature highs. Five of these were Arab countries, including Kuwait, which set a new record at 52.6 Celsius in 2010, only to be followed by 53.5 Celsius in 2011.
- The effects of warming are especially evident in the planet's polar regions. Arctic sea ice extent and volume have been decreasing for the past several decades. Both the Greenland and Antarctic ice sheets have lost significant amounts of ice. Most of the world's glaciers are in retreat.



Uppsala Glacier 76 years apart in time showing major ice retreat and the formation of a glacier lake where thick ice used to be. Notice how far back the front edge of the glacier now is.

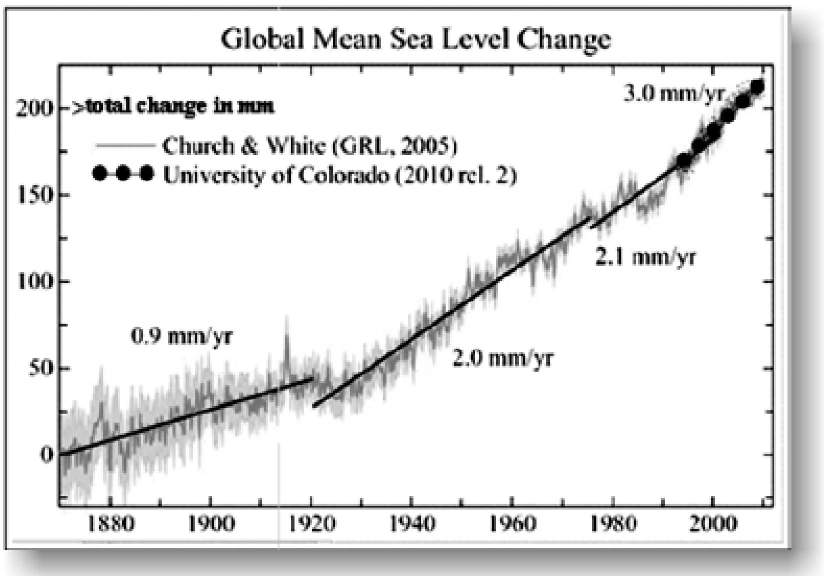
- The decade of the 1990s was very likely the warmest decade in the instrumental record (measurement using instruments), which dates back to 1861.
- On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2°C per decade. This has lengthened the freeze-free season in many mid- and high latitude regions.

Precipitation

- Precipitation has increased by between 0.5 to 1.0% per decade in the 20th century over most mid- and high latitudes of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2 to 0.3% per decade over the tropical land areas.
- It is also likely that rainfall has decreased by about 0.3% per decade over much of the northern subtropical zone (10°N to 30°N) land areas during the 20th century.
- The amount of rain falling in very heavy precipitation events (the heaviest 1% of all precipitation events) has increased over the last 50 years in many parts of the world.
- Rainfall in the drier parts of the world has become less predictable, with longer drought periods.

Sea level

- Global sea level has risen by about 17 cm over the past 100 years, and much of the increase is thought to be related to the rising global average temperature, with the rise accelerating since the early 1990s.
- Close to half of the sea level rise observed since the 1970s has been caused by water expansion due to increases in ocean temperatures. Sea level is also rising due to melting from continental glaciers and from ice sheets on both Greenland and Antarctica.



- Even small rises in sea level in coastal zones are expected to lead to potentially severe impacts, especially in small island nations and in other regions that experience storm surges associated with vigorous weather systems.

Melting of ice

- Freezing levels are rising in elevation, with rain occurring more frequently instead of snow at mid-elevations of mountains.
- Spring maximum snowpack is decreasing, snowmelt occurs earlier, and the spring runoff that supplies streamflow below snowy mountains is reduced in most mountainous regions of the world.

Seasonal changes

- Seasonal changes across many areas are being observed, including earlier springs, longer frost-free periods, longer growing seasons, and shifts in natural habitats and in migratory patterns of birds and insects.

ACTIVITY 3

1. Some people do not believe that human-induced climate change is real. They believe that all of the evidence can be explained differently. If you were such a person and you saw the photos of the Uppsala glacier from 1928 and 2004, what explanation might you give for the changes in the photos?

2. If you had to argue against your position in question 1, what might you say to convince someone that climate change is, indeed, real and worrying?

3. The global mean sea level change graph shows four separate lines between 1880 and 2010. Why was the graph presented in this way? What is the main point being made?

4. Read through the observed changes outlined above. Make a list of four different ways in which the ability to live sustainably, with minimal social disruption, and with decent food security, might be threatened by these changes in the future. Give examples where possible.

ANSWERS ON PAGE 144

Consequences of climate change (social and environmental)

There seems to be little doubt that rapid human-induced climate change is happening. From the previous lesson you would also know that a number of climate-related environmental processes may be reaching tipping points. There is also little doubt that climate change will continue into the future, certainly during our lifetimes and very likely beyond.

This raises the question of what the consequences of these changes are. There are environmental consequences, and because we are not separated from nature, there are serious social consequences as well.

This section continues in a similar way to the previous section by presenting a list of predicted changes and their impacts, this time with a specific focus on South Africa.

Predicted changes and consequences of climate change in South Africa

Warming

- South Africa's coastal regions will warm by around 1-2°C by about 2050 and around 3-4°C by about 2100
- South Africa's interior regions will warm by around 3-4°C by about 2050 and around 6-7°C by about 2100

Rainfall and water availability

- There will be significant changes in rainfall patterns and this, coupled with increased evaporation, will result in significant changes in water availability, for example, the drier western side of the country is likely to experience significant reductions in the flow of streams
- The moister eastern part of South Africa can expect more severe rainfall events with greater potential of flooding.
- Alien invasive plant species are likely to spread more and have an ever-increasing negative impact on water resources.

Biodiversity

- Our biodiversity will be severely impacted, especially the grasslands, fynbos and succulent Karoo where a high level of extinctions are predicted.

Farming and food security

- Small-scale and homestead farmers in dry lands are most vulnerable to climate change. Although those who follow intensive irrigated agriculture are better off than these farmers, they remain vulnerable to reductions in available water.
- Some predictions suggest that maize production in summer rainfall areas and fruit and cereal production in winter rainfall areas may be badly affected.

Climate change can cause increased crop failure and reduced food security

Health

- Because of our already poor health profile, South Africans are specifically vulnerable to new or exacerbated health threats resulting from climate change. Some health effects of climate change may already be occurring due to rainfall (drought and flood) and temperature extremes. For example, cholera outbreaks have been associated with extreme weather events, especially in poor, high density settlements, malaria might spread down the warmer and possibly wetter east coast, and tropical diseases might emerge here for the first time.

Extreme weather events

- There will be an increase in the frequency and severity of extreme weather events. Damage costs due to extreme weather-related events (flooding, fire, storms and drought) have already been conservatively estimated at being roughly 1 billion rand per year between 2000 and 2009.

Vulnerability to climate change

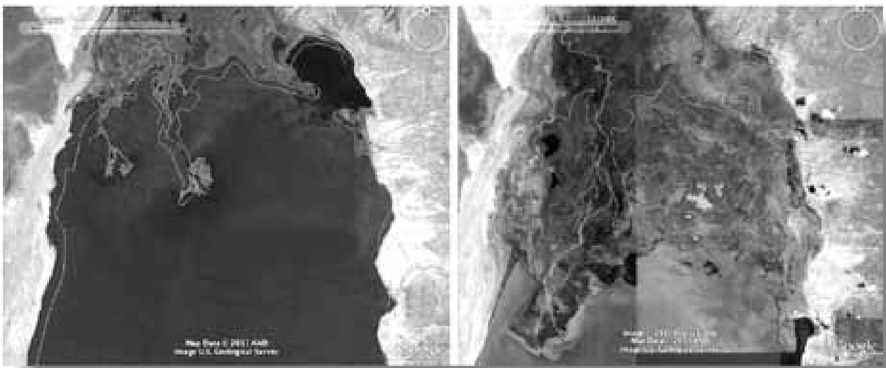
South Africa is particularly vulnerable to climate change because, among others

- a large proportion of our population has low resilience to extreme climate events (poverty; high disease burden;
- inadequate housing infrastructure and location)
- much of South Africa already has low and variable rainfall
- a significant proportion of our surface water resources are already fully allocated
- agriculture and fisheries are important for food security and local livelihoods
- although the poor are only minor contributors to climate change, they are the most vulnerable and will therefore be affected most adversely.

A short story – Climate change will be your problem when you can't eat

As I sat through the discussion discussing the statistical probability of halving poverty by 2015, all I saw were the faces of the starving women I met in the communities of Lake Turkana in northern Kenya. These were once vibrant communities abuzz with laughter and communal activity. Lake Turkana was the oasis of life, providing bountiful fish to feed the community. The grasslands provided ample grazing land. Now I stand on cracked earth and stare at the arid desert around me. The land is barren. The simmering blue shoreline has receded. The salinity of this gigantic inland sea has worsened. The fish have begun to die as the temperature increases. The conflicts have increased thanks to competition for scarce grazing lands. People wait in the blistering heat for relief to be brought in. They live a hair's breadth away from starvation, saved only by the monthly supply of basics donated by an NGO.

Jay Naidoo



Lake Turkana in 1973 and in 2005

ACTIVITY 4

1. From what you have learned about the evidence for climate change, how seriously do you think we should take the predictions listed in this section? Give reasons why.

2. From the above information try to work out what the main changes might be where you live.

3. Which single impact of climate change do you think will pose the greatest challenge to South Africa in the future? Give reasons and examples.

ANSWERS ON PAGE 145

Implications and limiting the damage

So, climate change is likely to bring about major environmental and social change and disruption. We still have a choice about how severe that will be, but it is now almost unavoidable. The question is what do we do about it? Can we prepare ourselves for future change? Can we find new ways of doing things that help us cope?

Mitigation and adaptation

> ***mitigation:***
> *to moderate or reduce the effect or force of something*
> *adaptation: the process of altering or adjusting to the conditions or circumstances around you*

There are two main ways that we can prepare ourselves. One is **mitigation**. We can reduce the amount of Carbon Dioxide entering the atmosphere and reduce the extent of the warming. Most mitigation measures are focussed on reducing levels of atmospheric Carbon Dioxide through reducing use of fossil fuels.

The second thing we can do is adapt. For example, instead of growing maize in areas that are likely to become drier we can find other crops like sorghum or even develop new varieties that are more able to cope with dry conditions. We can also do things like building ocean walls to protect coastal developments, or alternately, create 'no build' zones close to the sea. We will likely lose what is there already, but at least we can mitigate the effects of rising sea levels by not putting things where the sea might rise to.

Other examples of adaptation measures include using scarce water resources more efficiently, adapting building codes to future climate conditions and extreme weather events so buildings are safer and can be heated and cooled naturally, building flood defences and raising the levels of dykes, choosing tree species and forestry practices less vulnerable to storms and fires, and setting aside land corridors to help species migrate. A major adaptation challenge lies in the area of **food security**. If biological systems are disrupted, and if our normal crops cannot easily be grown, then we will likely face serious food shortages.

food security: *when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life*

The difficulty is that while variations in climate have been a normal experience, the speed with which climate is now changing will, in many cases, make it difficult to cope and adapt. Wealthy countries might be able to afford the huge effort required to adapt, but poor countries will not. So even though climate change affects everyone, it is the poor who are least able to adapt, and as the climate becomes ever more extreme, so will its impact on people's livelihoods and wellbeing.

Local responses to rising water levels. Using water hyacinth to build floating platforms for food gardens

Adaptation in a poor country

Rising sea levels are increasing the risks in Bangladesh. In response, the country is busy building and strengthening its 13,000-kilometre network of embankments, planting salt-resilient crops and storing fresh water. One project, supported by the United Nations Development Programme, taught 18,000 households in coastal communities to plant mangroves and fruit trees and to harvest rainwater by digging ditches. The project aims to provide fresh water and income as well as to protect against flooding and erosion.

In 2005, the country became one of the first to complete a national adaptation programme of action, and it later established a climate-change trust fund for financing local, small-scale projects in adaptation and mitigation. Although Bangladesh's per capita income ranks the nation among the world's poorest, the country has mounted such a strong response to climate change that it has become something of a model for other nations.

Research to help us adapt

At an international and national level it is important to carry out research so we better understand how we can mitigate the effects of climate change and adapt to the coming challenges. One example is from the Global Adaptation Institute (GAIN), which is developing an index for countries to assess their vulnerability to climate change and other global challenges. This Climate Change Vulnerability Index quantifies the vulnerability of 233 countries to three major effects of climate change:

- weather-related disasters
- sea-level rise
- reduced agricultural productivity.

The Index develops risk indicators for these impacts and has prepared a methodology for cost-effective allocation of resources to assist vulnerable countries in their adaptation efforts.

In addition to being aware of such high-level research, we also need to understand local impacts, and how people can adapt to changing conditions that will cause significant social and community pressures. This story provides an example.

A story from Alaska

Local Alaskan people in the Yukon River Basin took part in community research to understand climate change and its impacts and to help develop adaptation strategies for these local communities.

People here expressed concerns ranging from safety, such as unpredictable weather patterns and dangerous ice conditions, to changes in plants and animals and decreased availability of firewood. This study helps address that uncertainty and provides a deeper understanding of climate change as a socioeconomic issue by talking directly to those with traditional and personal environmental knowledge. This knowledge included observations, lessons and stories about the environment that have been handed down for generations, providing a long history of environmental knowledge. These observations helped uncover new areas for scientists to study.

The main results of the study include:

- Warmer temperatures in recent decades. It was observed to be warmer in all seasons, though most notably in the winter months.
- The thinning of ice on the local rivers. Thin river ice is a significant issue because winter travel is mainly achieved by using the frozen rivers as a transportation route via snow machines or sled dogs. Thinning ice shortens the winter travel season, making it more difficult to trade goods between villages, visit friends and relatives, or reach traditional hunting grounds.
- Unpredictability of weather conditions. These communities rely on activities such as hunting, fishing and gathering wild foods for their way of life. One does not want to 'get caught out in the country' when the weather suddenly changes.
- Shifting of vegetation patterns and unpredictability from year to year on whether vegetation, particularly salmonberries, could be relied upon. This leads to increased difficulty in subsistence activities.
- Changed range and decrease of species of mammals (moose and beaver) and birds (ptarmigan). These animals play an important role in the subsistence diets of Alaska Natives. Many also rely on hunting or trapping for their livelihoods.
- Less snowmelt water flowing in the rivers means fewer logs come down the river. This hampers people's ability to collect logs for firewood and building materials, placing a strain on an already economically depressed region through increased heating costs and reliance on expensive fossil fuels.

Solar energy installation in an Alaskan village to reduce dependence on firewood and diesel, both of which release Carbon Dioxide when burned

This rural Alaskan community will, of course, need assistance to adapt. They will need to find new or different ways of living and surviving here. Ideally this should enable them to continue living sustainably where they are, where they have lived for generations. But if the climate changes are overwhelming, this might not be possible. If their adaptation involves relocating then it also means major social disruption and loss of traditional ways of living that have worked for generations. Once again it is poorer and more vulnerable communities that get the worst of climate changes.

ACTIVITY 5

1. Define the terms mitigation and adaptation in relation to climate change.

2. Use information from the unit to give examples of mitigation measures that we all need to take.

3. Give examples of adaptation measures that can be taken by
   a. wealthy countries or communities
   b. poorer or more vulnerable countries or communities.

ANSWERS ON PAGE 146

Summary

In this lesson you learned about the greenhouse effect and how human activity causes increases in Carbon Dioxide levels in the atmosphere. The focus is on recent times, and in particular the last century. We examined observed climate changes during the last century and drew the conclusion that climate change due to human activities is happening and that it is likely to continue into the future. As a result we also look at the consequences, both environmental and social, of such changes and what can be done to reduce or moderate this impact and how societies might adapt to what is coming.

CHECKLIST

Are you able to:

- ❐ describe and explain how the greenhouse effect works
- ❐ explain how human activities have enhanced the greenhouse effect
- ❐ describe some climate changes that have been observed during the last century
- ❐ suggest some changes that might occur in the future, particularly in South Africa
- ❐ explain what mitigation and adaptation mean and provide some examples of these

NOTES

Answer section

Lesson 1

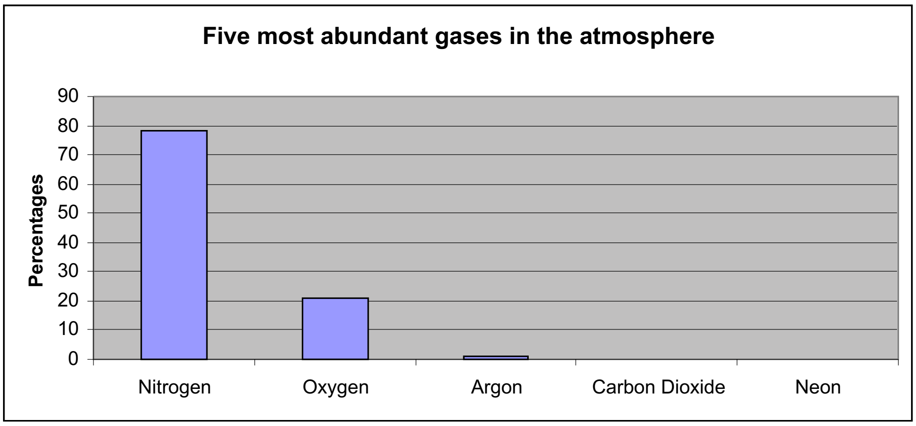
Activity 1

1. Oxygen and Nitrogen together make up 99.03% of the gases in our atmosphere

2. Around 100 km

3. 99% of our air is below that level

4.



Activity 2

1. Troposphere

2. The thermosphere and the exosphere, which include the ionosphere and the magnetosphere.

3. Extremely thin and spread out.

4. There is very little air there and it is extremely cold.

Activity 3

1. The ionopause is at the top of the ionosphere at about 250 km above the surface.

2. It allows long distance radio communication.

3. It is where ionising radiation from the Sun ionises the gas.

4. It is extremely cold, there is almost no oxygen, and the ionising radiation would give you cancer.

Activity 4

2. The electromagnet works because of an electric field around it. This is the same as what happens in the outer core of the Earth. The magnetic field around an iron nail electromagnet is very similar to that of the Earth. It has a north pole and a south pole, like the Earth.

Activity 5

1. The Sun releases a stream of charged particles – mainly electrons and protons. These are the solar wind.

2. The solar wind colliding with the magnetic field of the Earth causes the magnetosphere to form.

3. The outer core causes the Earth to have a magnetic field. This deflects the solar wind away from us. The solar wind is dangerous because it could strip away the Earth's atmosphere.

Activity 6

1. Jet aeroplanes fly in the lower parts of the stratosphere. This is because jet fuel burns well in the very low temperatures found there. The very thin air reduces the friction on the outside of the aeroplane, which reduces parasitic drag. At this level they can fly above most rough weather like thunderstorms and strong winds.

2. The ozone layer forms in the stratosphere and the ozone layer is very important for preventing the dangerous kind of UV radiation (UVC) from reaching Earth.

3. Ozone forms where it does because the radiation from the Sun is intense there and there are not many oxygen molecules. When an oxygen molecule is split by the Sun's energy the single oxygen atoms cannot easily reform, so they join onto other oxygen molecules to form ozone.

4. If the ozone layer were brought down to sea level it would be about 3 mm thick.

Activity 7

1. About 15-20 degrees

2. 6.5 ^{0}C per km

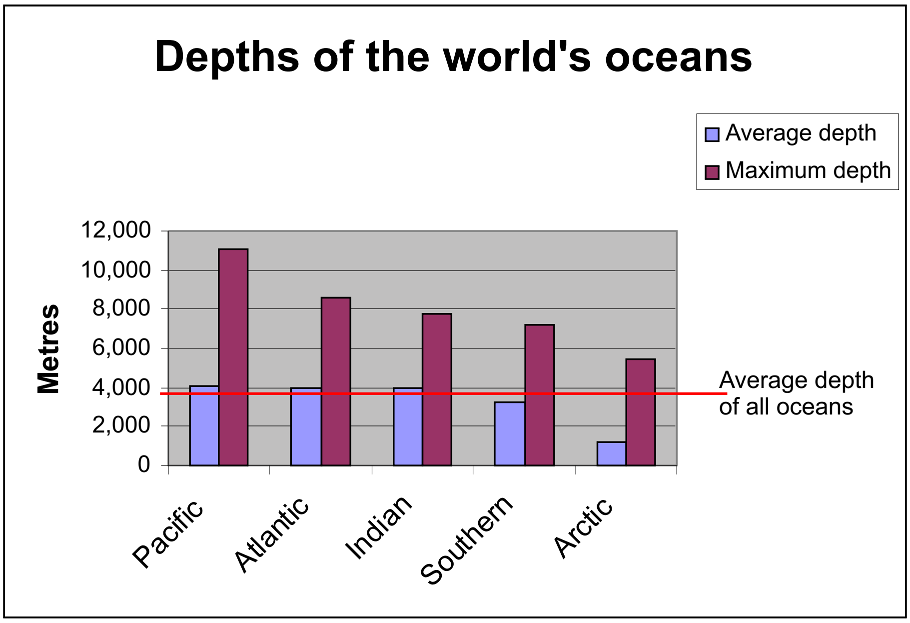
3. It gets warmer in the stratosphere because the ozone layer absorbs energy from the Sun and warms up

4. About -55^{0}C

5. About -90^{0}C in the lower thermosphere.

Lesson 2

Activity 1



Activity 2

1. An aquifer is a large amount of groundwater that can be used as a water source.

2. Groundwater filters through soil and rocks for many years before it reaches an aquifer. This means, unless it has been polluted, it would normally be very clean.

3. Groundwater is threatened by industrial pollution, spillage from chemical storage tanks and other forms of pollution that can soak into the ground.

Activity 3

1. Continental crust and oceanic crust

2. Continental crust: 30-50 km. Oceanic: 6-10 km

3. Continental crust is less dense, so it rides above oceanic crust.

4. Mines get very hot the deeper they go because not far below them the rock is molten. The deepest mine is about 3.9 km deep (It is AngloGold Ashanti's TauTona mine). Incidentally, this is about 2359 metres below sea level. Continental crust goes down to about 50 km, but it remains solid and rigid rock until about 200 km.

Activity 4

This is a practical activity. You should find that the continents fit reasonably well together. Note that the position of best fit is not at the present sea level, but at lower sea levels. If you could remove some sea the shapes would fit better.

Activity 5

1. All along the gray wavy lines. This is where we have all the splits from Pangaea to the present

2. I would draw them the same as in the diagram, showing the different continents moving away from each other.

3. The outer edges of Pangaea are on the west of the Americas and the east of Eurasia. The spiked lines lines in this diagram coincide with these as they push outwards into the Pacific.

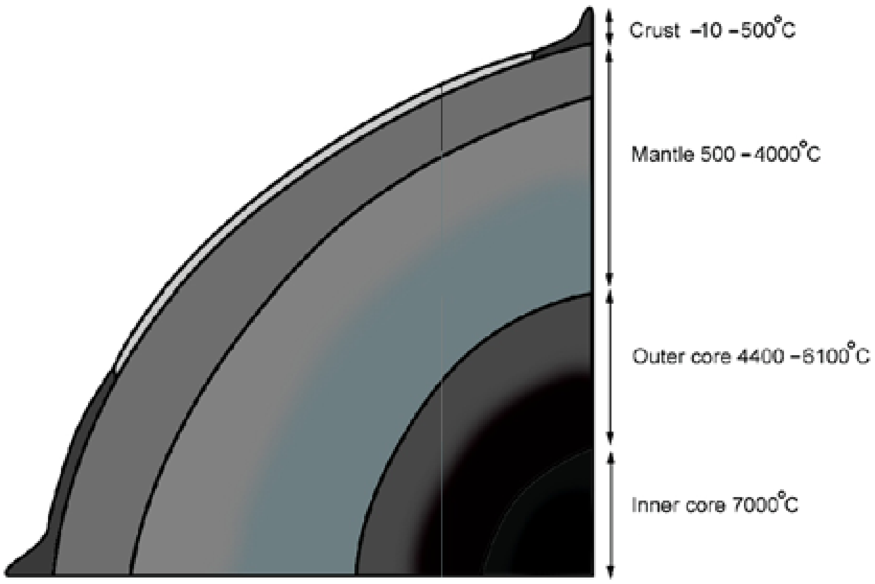
4. The Pacific Ocean

5. Indian and Atlantic Oceans

Lesson 3

Activity 1

1. Diagram showing internal Earth structures.



Schematic view of the interior of the Earth

2. The inner mantle so hot yet still solid because of the huge pressures experienced at that depth.

3. The most dense materials are at the centre of the Earth, the inner core, and the least dense materials are on the outside, the crust. This is because when the Earth was still forming, the more dense materials sank towards the centre while the less dense materials floated towards the top, or surface.

Activity 2

1. Most of the earthquakes are located along plate boundaries

2. Convergent and transform plate boundaries are responsible for the most earthquakes.

3. This is so because tectonic plates are huge and move together with extreme force. They often get stuck up against each other so that when they slip, immense energy is released.

Activity 3

1. Continental plates that collide happened because of their different plates moving away from where Pangaea was, so it is like an accidental collision. It is also a huge collision, so it could also be like two trucks colliding head-on – a lot of crumpling will happen.

2. The continental convergence described here took a long time to happen. The Indian plate had to move thousands of kilometres at a very slow rate before the two plates met.

3. Subduction zone earthquakes are more violent because the subducting oceanic plate can slip and move very suddenly and for long distances, thereby releasing very high energy. Earthquakes in the Himalayan region occur more from the compression and folding of rock, than sudden slippage of crustal plates.

Activity 4

1. The types of volcanoes:

    a. Shield volcanoes: formed from fluid, basaltic lava that flows easily and spreads far. They are not very explosive because their lava flows easily and can escape onto the surface easily. A shield volcano is a low and very wide volcano.

    b. Stratovolcanoes: very explosive because their lava is thick and not runny. The lava clogs up the vents of the volcanoes and resists high pressures before exploding. The lava also does not flow far from the mountain so it builds up steep-sided cones.

2. Most volcanoes are found on plate boundaries, mainly subduction zones. This is because as the oceanic crust is subducted it melts below the edge of the oceanic crust and releases molten magma upwards.

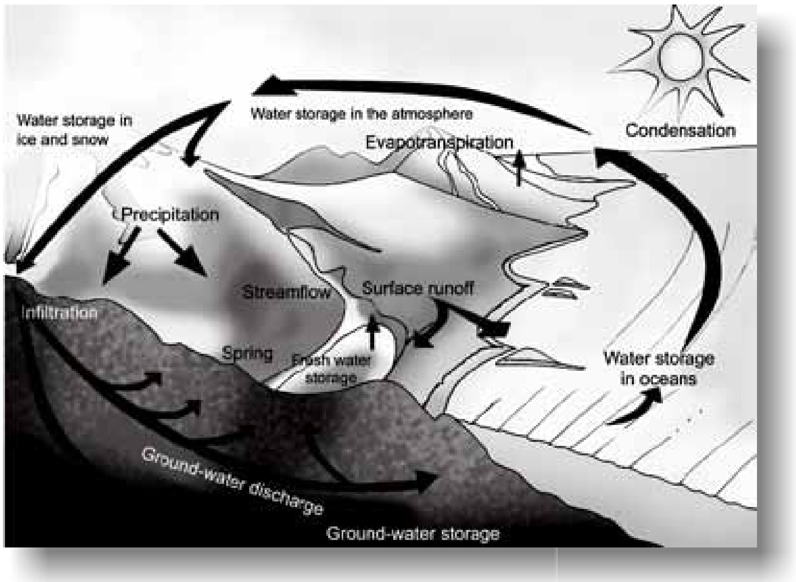
3. Hotspot volcanoes are not near plate boundaries because the hotspot comes from inside the mantle and doesn't move. They are associated with plate movement because as plates move over them they make a chain of volcanoes, usually islands in the sea.

Lesson 4

Activity 1

1. The water cycle causes water that might be polluted to evaporate and leave the pollutants behind, so that it can re-enter the water cycle clean. This is driven by the energy from the Sun, which is abundant and costs nothing.

2.

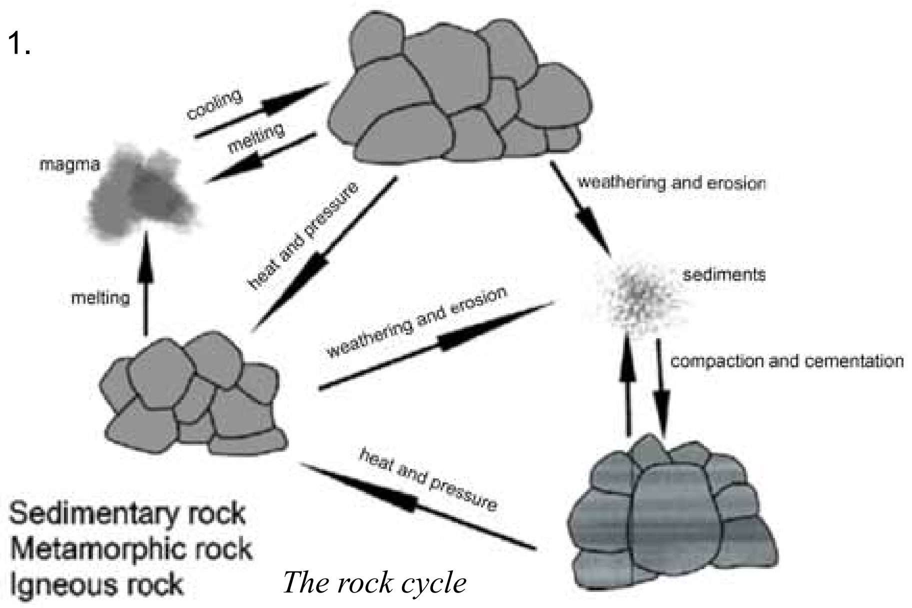


The water cycle

3. The water cycle is important because it assists in purifying water, at no cost. This ensures that we have fresh water for our use. It also ensures that we have precipitation. Without rain there would be no water for plants and crops, there would be no running water, because all of it would go down to the sea and stay there as salt water. Everything else would be totally dry and lifeless.

Activity 2

1.



The rock cycle

2. Metamorphic: metamorphic rock is caused by heat and pressure, and the two arrows leading the pile on the bottom left both have this label on them.

   Sedimentary: sedimentary rocks are made from sediments being compacted and cemented together. The pile on the lower right has an arrow leading to it with these words on it.

   Igneous: igneous rocks are made from heat magma and lava cooling down into rock. The top pile has an arrow from magma with the word cooling on it.

3. a. Sedimentary → Igneous: sedimentary rock can be subducted in a subduction zone and be melted as it goes into the mantle. Form here it can erupt as a volcano and form igneous rock.

   b. Igneous → Sedimentary: igneous rock can be weathered and its weathered particles can be transported and deposited as layers of sediment where it can become sedimentary rock.

   c. Igneous → Metamorphic: igneous rock can be subjected to great pressure and heat and be changed into metamorphic rock. This would normally happen at a convergent plate boundary, and mostly two continental plates.

4. We call it a cycle because one kind of rock can become another kind and keep going in this way over millions of years, continuously being recycled.

Activity 3

a. Four reservoirs: biosphere, atmosphere, fossil fuels and rocks in the Earth's crust.

b.
- Photosynthesis absorbs Carbon from the air into the biosphere
- Industry releases Carbon from fossil fuels into the atmosphere
- Carbon enters the soil when living things die
- The ocean absorbs Carbon from the air
- Living things consume Carbon when they eat food

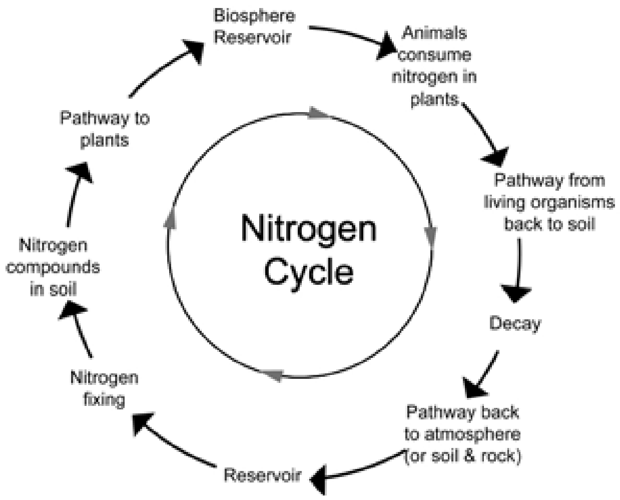
c. The Carbon that was in the food came mostly from the air (through photosynthesis) and also from the soil through plant roots.

d. It will mostly go into the soil or be stored in sediments or rocks. Some will go into one's body and some will be breathed out as Carbon Dioxide.

Activity 4

1. Atmospheric Nitrogen is in an inorganic molecular form that is not available to plants. It first needs to be fixed into inorganic Nitrogen compounds.

2. Nitrogen-fixing is the process whereby atmospheric Nitrogen is changed into organic Nitrogen compounds. This happens through the action of lightning and mainly through nitrogen-fixing bacteria.

3. 

Lesson 5

Activity 1

2. The Sun is on the left side
4. The northern hemisphere as it is summer

Activity 2

3. The northern hemisphere gets more sunlight
5. The southern hemisphere gets more sunlight?
   In Question 3 the model shows the northern hemisphere receiving more sunlight. It shows summer there and winter here. In Question 5 the southern hemisphere received more sunlight. It shows summer here and winter in the north.

Activity 3

1. The southern hemisphere

2. The northern hemisphere

a. Summer is for the southern hemisphere, winter is for the northern hemisphere

b. In position 3 the southern hemisphere has winter and the northern hemisphere has summer

c. The two hemispheres are getting the same amount of sunlight.
Northern hemisphere has Autumn, southern hemisphere has Spring

d. December: position 1
March: position 2
June: position 3
September: position 4.

Activity 4

1. We get more energetic and active at spring time. People in cold climates get depressed in winter (Seasonal Affective Disorder); we develop hobbies, and habits around the seasons we live in.

2. Animals tend to breed in spring so that their off-spring have plentiful food and shelter when they are young and growing up in time for the winter season. They also migrate to take advantage of warmer seasons in different parts of the world where there are more resources and better shelter. They return when the cold season starts arriving. Examples can come from own research.

Lesson 6

Activity 1

1. a. Car sub-systems: Steering, engine cooling, electrical, drive system (gear box, drive shafts etc.), fuel system and others.

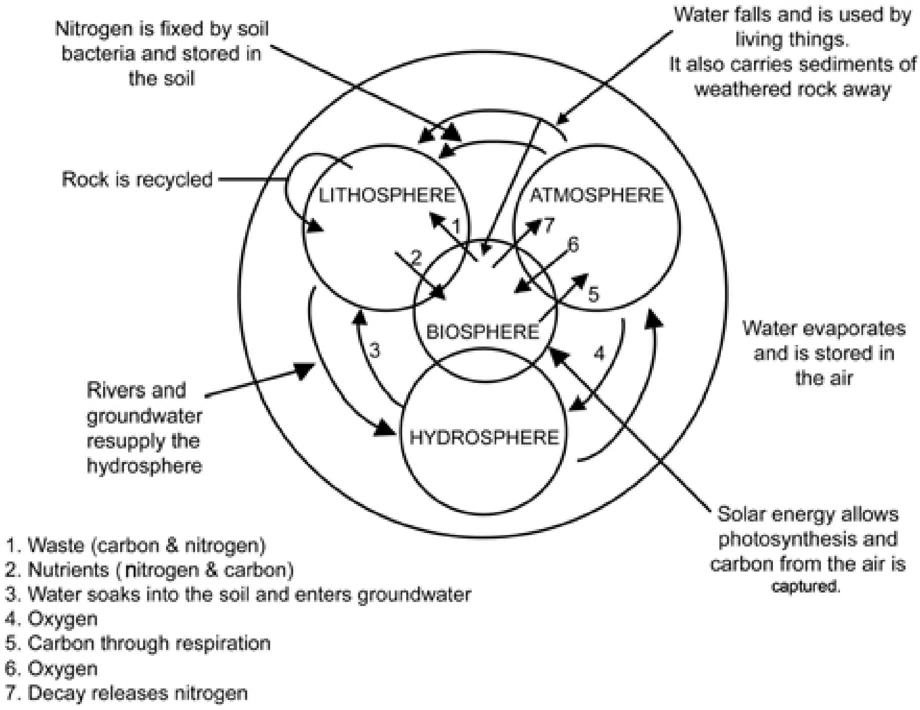
   b. Not many can – perhaps the mirrors and the window glass, but no others.

   c. Almost all cannot fail if the car is to continue working.

   d. Each sub-system is an important part of the whole. We cannot allow one component or subsystem of the Earth system to be compromised (damaged) and expect the Earth system to continue working well.

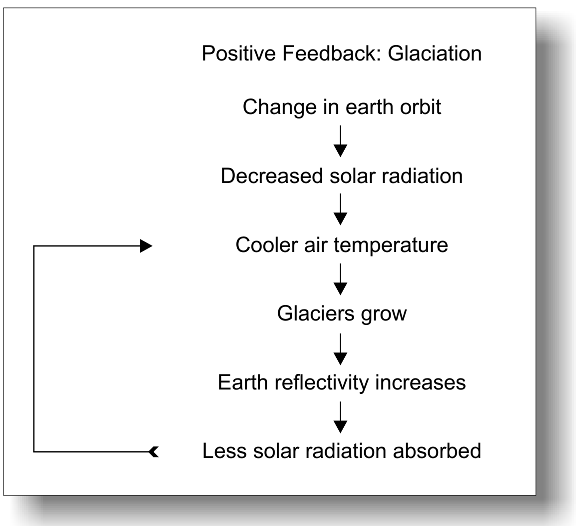
Activity 2

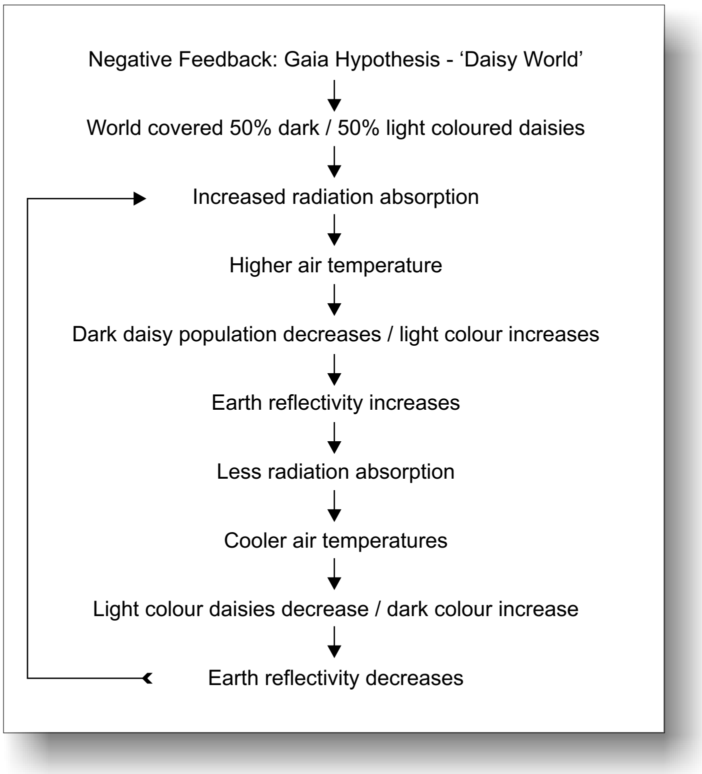
1. Redraw the diagram of the Earth system as a rough sketch on a large piece of paper. Make annotations and labels on or alongside the diagram giving information about and examples of reservoirs and pathways.



Activity 3

1. Population numbers of living things in this area: The elephants have become too numerous in this area and so they have caused damage to trees, which is a major source of food. Elephants rely on trees, so they might leave the area or begin to die off. Any other animals that also rely on trees for food will suffer (so might the soil with increases in soil erosion). These animals and the animals that eat them will also suffer a reduction in food supply and move to another area or begin to die off. With elephants and other animals reducing in numbers the trees will regrow, and the cycle can begin again. If, at any stage, some of the species are lost entirely (e.g. elephants die off and are not repopulated, or some specific trees are eradicated in the area), this could cause permanent changes that could lead to ongoing environmental damage.





Activity 4

1. Tipping point: a point at which a change moves faster and becomes irreversible, leading to a new equilibrium level.

2. Tipping points are important when we discuss the future of life on the planet because once a boundary is reached and that system goes over a tipping point, the original balances will be changed and quite possibly not be able to support life as they used to, and there will very likely be a period of great instability or chaos as the system begins to re-establish a new equilibrium.

3. According to the table, climate, biodiversity and the biogeochemical cycles have been most altered and might suffer irreversible damage.

4. a. Melting of ice causes reduced reflectivity and increased warming.
   b. An increase in the level of Carbon Dioxide causes an increased greenhouse effect, leading to greater warming.
   c. Higher temperatures might cause increased evaporation which will increase the amount of water vapour in the atmosphere. Water vapour is a greenhouse gas, so this might cause further increases in temperature.
   d. Increased temperatures might also cause increases in the number of forest fires, which will cause an increase in the amount of Carbon Dioxide in the air which might cause higher temperatures.

e. Removal of vegetation (which normally has quite a high albedo reflectivity) will release more Carbon Dioxide and expose soil and rock that absorbs more energy, both of which might cause an increase in temperature and possibly make it more difficult for forests to grow.

f. Increased temperatures can cause permafrost to melt, which can release Methane gas that has been stored in the permafrost for centuries. Methane is a powerful greenhouse gas that is likely to accelerate global warming.

Lesson 7

Activity 1

a. The climate in the photo is an arid one or even semi-desert.

b. Heavy rain is experienced.

c. Weather is the specific day-to-day conditions of the atmosphere at a particular place and time. It describes the state of the atmosphere with regard to meteorological conditions such as; wind, temperature , humidity, atmospheric pressure, visibility, cloud cover, and precipitation. Weather describes and measures the short-term variations of the atmosphere which can change on a daily basis. On the other hand, climate tells the normal pattern of weather experienced in a particular area over a long period of time. As such, climate stays much the same year after year and gives a general all year round weather of how hot, cold or wet different parts of the world will be at different times of the year.

Activity 2

1. The timescales eon, era and period are indicated on the diagram. Epochs and ages are not shown.

2. The four eons are Hadean, Archean, Proterozoic and Phanerozoic.

3. The eras in the most recent Eon (i.e the Phanerozoic Eon) are Paleozoic, Mesozoic and Cenozoic.

Activity 3

2. a. Cenozoic Era

3. 65 million years ago was the last major extinction when the dinosaurs went extinct.

Activity 4

1. Approximately 8 degrees down.

2. About 5 degrees up

3. 13 degrees altogether

4. It doesn't need all that much because from the middle point it was mostly not even 5 or 8, but lesser amounts that caused an glacial or an interglacial.

Activity 5

In order of most likely to least likely:

1. Atmospheric Carbon Dioxide variations. This is most likely because we are adding to carbon dioxide in the atmosphere.

2. Variations in the Earth's orbit. This is a powerful driver but at present the three cycles are not synchronised, so their effect is reduced.

3. Variations in solar output. This is not one of the most powerful causes of climate change.

4. Volcanic eruptions. We do not expect any volcanic eruptions of the scale that caused the major climate changes in the past.

Activity 6

a. They are likely to increase at first and then decrease as we move into the next glacial, perhaps in 50,000 years time.
b. In the next 100 years temperatures are likely to increase quite a lot. This is because it looks like the next glacial will be weak or will not even happen until about 50,000 years' time. In that time human-induced changes, mainly though adding to the greenhouse effect, is likely to be the main driver.

Activity 7

1.
   a. Around 1700 to 1750 after the Little Ice Age.
   b. Human-induced changes in greenhouse gases.
   c. The industrial revolution.
   d. Because it is an advance, but that advance might eventually bring about the destruction of the human race and life on the planet as we know it.
   e. We need to reduce our use of fossil fuels rapidly to reduce the amount of greenhouse gases.

f. No, we shouldn't worry about it because that is too long a scale for us to plan for and the changes that occur over that timescale are natural and beyond our control. And anyway, by then we will all be fried.

Lesson 8

Activity 1

1. The car is similar to planet Earth because shortwave radiation can enter the glass, which is like the atmosphere, heat up the atmosphere and the surface and then not escape because it is re-radiated as longwave radiation.

2. The greenhouse effect is cased by certain gases such as water vapour, Carbon Dioxide and Methane in the atmosphere that allow shortwave solar radiation to pass through them but do not allow longwave radiation to leave through them. In this way energy is retained by the atmosphere.

3. The thermal budget shows us that there is a balance between incoming and outgoing energy. Some energy is radiated away and does not pass to the Earth's surface, while some is absorbed in the atmosphere or the Earth's surface and causes warming. This is eventually re-radiated and some leaves the atmosphere. There is a balance now, but if the amounts of greenhouse gases change that balance will change.

   The calculations of Earth's thermal budget are as follows:

   Incoming:
   235 watts per square metre (W/m^2) of which 168 W/m^2 is absorbed by surface, 67 W/m^2 is absorbed by atmosphere.

   Circulated:
   324 W/m^2 absorbed by surface from atmosphere
   492 W/m^2 re-radiated from surface (452 W/m^2 back to atmosphere, 40 W/m^2 back to space)

   Re-radiated to space:
   40 W/m^2 from surface
   195 W/m^2 from atmosphere
   Total re-radiated: 235 W/m^2

   Therefore 235 W/m^2 incoming is balanced by 235 W/m^2 outgoing

4. If the thermal budget was not balanced Earth would steadily get cooler or warmer.

5. The feedback mechanism that keeps Earth's thermal budget balanced is based on incoming radiation being held in by the atmosphere for long enough that the Earth warms up. As the Earth warms up there is more re-radiation from Earth so eventually some of it escapes. The amount of greenhouse gases in the atmosphere is just enough to maintain a balance between incoming and outgoing so that the average temperature is around 14 to 15 degrees C.

Activity 2

1. Lower scenario: 550 ppm; Higher scenario: 900ppm

2. In the last 800 000 years the Carbon Dioxide levels have been between 170 and 300 ppm, but very recently it has reached 393 ppm. So the projected levels are extremely high by comparison.

3. The projections show that the interglacial will become even warmer and this means that we will have a very warm period. We are likely to have increased desert areas, reduced rainfall and more violent weather.

4. Human activities include burning a lot of fossil fuel for energy. This releases Carbon Dioxide, which is a greenhouse gas, so the thermal balance changes and temperatures increase. This then also causes the release of methane from previously frozen permafrost, which further increases levels of greenhouse gases.

Activity 3

1. If I believed that climate change was not real I would just say that there are always changes in nature, things fluctuate, and this is just one of those slightly warmer fluctuations. It won't be long and the ice will return. There's nothing to worry about.

2. I would argue that, yes, there are of course natural fluctuations, but the patterns that are emerging are everywhere and the evidence for it is extremely strong. Also, the temperatures we are now seeing are unprecedented in the last 800,000 years. That kind of change – the scale of the change and the rapidity of it are not the way natural fluctuations happen. So I believe we are seeing real climate change. All of the evidence fits together and what was predicted by the scientists is now happening. If it was just a natural fluctuation they would

have been proven wrong. Finally, we all know that pollution is wrong, so even if we are wrong about climate change, the measures we are taking to avoid burning fossil fuel is a good idea anyway. I will support alternative energy sources even if only for that reason.

3. The graph was presented in this way to show that there are very distinct shifts in what has happened. It is not a gradual change. This might be to make us sit up and take notice and realise that the next period might see an even more rapid shift.

4. Threats to sustainable living caused by climate change:
   i. reduced rainfall in some areas will threaten agriculture
   ii. rising sea levels will threaten people living in low lying lands, and cause flooding there
   iii. more energetic weather systems will cause more destruction (storm surges, hurricanes, heavier hail storms, violent winds etc.)
   iv. increased rainfall will also cause increased flooding in low lying areas, and it might cause major damage to topsoil, which could then destroy agricultural potential in some areas
   v. reduced snowmelt water will cause hardships as many people's water source dry up
   vi. growing seasons will change, many will be shorter, traditional crops may no longer be possible to grow
   vii. increased temperatures will promote bush and forest fires and cause destruction to habitat.

Activity 4

1. We should take the predictions very seriously because the evidence is very strong that climate change is taking place, and the impacts of that change could be very severe on human life on the planet.

2. Changes where you live: This answer depends on where you live. In South Africa the main changes will be drier and hotter conditions across most of the country with heavier or more intense rain on the east coast with possibly more hurricane-like conditions. Around the coast rising sea levels will have a major impact on buildings and infrastructure. These changes will all affect the kinds of human activities that take place, for example agriculture will have to change a lot.

3. The single impact of climate change in South Africa will most likely be the hotter and drier conditions because that will affect agriculture in a major way and might lead to widespread collapse of agriculture and starvation, unless we can find ways of dealing with it.

Activity 5

1. **Mitigation:** reducing the impacts of climate change, for example building ocean walls to prevent wave damage, although the main mitigation measures at present are to try to slow down climate change reducing carbon outputs.
   Adaptation: adapting ourselves to the changes, for example planting different crops in different areas, moving buildings and infrastructure away from the shoreline.

2. **Examples of mitigation measures:** reducing our dependence on fossil fuels, switching to alternative energy sources, reducing our overall use of energy, using motorised transport less, eating less meat, especially beef (cows produce a lot of methane gas which is a powerful greenhouse gas), protecting natural carbon reservoirs (sinks) like forests and oceans.

3. **Adaptation measures:** wealthy countries or communities: researching new crops, new ways of generating energy, new ways of producing water e.g. desalination, new ways of heating and cooling buildings, building safer buildings, shoreline protection walls, making energy efficient cars and so on.

   Adaptation measures: poorer countries or communities: move away from flood zones, move to areas where agriculture can survive, get used to eating 'traditional' crops (that are better adapted to drought conditions, like sorghum, planting flood resistant or salt resistant barrier plants, re-planting protective mangrove forests, learning to live above water, finding new ways of gathering water in drier conditions.