SPOTLIGHT

QCE Earth and Environmental Science

UNITS 1 and 2

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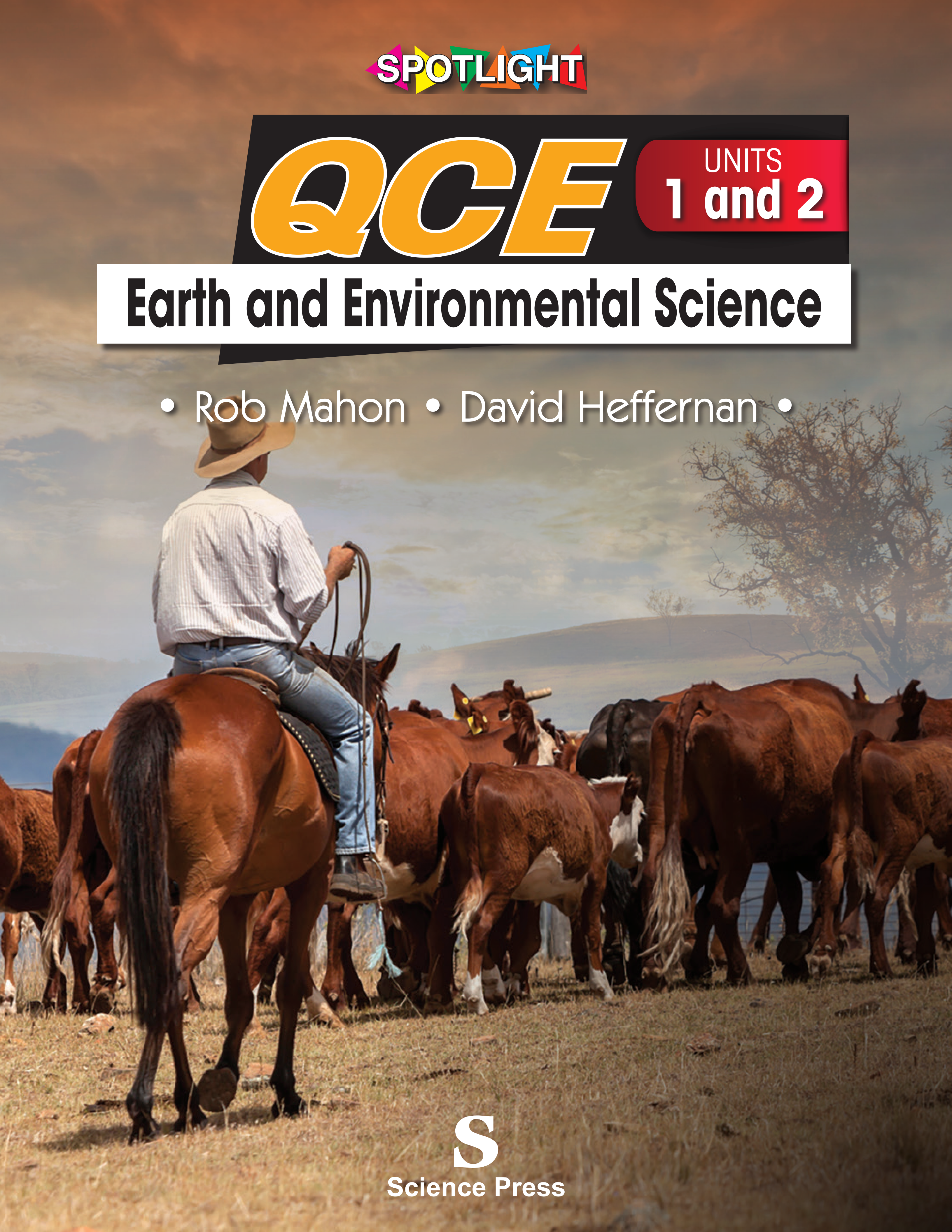

Science Press

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Chapter 1
EARTH SYSTEMS AND MODELS

Figure 1.1 Change and interactions Takes place throughout the Universe.

Interactive vocabulary
https://quizlet.com/_6xcazh

'When we try to pick out anything by itself, we find it hitched to everything else in the Universe.'

John Muir: pioneering naturalist and preservationist.

The study of the Earth is the study of changes and of connections. At times throughout its long history the Earth has experienced many periods of stability in its geology, climate and life forms. Inevitably however, these times are always overturned by changes in one form or another; from the very gradual (such as continental drift) to the very sudden (such as the eruption of a volcano or the impact of a meteorite).

1.1 Introduction to Earth systems

We are all familiar with the concept of change. During your lifetime your body and mind change dramatically. The 'you' of today is very different from who you were ten years ago, or who you will be in another 10 years. Human society itself changes. Today's society seems to be changing at an ever increasing rate.

In your short life you may have noticed large changes in the way you have been taught at schools or how you communicate with others. The Earth itself has undergone drastic changes too, though usually over much longer time frames than humans live for (and so it can be hard for us to notice them happening).

At one time in the past the entire Earth was covered with thick ice from pole to pole, and at other times it has been a planet free of any ice, with warm temperatures and even lush forests at the South Pole.

With the convergence of social media and digital communications in the 21st century, most students have an understanding of the intricate network of connections between people. What science continues to reveal to us is that nature itself also contains a vast number of interconnections, ranging from the powerful to the miniscule to the downright strange.

The most astounding fact
http://qr.w69b.com/g/tpXhRXlBu

Introduction to Earth science
http://qr.w69b.com/g/s7bBx9dTi

Earth science
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Spheres of the Earth

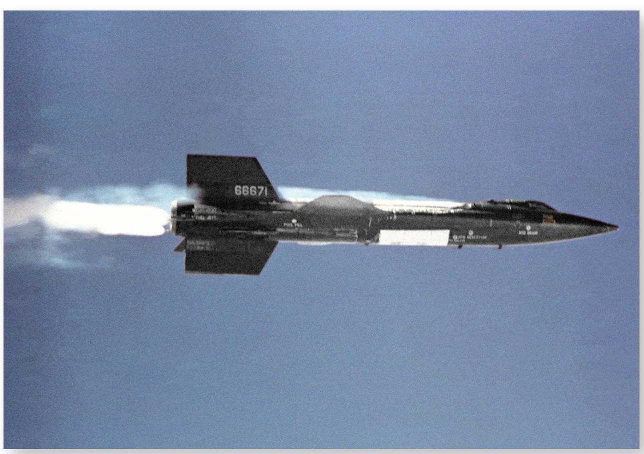


Figure 1.2 Where does the atmosphere begin and end? The pilots of the experimental X-15 rocket plane were regarded as astronauts as they flew at a height of 85 kilometres.

Earth system interactions
http://qr.w69b.com/g/tCaPmhiMw

For easier reference, scientists refer to various **spheres** of the Earth, each of which is simply a zone in which a particular feature is found. The spheres of major interest to Earth scientists include the atmosphere, lithosphere, hydrosphere and biosphere.

The atmosphere. The zone of gases extends from the surface upward until gases are so thin that we have entered outer space. This gradual thinning means there is no clear boundary between the atmosphere and space. Air particles have been detected at a height of 1000 kilometres. To put this into perspective, the International Space Station orbits at a height of around 400 kilometres. NASA defines space as beginning at an altitude of 85 kilometres (Figure 1.2). Around 80 per cent of the atmosphere's mass is located in the bottom 12 kilometres.

The geosphere. This is the zone of all rock on Earth, including all of the interior layers (Figure 1.3). Two subsections of this that are of particular importance when studying plate tectonics are the **lithosphere** and the **asthenosphere**. The lithosphere is the zone of rigid rock, including the crust and uppermost mantle. It ranges from 5 km thick below oceanic crust up to 100 km thick below continental crust. The asthenosphere is the zone of partially molten (plastic) upper mantle rocks. It can flow slowly due to convection and sits directly below the lithosphere and above the solid lower mantle.

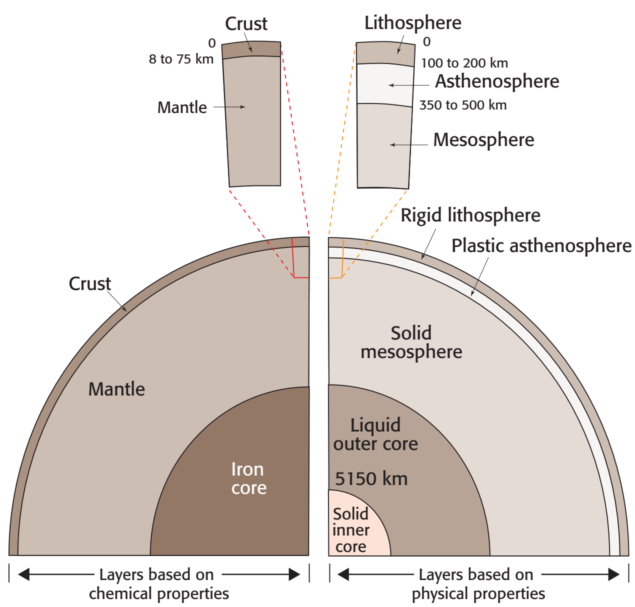


Figure 1.3 Geosphere This is the region extending from the surface down into the mantle until the rocks become partly molten.

1.2 Geologic time

'It has not been easy for man to face time. Some, in recoiling from the fearsome prospect of time's abyss, have toppled backward into the abyss of ignorance.'

Claude C Albritton, *The Abyss of Time* (1980).

It would be pointless to study history without also considering the order and time in which historical events occurred. Likewise, when studying the history of our planet, we must first understand the concept of **geologic time –** the vast period of time over which Earth's rocks have formed.

For centuries the question of 'How old is the Earth?' proved to be a challenging problem for scientists. Finding an answer to this puzzle would profoundly change the way in which humans would view their home planet and their place on it.

How old is the Earth?

In the year 1510 Florentine artist, inventor and genius Leonardo da Vinci (1452-1519) concluded that the sediments deposited by the River Po in Italy must have taken 200 000 years or more to accumulate and that the Earth itself must be much older than this. However, his conclusion was not made widely known. Typically for da Vinci, he was far ahead of his time in using evidence and observations (i.e. science) to inform his theories.

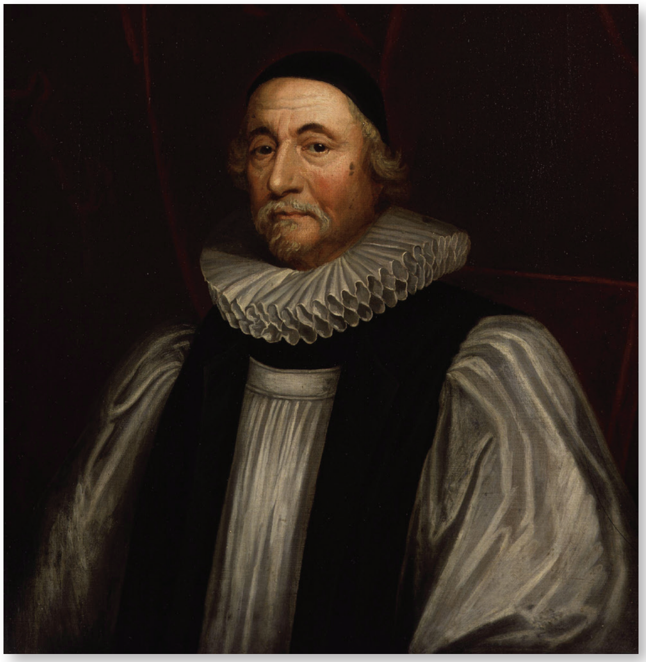


Figure 1.8 Creation James Ussher calculated that the Earth was created in 4004 BCE.

In 1654, the Irish Bishop James Ussher calculated that the Earth was created in 4004 BCE (Figure 1.8). He arrived at this date by starting with the birth of Jesus Christ (the start of year zero on our calendars), adding together all of the generations described in the Bible back to Adam (listed there as the first human) and then multiplying this by his estimated average generation gap.

Many scientists thought that Ussher's estimate of 6000 years was far too short a time span to explain such features as cliffs showing accumulated sediments hundreds of metres thick (Figure 1.9 (a)). However, due to the lack of any other credible theories, Ussher's estimate became widespread in European religious and scientific circles. Given the Bible's description of a catastrophic flood, the idea that the world had been shaped in the past by sudden, short-lived catastrophic events took hold. This idea is called **catastrophism**, and was used to explain a number of things seen in the rocks, including the following.

- Layers of sedimentary rocks were due to a worldwide flood where huge tides deposited massive loads of sediment that over a short period of time formed rocks (Figure 1.9 (a)).
- Fossils found in such rocks were buried during The Flood (Figure 1.9 (b)).
- Rocks such as basalt and granite had been crystallised from the waters of The Flood (Figure 1.9 (c)).

In 1778 French mathematician and naturalist Georges de Buffon (1707-1788) estimated Earth's age based on experimental observation. Correctly inferring that the interior of the Earth must be like iron, he heated iron cannonballs of various sizes and studied the rate at which they cooled. He applied the observed cooling rates to the Earth's diameter and concluded a much older age of 75 000 years.

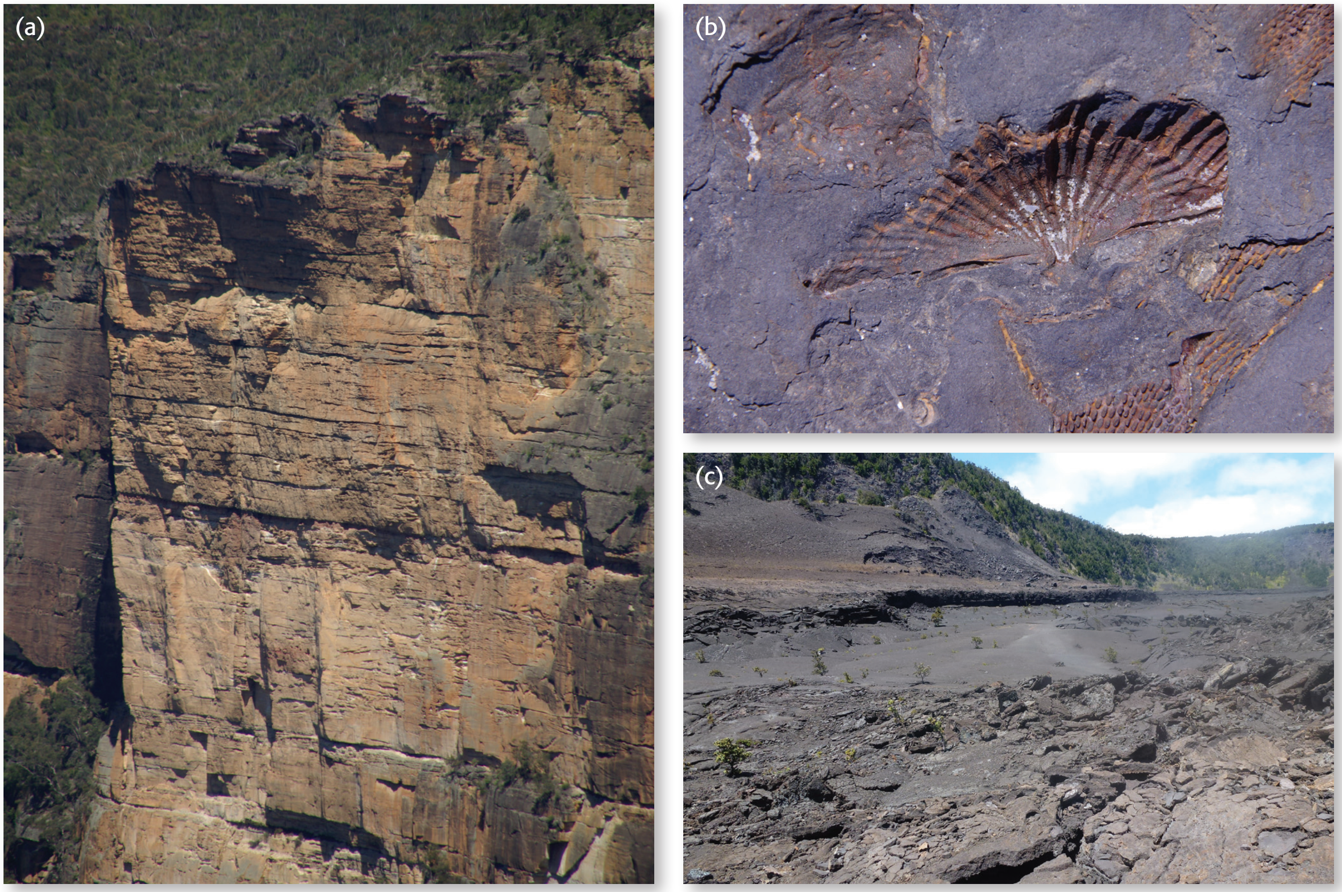


Figure 1.9 How did these form? (a) Beds of rock. (b) Fossils in sedimentary rock. (c) Layers of basalt.

Figure 1.10 Evidence (a) Unconformity showing rocks at different angles. The bottom rocks were deposited first before being tilted to a near vertical position. After being eroded, another layer of rocks was deposited horizontally and the whole formation tilted again. (b) Granite penetrating other rock showing that it must have been molten at the time.

9. Leonardo da Vinci studied the River Po in Italy. The average thickness of sediments is 1 km. **Calculate** the average thickness of sediment deposited each year if it took 200 000 years to form that thickness of sediment.
10. Figure 1.19 shows a layer of basalt.
    (a) Use catastrophism to **explain** this layer of rock.
    (b) Use uniformitarianism to **explain** this layer of rock.

1.3 Stratigraphy

Can you believe in **catastrophism** and still make major advances in science? Nicolas Steno (1638-1686) was just such a person (Figure 1.20). While motivated by the Bible (he joined the priesthood after becoming a medical doctor), he was able to make major advances in our knowledge of human anatomy as well as in geology.

Figure 1.20 Nicolas Steno Made contributions to many aspects of science.

Stratigraphy

Steno became interested in rock strata (layers) and the inclusions found within them. He tried to work out the geologic history of Tuscany in Italy, where he was living at the time. As he did so, he was able to devise some simple rules that are still used today. These rules form the basis of what we now call **stratigraphy** – the science of identifying the *relative* ages of the layers of sedimentary rocks.

1. The law of original horizontality

When observing sedimentary rocks, the strata (layers) were originally deposited in horizontal layers under the force of gravity. If strata are no longer horizontal (i.e. folded, faulted or tilted), then these changes occurred after the original rock formed.

2. The law of superposition

Normally sedimentary rocks are deposited from water. They settle to form horizontal layers. As long as they are not deformed in some way, a bed of rock is older than the one above but younger than the one below. Figure 1.21 (a) shows beds of rock where layer B is younger than A, but older than layer C. This is called **superposition**. These same principles work with beds of volcanic rock formed from lava flows or from volcanic ash. Figure 1.21 (b) shows rocks that have been deformed by folding and great care is needed to interpret them.

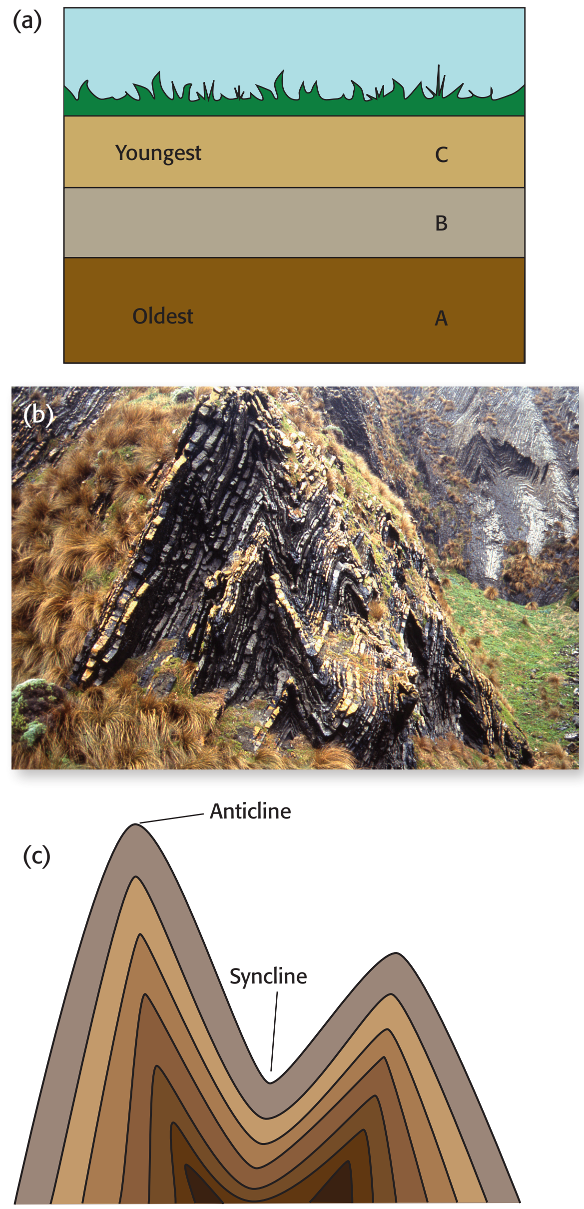


Figure 1.21 Superposition (a) Sedimentary strata are younger than the ones below them, like layers of icing on a cake. (b) These beds (which were horizontal when they formed) have been deformed into folds. (c) Folds that point upwards are known as anticlines, and those that point downwards are called synclines.

Table 1.4 The geologic time scale.

Eon and translations	Era and translations	Period	Series/epoch	Started (million years ago)	Animal life	Plant life
Phanerozoic 'Visible animals'	Cainozoic 'New animals'	Quaternary	Holocene	0.0117	Rise of civilisations. First *Homo*.	Diversification of angiosperms. Herbs increase.
			Pleistocene	2.58		
		Neogene	Pliocene	5.33	First *Australopithecus*. Dominance of the land by mammals, birds and insects.	Dominance of land angiosperms.
			Miocene	23.03		
		Palaeogene	Oligocene	33.9		
			Eocene	56		
			Palaeocene	66		
	Mesozoic 'Middle animals'	Cretaceous	Upper	145	Last of the dinosaurs. Insect radiation.	Gymnosperms decline. Angiosperms increase.
			Lower			
		Jurassic	Upper	201	Dinosaurs abundant. First mammals and birds.	Cycads, conifers. Primitive angiosperms.
			Middle			
			Lower			
		Triassic	Upper	251.9	First dinosaurs.	Land dominated by gymnosperms.
			Middle			
			Lower			
	Palaeozoic 'Old animals'	Permian	Lopingian	298.9	Reptile expansion. Decline of amphibians. Last trilobites.	Expansion of ferns and conifers.
			Guadalupian			
			Cisuralian			
		Carboniferous	Pennsylvanian	258.9	Age of amphibians. First reptiles. Spread of insects.	Great coal forests. Ferns, seed ferns, conifers.
			Mississippian			
		Devonian	Upper	419	Age of fishes. First amphibians and insects.	Primitive tracheophytes and liverworts.
			Middle			
			Lower			
		Silurian	4 divisions	444	Land invasion by a few arthropods.	Land invasion by some primitive tracheophytes.
		Ordovician	Upper	485	First vertebrates.	Abundant marine algae.
			Middle			
			Lower			
		Cambrian	Furongian	541	Marine invertebrates of most phyla.	Primitive marine algae.
			Miaolingian			
			Series 2			
			Terreneuvian			
Proterozoic 'First animals'	Neoproterozoic 'New first animals'	Ediacaran		635	Multicellular animals.	Multicellular plants.
				1000		
				2500	Bacteria/microbes only. First life?	
Archaean 'Of first rocks'				4000		
Hadean 'Hell-like'				4600		

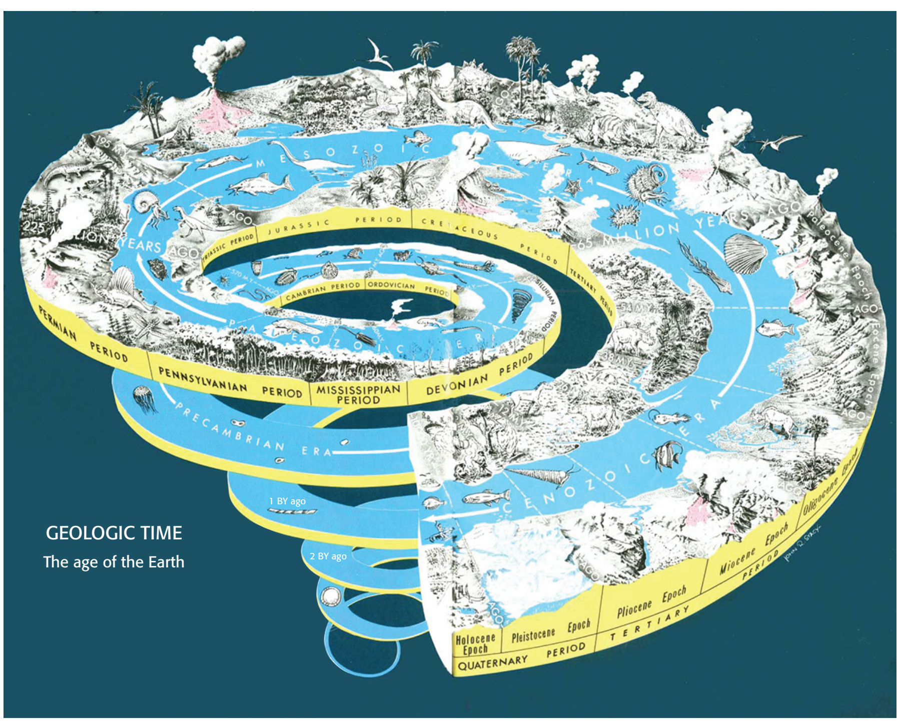


Figure 1.30 Geologic time scale
Artist's representation of geologic time.

1.4 Origins of the Universe

'Begin at the beginning' the King said, very gravely, 'and go on till you come to the end: then stop'.

Lewis Carroll: Alice's Adventures in Wonderland.

'Don't become a mere recorder of facts, but try to penetrate the mystery of their origin.'

Ivan Pavlov: Russian psychologist.

The history of the Universe
http://qr.w69b.com/g/lcRbNw6kw

The story of how the Earth began actually starts with the story of how the Universe began (Figure 1.32). The term 'Universe' means the collection of everything in existence that we know of – all space, all time, all matter and all energy. The Universe is vast beyond our comprehension. It contains between 100 billion and 1 trillion galaxies, each of which on average contains a few hundred billion stars. While you may know academically what a billion is, the reality of how big these numbers are is beyond our ability to truly comprehend.

Figure 1.32 The Universe How did the Universe originate?

Scientific notation is a way of writing numbers when they are either too big or too small to describe in the conventional numerical fashion. In this system all numbers are described as: $a = 10^b$ where the number a is multiplied by 10 to the power of b. In practice, b tells us how many spaces to move the decimal point in a. For example, 1000 metres can be described as 1×10^3 metres (1 with the decimal point moved 3 places to the right). 6 millimetres can be described as 6×10^{-3} metres (6 with the decimal point moved 3 places to the left due to the minus sign).

Interactive scale of the Universe
http://qr.w69b.com/g/rH7nTQuuk

A Universe of atoms

Of all the atoms in the entire Universe, scientists calculate that a whopping 90% of them are hydrogen (although because it is the lightest element, it only accounts for 74% of the total mass of the Universe). The Earth has a much lower proportion of hydrogen because most of this gas was lost as our planet formed (more on that later). Most of the hydrogen left on Earth is found locked up in water (H_2O). As a part of water and other molecules, hydrogen makes up about 61% of all the atoms in your body. The amazing fact is that while humans regard their age in years since they were born, these hydrogen atoms within you, around you and throughout the Universe were all born at the same time – moments after the Big Bang, about 13.7 billion years ago. As you celebrate your 18th birthday, spare a thought for the 61% of you celebrating a 13 700 000 000th birthday!

Figure 1.33 The Hubble Space Telescope Offered astronomers unprecedented views of the heavens. This image shows a mountain of dust and gas rising 3 light years tall in the Carina Nebula. This pillar of cool hydrogen is being worn away at the top by radiation from nearby stars, while stars within the pillar vent jets of gas that stream from the peaks.

In one corner were the **steady state theory** supporters. These men and women represented the established and ancient view that the Universe was generally unchanging and that it is infinitely old. ‘If the galaxies are moving apart’ they argued ‘then new matter must be continually created between them to fill the gaps. This would preserve the appearance and distribution of matter in the Universe for all time.’ This group was led by the eminent British astronomer **Sir Fred Hoyle**.

In the other corner were a group who supported the new idea that if the galaxies are flying apart then they must have been much closer together in the past. If you rewind the observed expansion, you are left with an impossibly small, hot and dense point where the Universe had, for some reason, burst into existence in the distant past. This radical idea was first proposed in 1927 by the physicist, mathematician and Catholic priest **Georges Lemaître** (Figure 1.35). In an attempt to either explain or ridicule this idea, Hoyle referred to it as the **Big Bang theory** during a radio interview and the catchy name stuck. This theory predicted that the Universe was created at some definite time in the past, and that it would look very different if you viewed it in the distant past or in the distant future. In other words; the Universe is evolving.

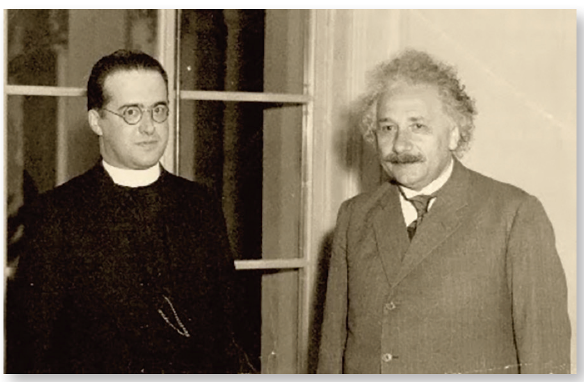


Figure 1.35 Monsignor Georges Lemaître Both a priest and a scientist. Albert Einstein publicly applauded Lemaître’s theory of an expanding Universe, which used Einstein’s new theory of general relativity as its basis.

Electromagnetic energies such as light and radio waves travel at the speed of light. While this is incredibly fast (about 300 000 kilometres per second), light still takes time to reach us over the vast distances of space. For example, we see the Sun not as it is right now but as it appeared 8 minutes ago, because its light takes 8 minutes of travel time (moving at the speed of light) to reach us. The brightest star at the base of the Southern Cross (Acrux) is 321 light years away, so we see it as it looked 321 years ago.

The most distant object we can see at night with the naked eye is our neighbouring galaxy Andromeda. The light that hits our eyes when we look at it actually left Andromeda some 2.5 million years ago (before modern humans walked the Earth). When we look into the heavens, we see objects not as they appear now but how they appeared when light left them. Telescopes therefore act as time machines, allowing us to glimpse the Universe as it appeared long ago.

The evidence mounts

As both radio and optical telescopes improved, astronomers were able to peer deeper and deeper into the Universe, and therefore further and further into the past. What they found was strange, but it supported the Big Bang theory and made steady state theory look increasingly shaky.

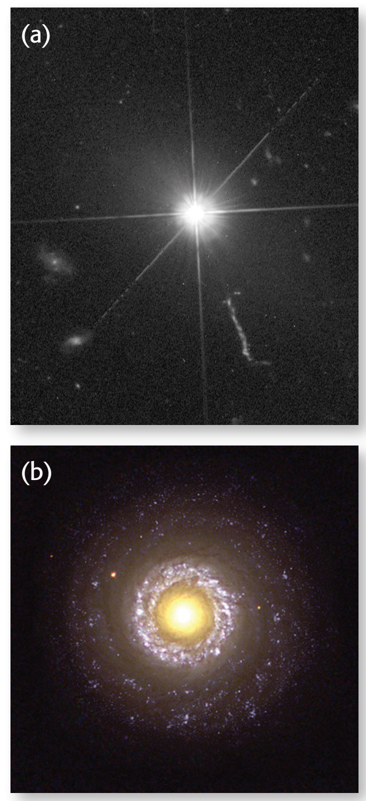


Figure 1.36 Evidence for the Big Bang (a) Quasar 3C 273 in the constellation Virgo is 2.4 billion light years from Earth and was the first quasar ever discovered. (b) Seyfert galaxy NGC 7742.

In the 1950s some strong radio signals from deep space were studied and found to resemble stars in that they were a point source rather than diffuse (spread out) like galaxies. They became known as quasi stellar radio objects, or **quasars** (Figure 1.36 (a)).

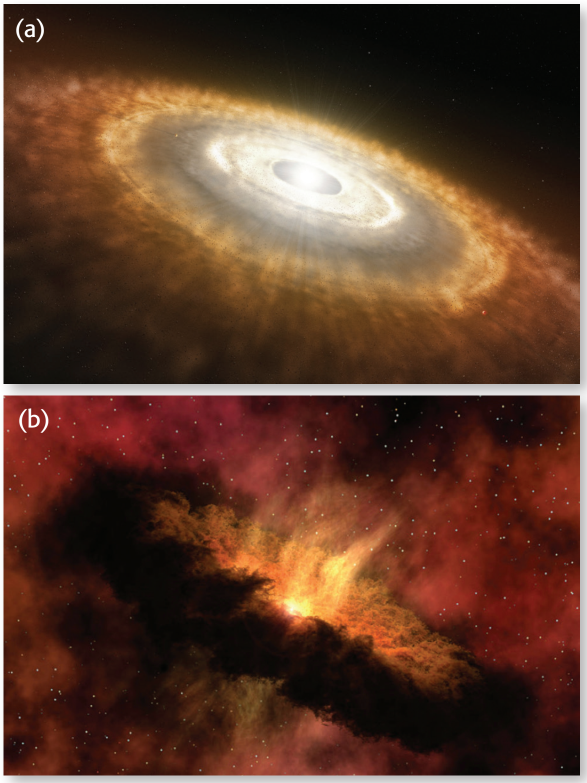


Figure 1.39 Protoplanetary disc (a) An artist's impression of a protoplanetary disc. The centre region eventually ignites as a true star while the surrounding disc of debris forms the protoplanets. (b) A protoplanetary disc as seen through the Hubble Space Telescope. The light coloured background is the Orion Nebula.

Due to the huge internal pressures caused by its collapse, the central protoplanetary sphere became very hot and glowed dimly, forming a **protostar**. Debris within the disc around the protostar gathered into numerous large clumps or **protoplanets** by the process of **accretion –** the gathering together of small bodies into larger ones by gravity (Figure 1.40). Accretion is the underlying process responsible for the initial formation of the Solar System and the associated changes that occurred.

These protoplanets numbered in the hundreds if not thousands. They would 'vacuum' up and concentrate most of the dust in the disc surrounding the protostar that was to become our Sun.

Gravitational squeezing caused temperatures and pressures within the protostar to increase to enormous levels. When pressure and temperature reached the critical temperature of tens of millions of degrees, hydrogen atoms – the most abundant component of the protostar – began to fuse together to make helium atoms. This **nuclear fusion reaction** releases huge amounts of energy in the process. It follows Einstein's famous equation $E = mc^2$.

This equation states that energy (E) = mass (m) multiplied by the speed of light squared (c^2). The speed of light squared is a huge number, so in effect this equation means that even small amounts of matter can be converted into very large amounts of energy. As it undergoes constant nuclear fusion reactions our Sun loses 4 tonnes in mass every second!

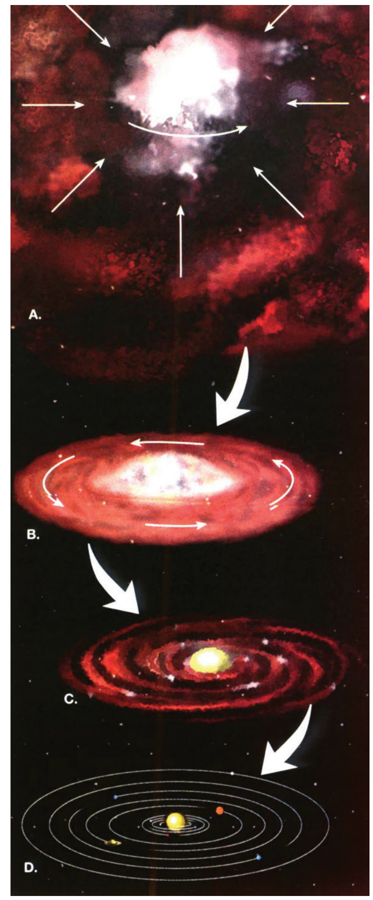


Figure 1.40 Formation of the Solar System The Earth and other planets are the result of the accretion of dust and gases orbiting the Sun.

When fusion reactions started, the protostar ignited like a massive and sustained nuclear bomb, becoming a **true star**. Further collapse was prevented by these nuclear fusion reactions in the core of the Sun pushing outwards against gravity. The ignition of our Sun blew away much of the surrounding material, including most of the gases around the inner planets. This is why the inner planets of our Solar System are small and rocky while the outer planets are gas giants (they were far enough away from the Sun to avoid being blasted so strongly). The ignition of fusion reactions within the Sun marks the moment of 'birth' for our entire Solar System, and it occurred around 4.6 billion years ago.

The formation of the Earth

Even though the planets were forming by accretion of dust particles at the same time as the Sun was forming, it would be a mistake to think that the planets were 'born' as we know them today at the same time as the Sun exploded to life. The infant Solar System would have contained hundreds of small protoplanets with overlapping orbits. At this time the Solar System would have resembled a giant smash up derby.

These protoplanets would have been constantly bombarded with meteorites as they swept into each other or cleared their orbits free of debris. This bombardment not only increased the Earth's size and mass but also heated its rocks to melting point. The gases released from these molten rocks would form Earth's first atmosphere. Below the surface, heavier metallic elements sank deep into the liquid Earth, while the lighter elements floated at the surface like volcanic froth.

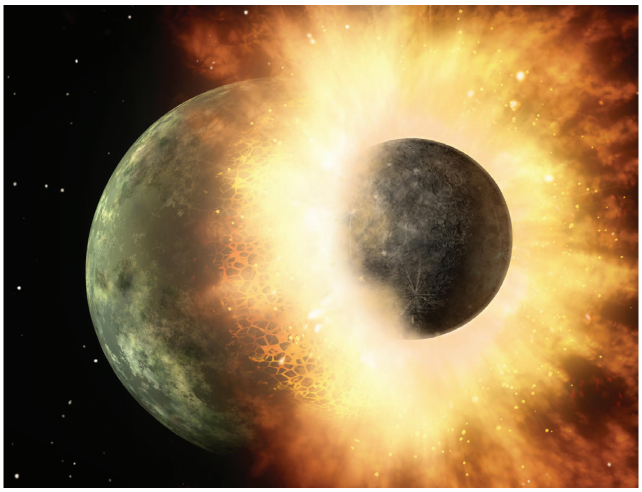


Figure 1.41 Formation of the Moon Artist's impression of the collision that led to the formation of our Moon.

Our Moon is believed to have been born out of one colossal impact between the Earth and another protoplanet the size of Mars (Figure 1.41). Huge amounts of debris exploded into space; much of it falling back to Earth and some of it coalescing to form the Moon. This theory accounts for the fact that Moon rocks seem to have formed 100 million years after the Earth did. It also explains the fact that although Moon rocks have a similar chemical signature to Earth rocks, they are deficient in iron. If the Mars-sized meteorite hit the Earth with an off centre blow, Earth's core (where most of the heavy molten iron had accumulated) would have remained intact.

ACTIVITY 1.9
THE MAKING OF THE MOON

Search online for an animation, applet or video on the formation of the Moon. Save screenshots to show a sequence of steps starting with 'Earth and protoplanet on collision course' and ending with 'Moon fully formed and in orbit around Earth'.

Eventually, the planets as we know them today were the 'winners' of the protoplanetary smash up derby. As they settled into stable orbits and swept the space around them free of debris, they experienced decreasing meteorite impacts. The Earth cooled enough for the abundant water vapour in the atmosphere (released from the molten rock) to condense and form thick clouds. Rain fell heavily (probably for many decades) and continued until oceans covered the low-lying areas and most of the planet's surface.

Earth's formation
http://qr.w69b.com/g/qmzhX0MF2

ACTIVITY 1.10
HAPPY BIRTHDAY EARTH!

18th birthdays are a special occasion in our society. They mark the transition from the age of childhood to the age of adulthood. They are often accompanied with embarrassing childhood photos or videos and speeches remembering the key moments of the person's life to date.

You are to organise a presentation of the key events (described previously in this chapter) which led to the formation of a solid Earth with land and ocean. It should include pictures with descriptions, stories or anecdotes (either written or spoken). Don't just restate the science content as told in this text. Deliver your story as though the Earth is your best friend and that you are doing a slideshow at Earth's 18th birthday party.

Table 1.11 Rock-forming minerals.

Mineral group	Appearance	Subgroups	Description
Feldspar		• Orthoclase (potassium) • Plagioclase (sodium or calcium)	Porcelain-like blocky rectangular crystals. Colour ranges from white, pink, grey, yellow and occasionally greenish. **Hardness** = 6. The most common mineral group in the Earth's crust. Large pink or white feldspars are common in granites. Good **cleavage** in two directions at approximately 90°. Earthy **lustre**.
Mica		• Biotite (black) • Muscovite (white)	**Soft** (hardness = 2 to 3) and **glassy** minerals which have perfect **cleavage** in one direction. This allows micas to be broken into thin, elastic flakes. Abundant in granites and many sandstone and metamorphic rocks. Old fashioned ovens, heaters and airplanes used mica sheets as windows.
Quartz		• Rock crystal • Amethyst • Rose quartz • Milky quartz	Silicon dioxide (SiO_2). Distinguished by its **hardness** of 7 and **glassy lustre**. Colourless when pure, but impurities can give it a variety of colours. Where crystals grow freely they form long six sided shapes which terminate at a point. Common in granite but since it solidifies after most other minerals, it fills available gaps and does not show well developed crystals. Because it is chemically stable and physically hard, it is one of the most durable minerals. Sand on beaches and in sandstones is usually mostly quartz grains rounded by weathering and erosion. Shows **conchoidal (curved) fracture** due to no cleavage lines.
Ferromagnesian minerals	 		All contain medium to large amounts of iron or magnesium. Are dense and range in colour from dark green to black. They are most common in basalts where they are responsible for the overall dark colour. **All are harder than glass**.
		• Olivine	The most abundant mineral in the mantle. **Green** and **glassy** appearance and occurs in **granular** masses. Hardness = 6.5 to 7.
		• Pyroxenes	Dark green to black **crystals** which are either **four or eight sided**. Hardness = 5 to 6. **Cleavage** in two directions at 90°.
		• Amphiboles (hornblende)	Chemically similar to pyroxenes, but form **elongated crystals**. Hardness = 5 to 6. **Cleavage in two directions of 60° and 120°**. Characteristic odour when breathed upon.
Clay minerals			Produced by the weathering of other minerals near the Earth's surface. Form a major part of the soil. Come in a wide variety of colours. **Crystals** are always **microscopic** and have **sheet structure**. Hardness = 1.5 to 2.5.
Calcite			Calcium carbonate ($CaCO_3$). The main mineral in limestone and marble. It is precipitated from sea water by organic and inorganic means and from ground water by evaporation in caves. Hardness = 3. **Bubbles** readily when **dilute hydrochloric acid** is applied. Clear or milky to yellow in colour. Perfect **cleavage** in three directions at about 75°.
Dolomite			Carbonate of calcium and magnesium ($CaMg(CO_3)_2$). Hardness = 3.5 to 4. **Bubbles** slowly in **hydrochloric acid** and only if powdered first.
Halite			Sodium chloride (NaCl). Soft and easily dissolved mineral mainly responsible for the salty taste of sea water. **Crystals** are **colourless** and form **perfect cubes**. Hardness = 2.5.
Gypsum			Also abundant in sea water. **Colourless to white** and **hardness = 2** with an **earthy lustre**. The sheets used to cover walls on the interior of houses are normally gypsum bound in paper (gyprock). **Cleavage perfect** in one direction, poor in two directions.

Minerals

Most rocks are made up of a mixture of different solid particles. These rock-forming solids are called **minerals**. Each mineral type has a specific chemical composition and specific physical and chemical properties. Knowing these properties allows the observer to determine which mineral they are looking at.

Fewer than 20 kinds of minerals make up almost all of Earth's crust and upper mantle. The most common of these are listed in Table 1.11. The most helpful properties for identifying each mineral are in bold type. Some of the specific terms, such as *hardness* and *cleavage*, are described in the next section.

Identifying minerals

While the most accurate way of identifying a particular mineral is by chemical analysis in a laboratory, this is both expensive and impractical for geologists in the field (or students in the lab). Therefore, a combination of simple field tests that determine the physical characteristics of a mineral is normally used to identify a mineral. These tests include **hardness**, **streak**, **lustre**, **density/specific gravity** and **cleavage**.

Hardness

A mineral's hardness – its resistance to being scratched – can be determined by rubbing it against minerals or other substances of known hardness (Figure 1.48). If two minerals of different hardness are rubbed, the softer mineral becomes scratched; if two minerals of equal hardness are rubbed, both will be scratched. **Moh's hardness scale** is the standard scale used when identifying mineral hardness (Table 1.12).

Figure 1.48 Chalk A soft rock mineral which is scratched by any surface harder than it is.

Table 1.12 Moh's hardness scale.

Hardness	Standard mineral	Test materials
1	Talc	
2	Gypsum	Fingernail (2.5)
3	Calcite	Copper coin (3.5)
4	Fluorite	Knife blade (5)
5	Apatite	Window glass (5 to 5.5)
6	Feldspar	Steel file (6.5)
7	Quartz	
8	Topaz	
9	Corundum	
10	Diamond	

Lustre

Lustre refers to how shiny a mineral's surface is. It is a comparison of the mineral's appearance with that of a known standard. Lustre is broadly described by subjective terms, such as *metallic* and *non-metallic*. Different non-metallic lustres include glassy, adamantine (diamond-like), resinous (resin-like), silky, fibrous, pearly, greasy, waxy and earthy (dull). Generally, the lustre descriptions most needed for common minerals are *metallic*, *glassy* and *earthy*.

Streak

The observed colour of a mineral can be misleading because of impurities. A mineral's colour when powdered – called its **streak** – is usually more consistent and able to be used as a diagnostic test. It is seen by scraping the mineral on the unglazed back of a white tile (Figure 1.49). If the mineral is harder than the porcelain, however, it will need to be crushed on a harder surface. An example of the usefulness of streak is when comparing the similar-looking gold and pyrite (fool's gold): gold's streak is gold while pyrite's is black.

Figure 1.49 Streak plates Pyrite (left) and rhodochrosite (right) showing their characteristic streak colours.

Specific gravity

Specific gravity describes a mineral's density relative to water (Figure 1.50). For example, halite (rock salt) has a specific gravity of 2, meaning it is twice as heavy as an equal volume of water. The density of water equals 1 gram per cubic centimetre and its specific gravity is 1. Most metallic minerals have a high specific gravity (greater than 3.5).

Mineral properties and identification lab http://qr.w69b.com/g/msYbMFWIo

Figure 1.50 Gold Gold has a very high specific gravity of 19.3.

To accurately determine a mineral's specific gravity, you must divide its mass (in grams) by its volume (in cubic centimetres, or cm^3). The volume of a mineral sample can be determined by measuring how much water it displaces when submerged.

Cleavage and fracture

Cleavage refers to how a mineral naturally breaks or splits (Figure 1.51). Many minerals have specific lines of weakness (cleavage planes) owing to their crystal structures and so will break in a particular way, such as the flat sheets seen in mica.

Figure 1.51 Cleavage The mineral calcite showing three cleavage planes.

Other minerals have no specific lines of weakness and so break in uneven but identifiable ways. For example, when quartz is chipped it exhibits a curved (conchoidal) fracture similar to chipped glass.

Special properties

Some minerals have other unique properties which can be used to identify them. For example, halite (rock salt) can be identified by its taste and calcite will bubble if acid is dripped on it. Some minerals are magnetic, others fluoresce in different colours under UV light (Figure 1.52), while some have a distinct smell; all of which can be used to identify the mineral.

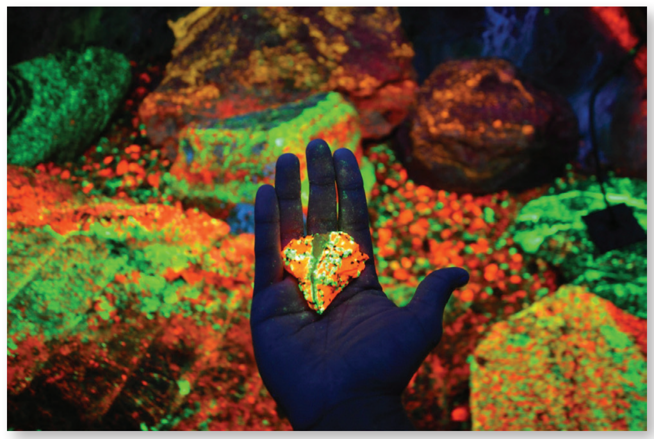


Figure 1.52 Fluorescent A geologist collects fluorescent willemite (green) and calcite (red) from the Franklin Hill site in New Jersey, USA. These minerals glow when illuminated by a shortwave UV spotlight.

ACTIVITY 1.16 EXPERIMENT: MINERAL PROPERTIES

Aim: To determine the colour, streak, hardness and density of various mineral samples.

Apparatus: Mineral samples, Moh's hardness kits, white ceramic tiles, electronic balance, various measuring cylinders, safety goggles.

Risk assessment

Hazard: Broken glass.

Risk: Injury.

Precaution: Lower rocks slowly into measuring cylinder, or use plastic measuring cylinder.

Chapter 2
DEVELOPMENT OF THE GEOSPHERE

Interactive vocabulary
http://qr.w69b.com/g/pb17Ft160

Introduction to our atmosphere
http://qr.w69b.com/g/oI5TmhTEY

The purpose of this chapter is to focus on the major changes that Earth has undergone during its long 'life', to reveal the origins of some of its vital features, and to explore some of the ways in which its different systems interact with each other.

2.1 How the atmosphere formed

The majority of life forms on Earth today have evolved to be well adapted to the current atmosphere, specifically to the high levels of oxygen. However if oxygen-loving organisms, such as humans, were exposed to the Earth's *original* atmosphere, they would die quickly (Figure 2.1). This would be the result of not only a lack of oxygen but also high concentrations of poisonous gases, like ammonia and carbon monoxide.

Figure 2.1 Life on Earth Current life forms like this whale could not survive in the Earth's original atmosphere.

Earth's original atmosphere

The original source of the gases that made up Earth's original atmosphere was the planet itself. The process is called **outgassing**. The molten rocks of the young, hot Earth released a mixture of gases, just as volcanoes still do today. Some of these gases remain in the atmosphere to this day; others were quickly removed by a variety of processes. While their relative proportions are uncertain, the main gases of the original atmosphere seem to have been nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O).

Earth's current atmosphere

Careful measurement and chemical analysis have allowed scientists to determine the proportions of gases that make up the atmosphere. Those for dry air are found in Table 2.1. Water vapour, which is not listed with the others because of its variability, ranges between 0.1 and 3 per cent.

Figure 2.2 Limestone This limestone was formed in ancient seas.

2. Figure 2.8 shows the changes in composition of the oceans during the early history of the Earth.

(a) **Explain** the changes in oxygen concentration at the ocean surface.

(b) **Explain** the changes in oxygen concentration at the bottom of the ocean.

(c) **Explain** the changes in concentration of iron in the oceans.

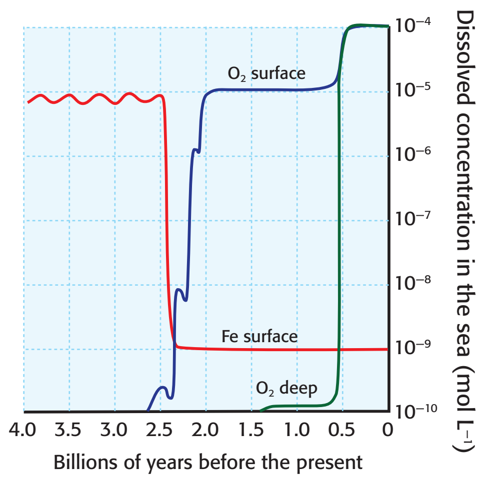


Figure 2.8 Ocean composition Changes in the composition of the ocean over time.

TO THINK ABOUT

Set 1

1. **Identify** the probable first type of photosynthetic creatures and when they first appeared.

2. **Outline** how chemical precipitation could have removed carbon monoxide and carbon dioxide from the atmosphere.

3. Methane is thought to have been abundant in the early atmosphere. What did methane react with and what compound did this reaction form? What became of the resulting atmospheric compound?

4. **Explain** why oxygen did not begin to accumulate in the atmosphere until almost 1000 million years after the appearance of the first photosynthetic organisms.

5. **Describe** the forms in which carbon is now locked up in the lithosphere and biosphere.

Set 2

6. **Describe** differences in the composition of the atmosphere before and after the evolution of photosynthesis.

7. **Describe** where the precipitated carbonate minerals of the early Earth were deposited and why. Where are minerals such as calcium carbonate deposited today?

8. Almost 1000 million years elapsed between the arrival of the first photosynthetic organisms and the accumulation of oxygen in the atmosphere. **Explain** the changes to the ocean's composition during this time.

9. How could you **demonstrate** that plants produce oxygen by photosynthesis?

10. **Explain** why life could evolve in the Earth's early atmosphere but could not evolve in its atmosphere today.

2.2 Structure of the atmosphere

Figure 2.9 Sunburn Australians have the highest levels of skin cancer in the world.

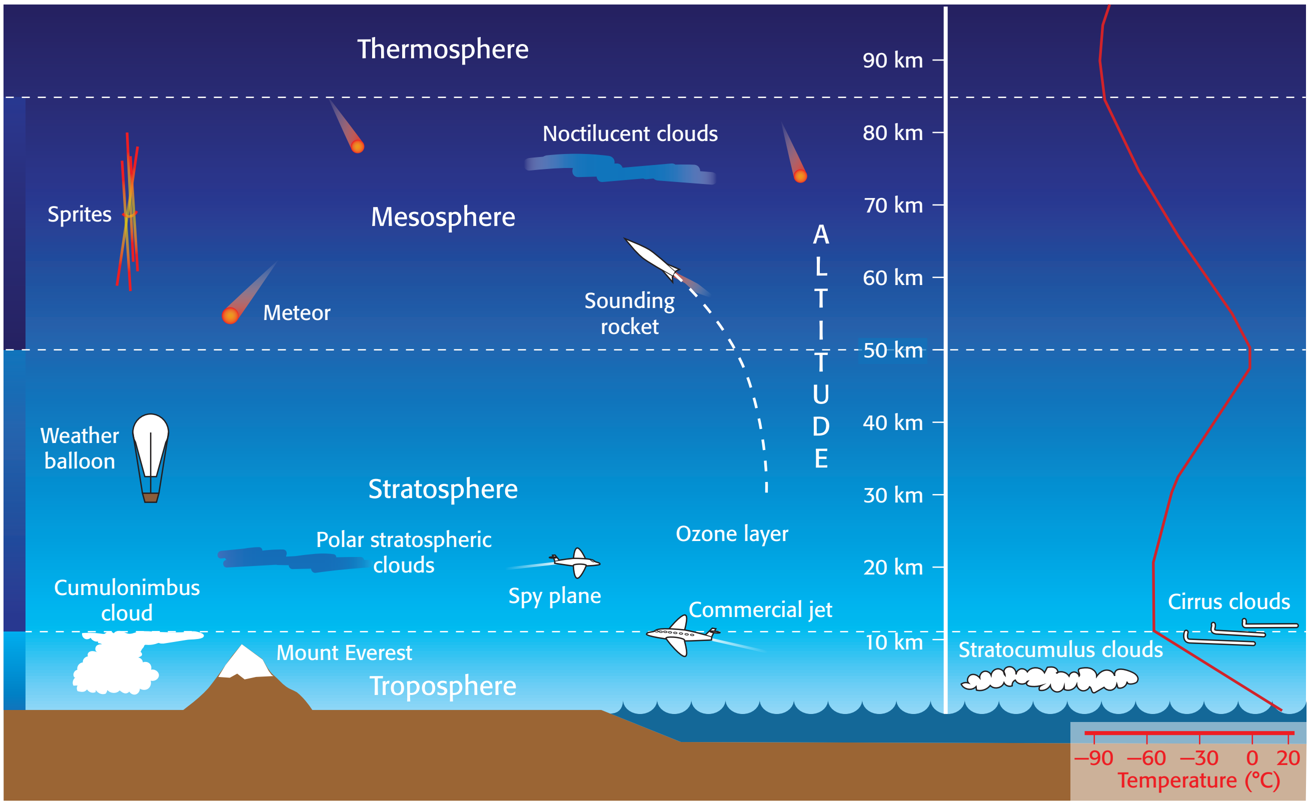


Figure 2.10 Layers in the atmosphere From the ground up, the layers of the atmosphere are the troposphere, stratosphere, mesosphere and thermosphere. The graph on the right indicates the temperature changes that allowed meteorologists to identify these separate layers. (Randy Russell, UCAR)

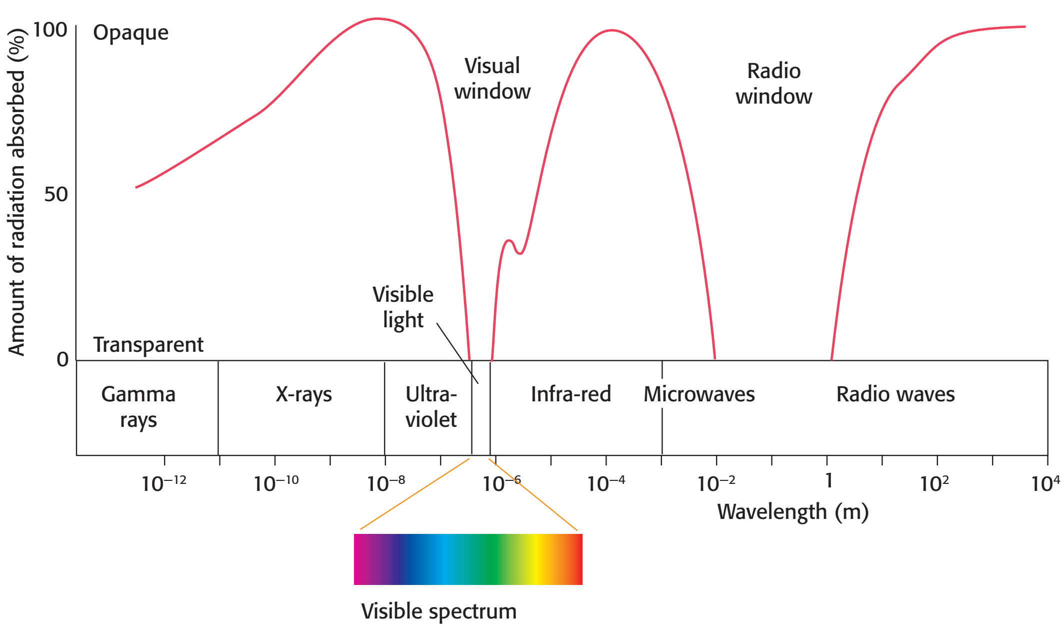


Figure 2.11 Electromagnetic spectrum Some radiation reaches the Earth's surface but most is absorbed as it passes through the atmosphere.

2.3 Origins of water on Earth

When seen from space, three-quarters of our planet's surface is covered by water (Figure 2.16). This liquid water, which is so abundant on Earth, is a very rare substance elsewhere in our Solar System. It is also one of the key reasons why our planet has life. The rocks that form the skeleton of our environment have been gnawed away by the action of water over time. The resulting soils reflect the availability of water in that region to some extent.

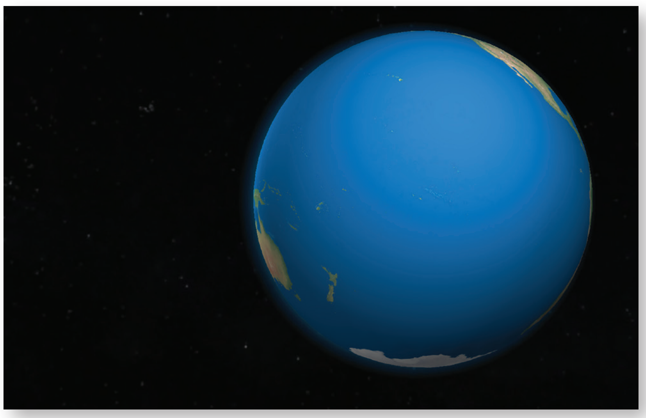


Figure 2.16 Planet water When seen from space, three quarters of our planet's surface is covered by water.

Although Earth has abundant water, little of it is fresh. It is the uneven distribution of this fresh water that mainly determines the types of habitats that occur across Australia. From the desert to the Daintree, all Australian environments reflect the quality and amount of water they receive. In the past 200 years, human activities have altered the quality and distribution of water in this country. Governments are now struggling for solutions to protect one of our most neglected natural resources.

Introduction to water
http://qr.w69b.com/g/qVVb5pI9W

The origin of Earth's water

For long time scientists were unsure as to the original source of Earth's water. During the formation of the Solar System, the ignition of the Sun would have blown materials with low boiling points (like water and gases) out of the inner Solar System, leaving behind mostly rocky and metallic material.

This means that water must have been returned to Earth from the frosty outer Solar System sometime after the Sun ignited.

The most likely candidates for this were believed to be comets as they are made mostly of water ice, are common visitors from the outer Solar System and can be quite large. However, in 2004 the NASA space probe **Stardust** flew through the tail of a comet, allowing the first ever capture and direct analysis of comet water. This analysis showed that comet water has twice as much heavy hydrogen isotopes as Earth water does, ruling these out as the main source of our water.

The only match to the hydrogen isotope ratios found in Earth water is a type of meteorite called a **carbonaceous chondrite**. Within this common type of stony meteorite, water is bound up within the minerals rather than existing as liquid or solid H_2O. As the young planet Earth grew by accretion, huge amounts of these meteorites brought water and rock minerals from the outer Solar System. As they struck Earth, the water in these minerals either vaporised and became part of the first atmosphere or became part of the geosphere, available for release from volcanoes at some time in the future.

Where did Earth's water come from?
http://qr.w69b.com/g/twQINUrjG

ACTIVITY 2.9
EARTHILOCKS AND THE THREE POTENTIAL SOURCES OF TERRESTRIAL WATER

Follow this QR link and use it to create a digital cartoon/presentation about the origin of Earth's water.

Earthilocks and the three potential sources of terrestrial water
http://qr.w69b.com/g/t7Rtr1B2E

Latitude

Many of the world's deserts are located on or near the Tropics of Cancer (Northern Hemisphere) and Capricorn (Southern Hemisphere). Areas along the equator, however, tend to receive some of the highest rainfalls (Figure 2.18). Both of these occurrences are the result of the convection of air in the atmosphere.

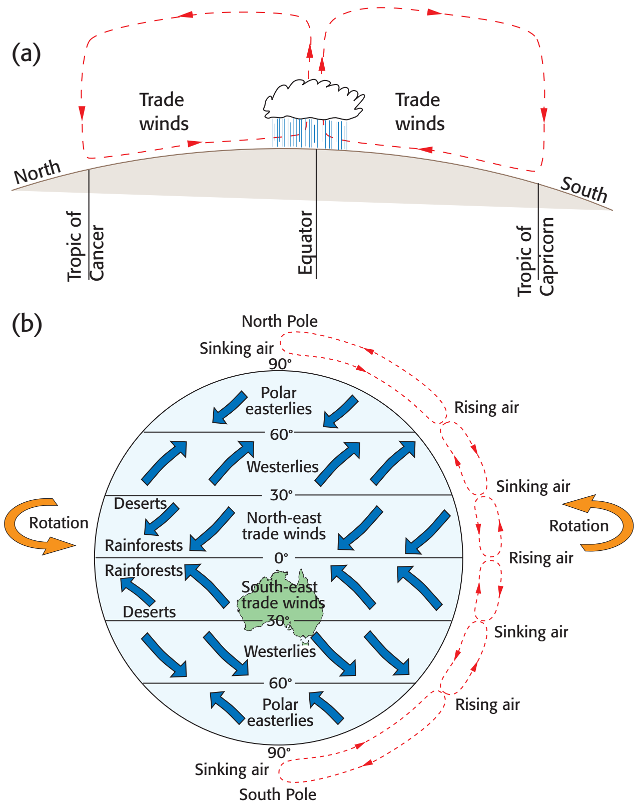


Figure 2.18 Latitude (a) Hot air rises over the tropics, loses its moisture and descends over desert areas. (b) The circulation of the atmosphere creates tropical regions along the equator and deserts along the Tropics of Cancer and Capricorn.

Equatorial regions are typically hot all year round, causing air to rise by convection. As air rises, it cools, cloud develops and high levels of rainfall result. This same air is moved to both the north and south of the equator. It then becomes cooler and sinks around 30° above and below the equator. This sinking air warms as it descends, preventing clouds from forming in the already dry air. The warm, dry, descending air is the reason why most deserts occur near the northern Tropic of Cancer, and the southern Tropic of Capricorn.

Climate

An area's **climate** is its long term typical weather patterns and will determine how much precipitation it receives. Climate is the end result of many factors: besides latitude and topography, it is also influenced by altitude, wind directions, ocean currents and proximity to the ocean (Figure 2.19).

If you live near the coast, you know from experience that the oceans moderate the local climate. In summer, the oceans absorb much of the heat so that nearby areas remain cooler. In winter, the oceans remain warmer than inland, and this helps moderate the low temperatures. Inland, the days are hotter as less heat is absorbed and the nights are much cooler as there is less heat released.

This all arises because of the specific heat of water. One kilogram of water will absorb more than five times the amount of heat than soil to produce a temperature rise of 1°C compared to nearby land. At night, or in winter, the water will have to release more than 5 times the amount of heat compared to soil to reduce its temperature by 1°C.

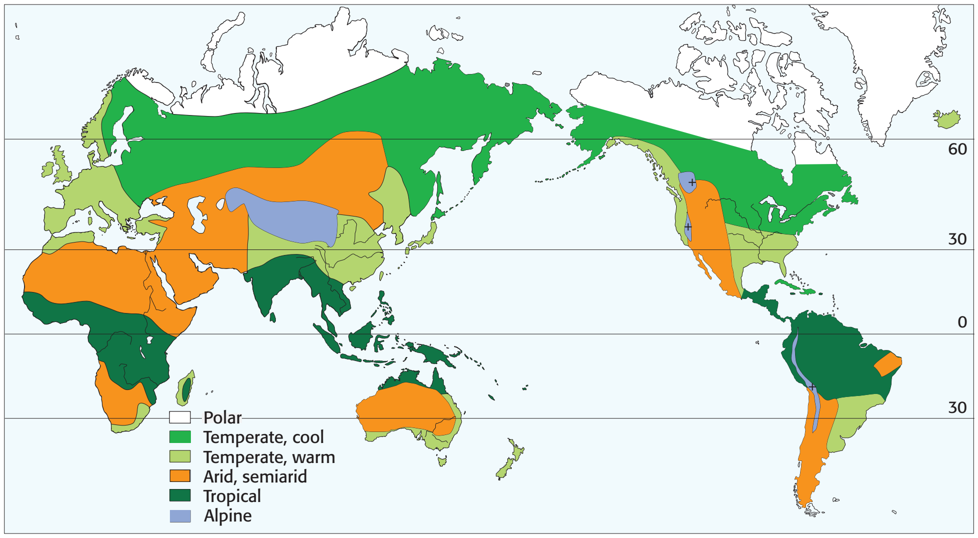


Figure 2.19 Climatic zones of the world Climate is influenced by latitude, topography, altitude, wind directions, ocean currents

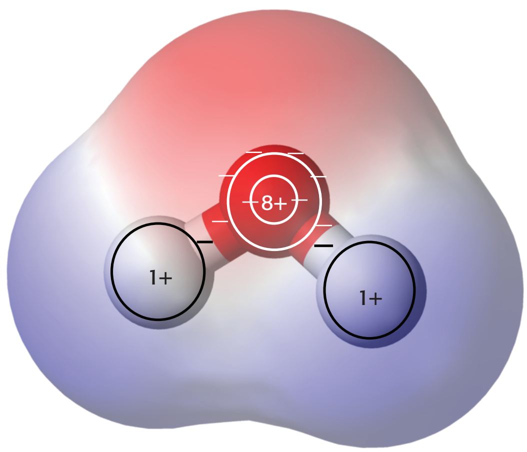


Figure 2.21 The polar nature of water molecules The polar nature is responsible for several of water's unique properties. The oxygen atom pulls the electrons (–) in tight and so has an overall negative charge surrounding it (in red); while the hydrogen ends of the water molecule have an overall positive charge surrounding them (in blue).

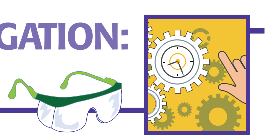
Water as a solvent

Polar liquids like water are excellent solvents for other polar molecules, be they solids, liquids or gases. These include:

- Ionic solids which are compounds such as salts where a metal joins with a non-metal, e.g. sodium chloride.
- Gases such as oxygen and carbon dioxide.

Because it is such a good solvent, water is sometimes referred to as the universal solvent (although this is not quite correct because non-polar molecules such as silica and oil will not dissolve in it). Its ability as a solvent allows biological processes to occur rapidly in solutions. For example, water carries nutrients and oxygen quickly to the cells where they are needed, and then transports carbon dioxide and other wastes quickly away. All forms of life on Earth must maintain a high proportion of water within their cells. Otherwise, vital biochemical reactions slow down or fail, causing death.

ACTIVITY 2.12 INVESTIGATION: WATER AS A SOLVENT



Aim: To test various household solids/powders to see if water acts as a solvent for them. Construct a data table to record your predictions and results.

Before you begin, refer to Chapter 7 (Investigating Earth and Environmental Science) to identify the following components of your experiment: Aim, hypothesis, risk assessment, apparatus, variables (independent, dependent and fixed), control and method. Have your teacher check your method for safety.

Note:

- Substances in your kitchen pantry are most likely to resemble those in nature.
- Shaking, stirring or using hot water will accelerate the dissolving rate.

Solubility of oxygen and carbon dioxide

Oxygen gas and carbon dioxide are the two most vital gases for living things on Earth. All organisms are classed as either **autotrophs** (meaning 'self-feeders' because they manufacture their own food from raw materials) or **heterotrophs** (meaning 'other feeders' because they must consume other organisms).

All autotrophs require carbon dioxide as one of the raw materials for making food by photosynthesis. All heterotrophs obtain their energy from autotrophs through the food chain; therefore they too rely indirectly on carbon dioxide.

The majority of life forms respire aerobically. Oxygen is needed for their cells to produce energy; carbon dioxide is produced as a waste product of this process. This is why the air you exhale is much richer in carbon dioxide than the air you inhale – the increase is the waste product of respiration within your cells.

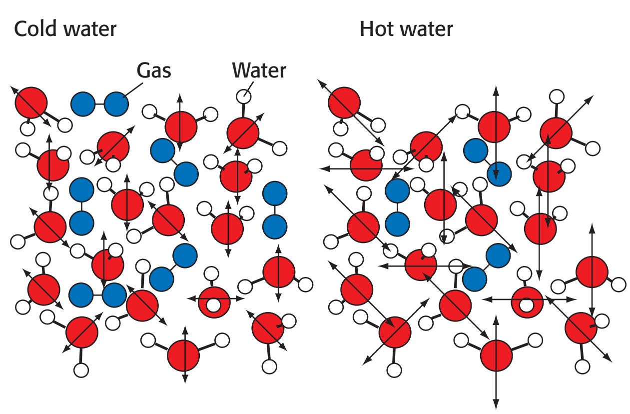


Figure 2.22 Water as a solvent Water molecules vibrate less in cold water, allowing more gas molecules to fit between the water molecules.

Chemical weathering of rocks

Weathering is the physical or chemical breakdown of rocks. Chemical weathering occurs when water dissolves and removes minerals. Salts in the oceans (there are many salts, not just sodium chloride) are all minerals dissolved by water from rocks both on land and in the ocean basins. As well as being a solvent for many minerals, water accelerates chemical reactions between minerals and the air, further acting as an agent of weathering. Areas that are moist and warm experience the greatest chemical weathering by water.

Pure water has a pH of 7 and is therefore neutral. However, water in nature is never pure. As raindrops fall through air, they absorb carbon dioxide and become a weak acid called carbonic acid. (This is a normal process and not associated with acid rain caused by humans.) Water can become even more acidic if it moves through decaying organic matter in the soil. The result is that most liquid water in the environment is weakly acidic.

Water is usually such a weak acid it has little or no effect on most things. However, limestone rocks contain the mineral calcium carbonate that is particularly reactive with acids. These rocks will instantly bubble if a strong laboratory acid, like hydrochloric acid, is added. If a weak acid (like rainwater) is added to them, this reaction happens far more slowly, although its effects over geologic time can be dramatic. Limestone caves are among nature's most spectacular features and are the result of the dissolving of limestone by water (Figure 2.28).

Figure 2.28 Limestone caves Limestone caves are the result of the dissolving of limestone by water.

Explore a virtual cave system
http://qr.w69b.com/g/ta0pIJUoo

ACTIVITY 2.17 EXPERIMENT: BOUNCY EGGS

Aim: To determine the effect of a dilute acid on calcium carbonate.

Like limestone, eggshells are mostly made of calcium carbonate.

Apparatus

- Raw egg
- Beaker or glass
- Vinegar

Risk assessment

Hazard: Chemicals.

Risk: Injury.

Precaution: Wear safety goggles.

Method

1. Place an egg in a glass and cover it with vinegar.
2. After a few minutes you can see bubbles forming, resulting from the reaction of the acid with the carbonate. What gas could this be? How could you verify your answer?
3. After a few days, remove the egg. How is it different?

Conclusion: Answer the objective at the start.

SCIENCE SKILLS

1. Figure 2.29 shows electrical conductivity of the water in the Murray River at the town of Morgan.
   (a) In which year(s) were salinity levels highest?
   (b) In which year(s) were salinity levels lowest?
   (c) Is there any correlation with river flows. **Explain** your answer.

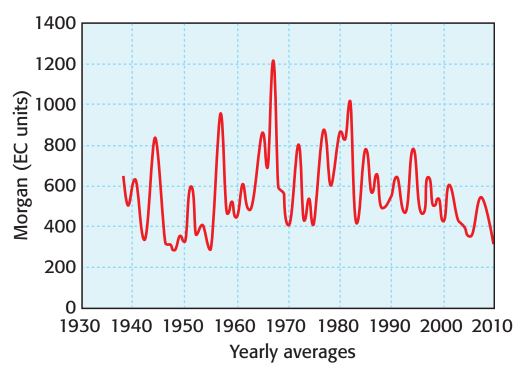


Figure 2.29 Salinity Electrical conductivity in the Murray River at the town of Morgan in South Australia.

2. Draw a flow chart showing the stages a river may go though to produce an algal bloom.

TO THINK ABOUT

Set 1

1. **Describe** how the solubility of oxygen and carbon dioxide changes with water temperature.
2. One reason why water is vital to life is that it dissolves many substances that living things need to absorb or excrete. **Identify** three substances important to life that are dissolved by water.
3. Which of the following aquatic environments would experience the greatest range of salinities? **Explain** your answers.
   (a) Oceans.
   (b) Deep and permanent freshwater lakes.
   (c) Inland rivers of Australia.
4. **Identify** the pollutants mostly responsible for algal blooms.
5. **Explain** how and why evaporation can affect the salinity of water.

Set 2

6. **Outline** why fertilisers and detergents can produce algal blooms in waterways.
7. Water in small ponds can often warm considerably during hot weather. If this happens, fish in the pond can be seen gasping for air at the water surface. **Explain** why the fish are unable to get what they need from the water under these conditions.
8. Predict the potential impact of excessive water evaporation and subsequent increase in salinity on common terrestrial organisms. **Explain** your answer.
9. ‘Although the exact range of salinity tolerance for most fish in Australian inland rivers is not known, they are assumed to be tolerant of a wide range of salinities.’ **Explain** this statement.
10. **Outline** the effect of common detergents on growth of algae in ponds.

Surface tension

Water’s surface tension results in two important properties: it is both cohesive and adhesive. **Cohesion** refers to the tendency of water to stick to water (Figure 2.30). It has some important results in nature, including the formation of raindrops, the behaviour of flowing surface water, and the ability of the wax coating on leaves to shed water to allow gas exchange.

Adhesion refers to the ability of water to stick to other surfaces. Adhesion is what causes the upward curve of the meniscus in narrow containers such as measuring cylinders. Place a very narrow glass tube into a beaker of water and adhesion will pull the water up the sides of the tube above the level in the beaker. One of the greatest effects of adhesion is the ability of plants to draw water up from the soil to their leaves through narrow water conducting xylem tissue (although this process also involves the cohesive pull between water molecules).

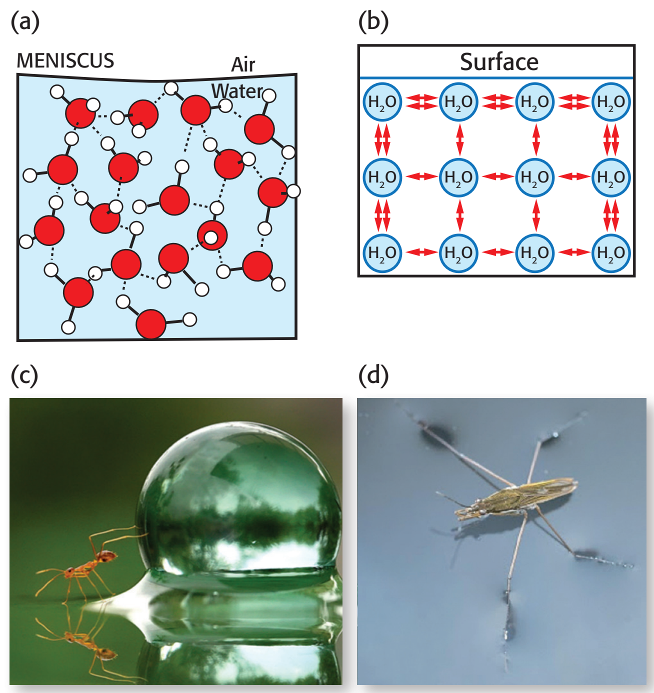


Figure 2.30 Surface tension (a) The polar charges of water molecules means that they are attracted (dotted lines) to the water molecules above, below and beside them. (b) Surface water molecules have no molecules above them, so they bind more tightly with the molecules beside them, resulting in surface tension. (c) Surface tension acts like a skin and results in the rounded shape of water droplets. (d) Surface tension allows some specially adapted small animals to walk on water.

ACTIVITY 2.18 EXPERIMENT: SURFACE TENSION

Aim: To investigate whether different types of water have different surface tension.

Hypothesis: Write your prediction to the outcome of the aim as an 'If … then … because …' statement.

Apparatus

- 3 × 5 cent coins
- Dropper for each water type
- Small beaker for each water type
- Various water types: deionised water (with all dissolved solids removed), salt water, tap water (hot, room temperature and cold), soda water, limewater
- Small towel

Risk assessment

Hazard: Hot water and chemicals (limewater = calcium hydroxide solution).

Risk: Injury.

Precaution: Handle hot water with care. Wear safety goggles when using limewater and rinse skin if it comes into contact.

Method

1. Predict how many drops of deionised water you think will be able to fit onto the surface of a 5 cent coin. Record this.
2. Test your prediction using an eyedropper on the first coin and record your results. Repeat the test twice more using the same dropper and calculate the average (round off to the nearest whole drop).
3. Dry the coins, then repeat step 2 for all water types you are testing using fresh droppers.

Questions

1. Draw a labelled diagram of the shape that the water formed on the coin. Explain why it did this.
2. What was the control in this experiment? Why was this chosen as the control?
3. What were the two independent variables tested here?
4. How could this method be altered to improve the accuracy, reliability or validity of the experiment?

Surface tension experiments
http://qr.w69b.com/g/qLtlmWxwc

Density

The density of any substance can be determined by dividing its mass (in grams) by its volume (in cm^3 or mL). Almost every substance increases in density as it cools because the atoms within it vibrate less. This reduction in the movement of the atoms decreases the volume of the material while the mass remains the same, resulting in an increase in density. Test this yourself by calculating density using a made up mass and volume, then repeat using the same mass but reduce the volume. This means that as you freeze most liquids, their density increases.

One of the strangest qualities of water is that its volume expands when it freezes, reducing its density (Figure 2.31). Warm water cooled to almost freezing will reduce in volume and increase in density just like other substances. However, as water begins to freeze, the polar molecules that were free moving and arranged chaotically begin to lock into fixed positions at fixed distances from each other in a crystalline lattice. This crystal arrangement creates more space between the molecules. Therefore, as water freezes, its volume increases, decreasing its density.

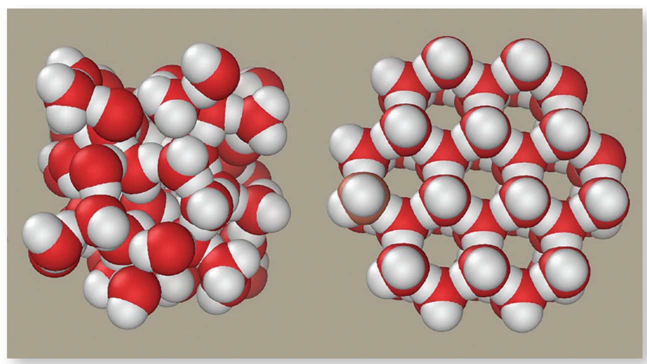


Figure 2.31 Water freezing As water freezes, its molecules change from a close and chaotic arrangement (left) to a more orderly and spaced apart crystal structure (right). This increases the volume of ice and therefore decreases its density.

This seemingly small quirk of water at a molecular level has global consequences for our planet. As water freezes in very cold climates, the ice that is formed floats on the surface due to its decreased density. This allows lakes and oceans in cold climates to form an insulating layer of ice that protects them from the frigid air, which in turn prevents the entire body of water freezing solid. The fact that water ice floats on top of liquid water has major consequences for the absorption and redistribution of heat in the oceans. It is therefore also a major influence on global climate.

On the ocean, when the water temperature drops below zero, fine needle-like crystals of freshwater ice form that expel the salt. This increases the salinity of the remaining water and lowers its freezing point to about minus 2°C. Over time this forms a layer of ice. Antarctic sea ice is usually only 1 to 2 metres thick because it soon moves away from the coldest regions into the Southern Ocean. Arctic sea ice is more land locked and cannot move as easily. It usually reaches 2 to 3 metres thick with some regions 4 to 5 metres. In the Arctic, this layer once covered the whole Arctic Ocean providing a habitat for polar bears and other life (Figure 2.32). With global warming, the extent of this sea ice is decreasing and threatening some species with extinction.

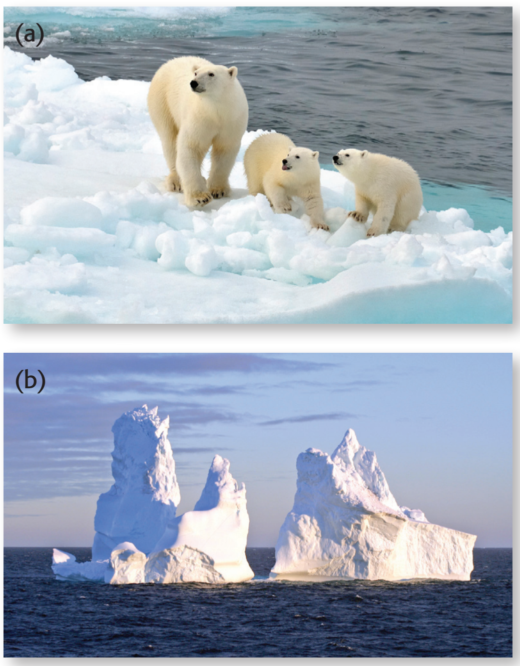


Figure 2.32 Sea ice (a) Sea ice is a habitat for polar bears. (b) Icebergs can be a danger for shipping.

Ice forms on lakes and rivers in much the same way. It depends on the number of days the regions is below zero, as well as the effects of the wind. Again, this layer of ice helps protect life below from the extremes of low temperature. The thickness of ice varies, and in some very cold regions is thick enough to drive on.

Giant glacier piece breaks off http://qr.w69b.com/g/o4SD0yHIs	

Some sea ice comes from glaciers – snow that has fallen high in mountain ranges moves slowly towards the ocean. The glacier may form an ice shelf out into the ocean.

In the Antarctic, these shelves are huge and pieces break off to form icebergs. The water beneath the ice shelf is protected from the very extreme weather above. Ice shelves occur around Greenland and other landmasses of the Arctic. It was an iceberg from this region that the *Titanic* collided with and sank with enormous loss of life (Figure 2.32 (b)).

SCIENCE SKILLS

1. Figure 2.33 shows the size of the Wilkins Ice Shelf over many years.
   (a) In which years was the ice shelf at its largest and smallest size?
   (b) Which side of the ice shelf changes most slowly?
   (c) **Explain** why this side may have melted more slowly.

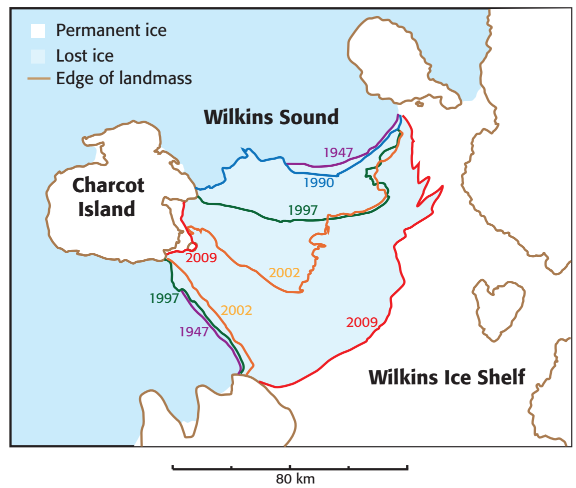


Figure 2.33 Antarctic ice The Wilkins Ice Shelf is going.

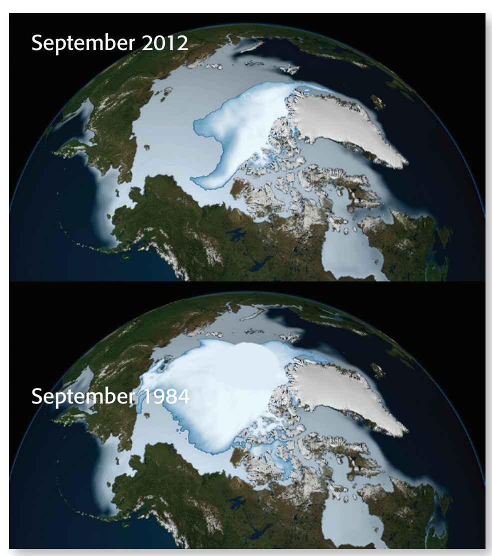


Figure 2.34 Arctic ice The extent of the Arctic ice sheet in the northern autumn of 1984 and 2012.

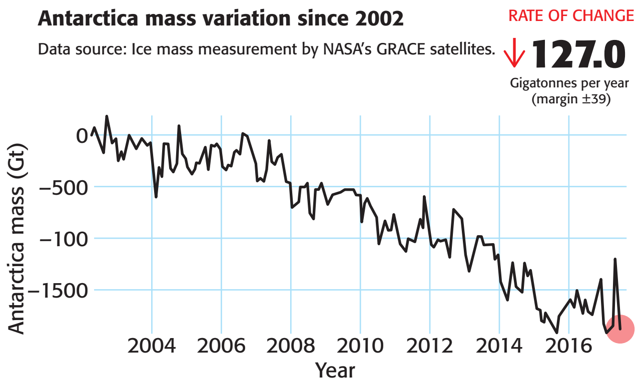


Figure 2.35 Antarctica mass variation since 2002. (NASA)

2. Figure 2.35 shows changes in the mass of the Antarctic ice sheet over time.
   (a) **Identify** the first and last years of data shown in this graph.
   (b) This graph shows that Antarctic ice mass increased between 2004 and 2006. What would you say if someone used this fact as evidence that global heating is not happening?
   (c) **Describe** the overall trend in this data.
   (d) **Explain** how this data could be used to make a prediction for the year 2030.

Mechanical weathering of rocks

Water's density properties also make it a powerful agent of mechanical weathering – the physical breaking down of rocks. Liquid water is dense and as it flows through the landscape under gravity, it can exert enormous force. Water itself is not hard, so it cannot physically wear rocks down by **abrasion** (rubbing). However, water does carry hard rocks and pebbles if it is flowing quickly enough. These sediments can gouge away like sandpaper at any rock surface. The abrasion of rocks involving water as the moving force typically occurs in areas where water flows in large volumes at high speeds (at least occasionally). Mountain streams and exposed rocks at beaches show obvious signs of abrasion by waterborne particles; large scale abrasion can also occur during floods (Figure 2.36).

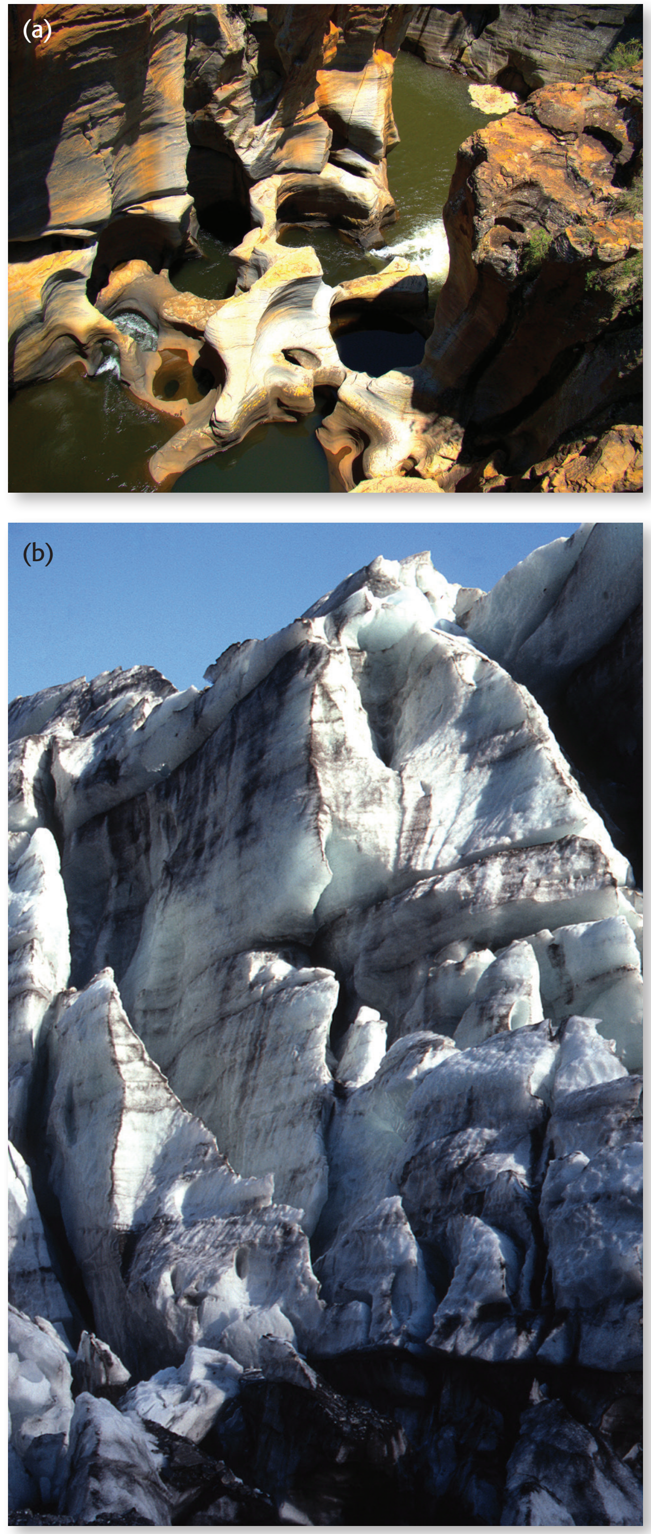


Figure 2.36 Abrasions of rocks (a) Floods cause large scale abrasion. (b) Glaciers are frozen rivers. Their heavy mass and rubble-encrusted bottom makes them very abrasive when they move.

Water as ice in glaciers also causes the abrasion of rocks (Figure 2.37). **Glaciers** are effectively rivers that are frozen solid. They flow slowly downhill, usually at a rate of only a few centimetres per day. Rocks frozen into the sides and base of a glacier act as abrasives to scour the landscape over which the glacier moves. Therefore, glaciers cause massive weathering of rocks in the regions where they occur. If the climate warms and glaciers retreat or vanish, deep U shaped valleys and scoured rocks remain as testament to their power.

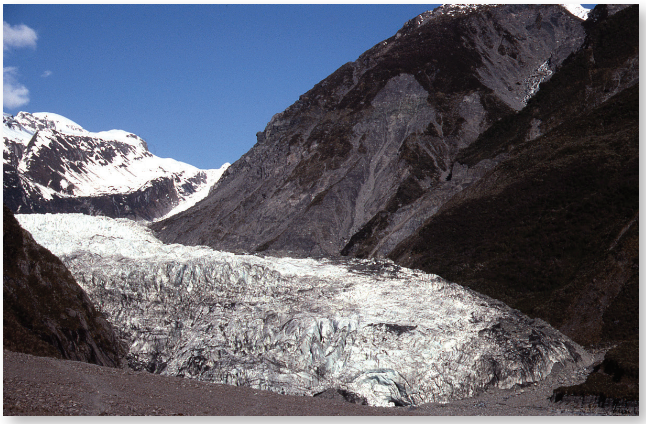


Figure 2.37 Glaciers Moving glaciers carry rocks that can abrade rocks beneath.

What is a glacier?
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Ice wedging is another form of mechanical weathering. It results from the tendency of water to expand as it freezes. All exposed rocks naturally have at least some **joints** (cracks) in their surface. When it rains, water seeps into these joints, where it can remain for long periods of time (Figure 2.38). If the air temperature drops below 0°C, the liquid water turns to ice, expands in all directions and pushes against the rock, widening and lengthening the joint. If the temperature rises above zero degrees Celsius, the ice thaws and the water seeps further into the joint. This process can occur repeatedly in the same joint with the same water. This is known as ice wedging because the ice acts like a wedge to force open cracks in rocks, thereby physically weathering them into smaller pieces (Figure 2.39). Ice wedging occurs most frequently in regions where the freeze-thaw cycle happens often, such as mountain areas or elevated inland plateaus with sunny days and freezing nights.

Figure 2.38 Jointing Rocks often have joints into which water can seep.

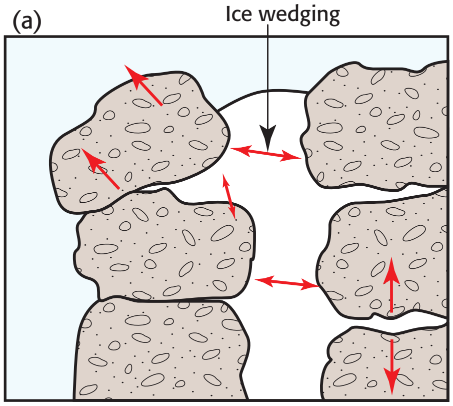

Figure 2.39 Ice wedging (a) Ice acts like a wedge to force open cracks in rocks, thereby physically weathering them into smaller pieces. (b) The exfoliation of granite results in part from ice wedging.

Frost wedging
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Chapter 3

DEVELOPMENT OF THE BIOSPHERE

Interactive vocabulary
http://qr.w69b.com/g/qjEkKh2j6

Urey-Miller experiment
http://qr.w69b.com/g/obCiicclW

3.1 The origin of life

Eggs come from chickens. Chickens come from eggs. So which came first – the chicken or the egg?

This question and ones like it are often called **chicken or the egg questions**. One such question regarding the origin of life on Earth challenged scientists last century. All living things are made of organic molecules and organic molecules are only produced by living things, so how could either of these things come into existence without the other one coming before it?

This contradiction presented such a problem for scientists in a variety of fields that some suggested it could never be answered. The answer finally came from an unlikely source in a surprisingly easy way.

The Urey-Miller experiment

In 1953 a 23 year old graduate student in chemistry at the University of Chicago, Stanley Miller (1930-2007), planned an experiment to reproduce conditions similar to those on Earth 4000 million years ago. He asked a glassblower to make a simple apparatus in which water and gases, representing the Earth's early sea and atmosphere, could be heated and circulated (Figure 3.1). He generated electrical sparks, simulating lightning, in the atmospheric chamber and let his apparatus run for a week.

After a while the water began to turn pink and then red. When Miller analysed the chemicals in the water, he found a large variety of **amino acids** – organic molecules that are the building blocks of **proteins**. Proteins are structural components in cells and they control the thousands of metabolic processes that take place in cells.

News of this result electrified the scientific world and made Miller famous. He had solved this chicken-or-the-egg puzzle by demonstrating that, in the right conditions, organic molecules can form spontaneously from inorganic ingredients. It has since been shown that the building blocks of DNA, carbohydrates and other organic molecules can also be formed in this manner. Ultraviolet light and heat have been successfully used instead of sparks as the energy for breaking the chemical bonds of the gases in other versions of the Urey-Miller experiment (American chemist Harold Urey (1893-1981) was Miller's overseeing professor).

Urey-Miller interactive
http://qr.w69b.com/g/pijt50PjG

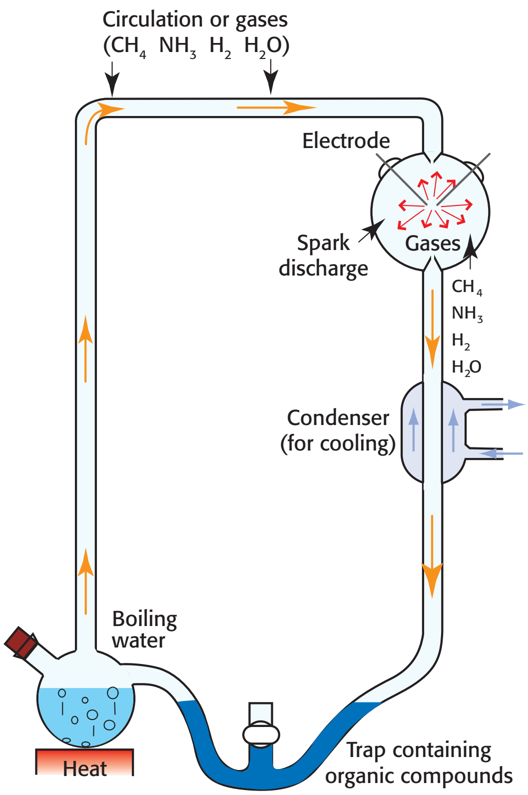


Figure 3.1 Urey-Miller experiment A mixture of chemicals was subjected to electrical sparks.

The origin of life

While this experiment does not prove how life evolved, it does provide one plausible theory by which it may have occurred. Since the presence of oxygen would destroy life, conditions need to be found that are free of oxygen. We say they are **anoxic**. Since we are dealing with a time before the evolution of photosynthesis, the atmosphere would have been naturally anoxic.

Figure 3.2 Volcanic lightning Massive lightning around an eruption.

Two possible senarios include:

- A shallow water setting as a result of lightning strike.
- An ocean floor setting due to hydrothermal activity.

A shallow water setting as a result of lightning strike. In the Urey-Miller experiment, electric sparks were used to provide energy. In the natural environment, sparks come mainly from lightning. The lightning can be that of a storm, but in the early Earth intense volcanic activity could also have produced intense lightning (Figure 3.2). American chemists recently examined some of the samples left by Miller and found evidence that volcanic activity could have been involved. If the environment was volcanic island tide pools and lagoons subjected to intense lightning then the conditions would be similar to that of the Urey-Miller experiment. The first organic molecules such as amino acids would have been produced.

An ocean floor setting due to hydrothermal activity. Not all theories for the origin of life follow the Urey-Miller experiment lead. What is needed is a source of energy that can allow organic molecules such as amino acids to form. One such theory from German and British molecular biologists proposes that life began on the ocean floor near hydrothermal vents (Figure 3.3). These sources of very hot water from deep in the Earth may carry sulfides which react with chemicals in sea water to produce 'black smokers'. They also carry large amounts of methane (CH_4) and ammonia (NH_3) which in the right conditions can react to produce amino acids and other organic molecules. Clay particles also occur near these vents and we know that the surface of clay can catalyse the necessary reactions. This would need to be in a region between the very hot water from the vent and the very cold water on the ocean floor.

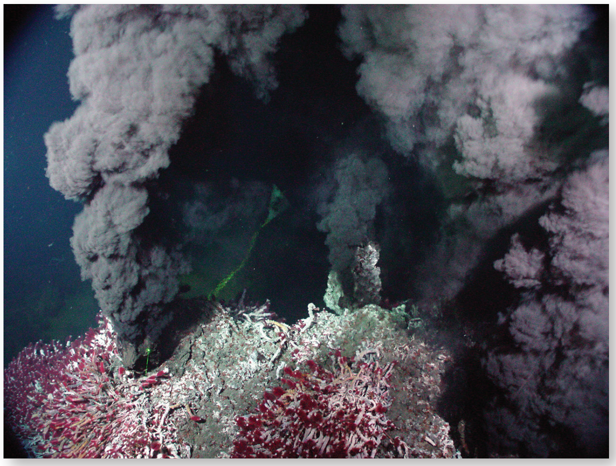


Figure 3.3 Black smokers Hot water from deep in the Earth can be rich in methane and ammonia.

Currently, the oldest microfossils yet positively identified by Australian, British and American scientists are around 3460 million years old. Surprisingly, these fossils show considerable diversity. This strongly suggests even earlier and simpler life forms from which the different types of observed fossils evolved. Fossils of these earlier life forms might never be found.

Despite existing so long ago, some of the earliest known fossils do have living relatives. Their modern day relatives survive in environmental conditions similar to those their ancestors endured, such as aquatic, mineral-rich, oxygen-poor and warm. Some of the modern relatives include stromatolite cyanobacteria and archaeobacteria.

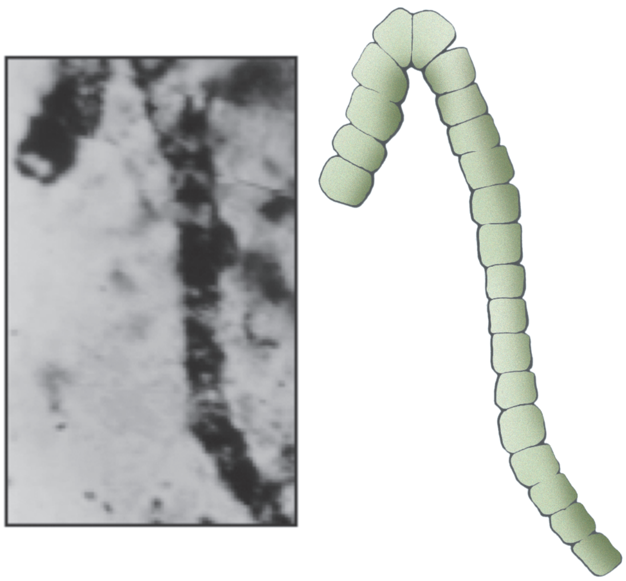


Figure 3.5 Archaeobacteria This bacterium is one of the earliest fossils found.

Recent improvements in technology have opened up new methods of detecting ancient life from the rock record. One of these is the study of **molecular fossils**. Under specific conditions, the organic molecules that make up organisms (nucleic acids, proteins, carbohydrates and lipids) can be preserved. Different forms of life exhibit differences in these molecules (e.g. plant lipids versus animal lipids), and these can therefore be used in the analysis or detection of ancient life. An example of this was the confirmation that the mysterious Ediacaran fossils were indeed the first multicellular animals, not protists or plants as some had hypothesised. This conclusion was possible because of the detection of animal-specific molecules preserved within these fossils at one site.

Another indirect method of detecting life is **isotopic analysis**. In nature, the element carbon exists as different isotopes: carbon-12 and carbon-14. These are chemically identical but carbon-14 is heavier due to having two more neutrons in its nucleus. The ratio of carbon-12 and carbon-14 in the atmosphere is constant. However, during photosynthesis, carbon-12 is absorbed more readily because it is lighter. This means that living things have a higher ratio of carbon-12 within them than inorganic sediments. This higher ratio of carbon-12 to carbon-14 can be used to identify **biogenic** (i.e. made by life) sediments in the rock record. One recent study has identified biogenic graphite within zircon crystals from Jack Hills in Western Australia: the oldest part of Earth's surface. If confirmed, this result will push back the start of life on Earth by at least 300 million years.

Fossilised lipids confirm theory
http://qr.w69b.com/g/psGd01Nmg

Biogenic graphite found in zircons
http://qr.w69b.com/g/pe0U0IFlk

ACTIVITY 3.1
THE ORIGIN OF LIFE

1. It is believed the early Earth's atmosphere contained a mixture of methane, ammonia and hydrogen while water was present in the air and the oceans. The chemical formula for each is given in Table 3.1. Copy this table into your notebook and fill in the gaps. Use molecular modelling kits to construct one molecule of each gas and draw it in the right hand column.
2. All amino acids are made up of atoms of carbon, hydrogen, oxygen and nitrogen, but they are arranged differently from the inorganic substances shown in Table 3.1. What part of Miller's apparatus would be responsible for breaking the chemical bonds of the inorganic molecules, allowing them to re-form as organic molecules?

8. **Outline** how the conditions near ancient hydrothermal vents might provide conditions for the origin of the first organic molecules.
9. **Explain** why scientists are keen to investigate conditions on other planets and their moons.
10. **Explain** why life could evolve in the Earth's early atmosphere but could not evolve in its atmosphere today.

3.2 Fossils and life

As we have seen, the Earth is believed to have formed around 4.5 billion years ago. At the time of writing the earliest known fossils occur in Western Australia. They are dated to around 3.5 billion years ago. The fossil was found inside a lump of sandstone and is the remains of what once was a purple-and-green slimy, smelly mat of single cell microbes.

Figure 3.7 Fossil bones The bones of *Tyrannosaurus rex*.

Figure 3.8 Fossil mould A brachiopod preserved in rock.

Fossilisation

Fossils are the remains of a once living organism or they are direct evidence of its presence. Fossils can be actual bones or teeth, footprints or tracks, all preserved in rock. They can also be whole animals trapped inside amber or ice. There are many types of fossils and organisms represented by them, including humans.

A fossil however, will only form when conditions are right. This means that although we have many examples of fossils to guide us about life in the past, our record also has many gaps. Some parts of an animal will fossilise easily and some environments will yield more fossilisation. To be preserved as a fossil the following conditions are usually required.

Figure 3.9 Fossil cast The cast of an ammonite.

Conditions for fossilisation

1. Quick burial – the organism, its impression or its body parts must be buried quickly. This will prevent its bones being eaten by predators or scattered by scavengers. It will also slow down the process of decay and keep the organism's parts generally intact.
2. Suitable body parts – hard body parts like shells, bones or teeth will survive the fossilisation process more easily than soft body parts or soft bodied animals like jellyfish.
3. Little geologic disturbance – when fossils form it is usually in sedimentary rocks which are laid down as layers of sediment and are left generally undisturbed to form rock. These sediments hold the pattern of the organism or its passing in them and will form fossils if left to consolidate.

Of course, there are exceptions to these rules. For instance, in a cave on the Nullarbor Plain, an intact Tasmanian tiger was found preserved in a mummified state by the dry heat. It had not been buried by sediments and was dated at about 4500 years old (Figure 3.10 (a)).

Likewise, many insects have been preserved in amber, a rock that forms from hardened sugary tree sap (Figure 3.10 (b)). There are even examples of fossils such as the sabre tooth tiger that formed in pits full of tar into which an animal has fallen and been preserved. Some woolly mammoths related to elephants have been preserved in ice.

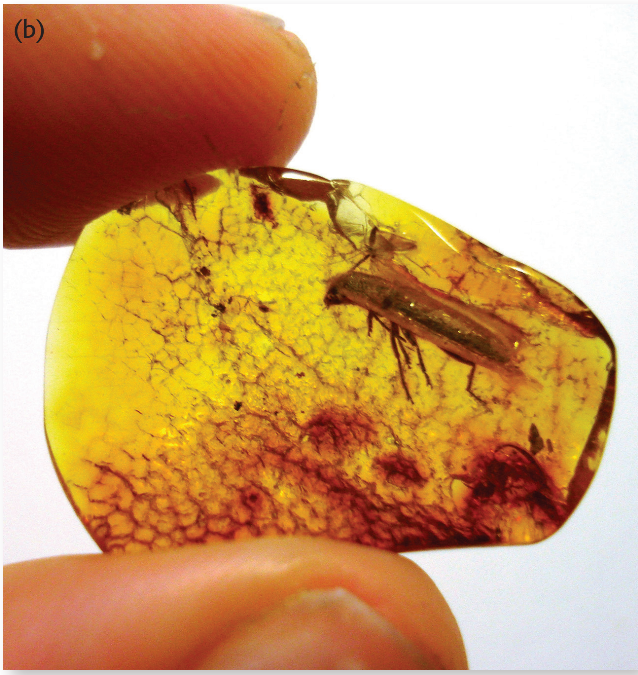


Figure 3.10 Unusual fossils (a) Mummified *Thylacine* bones. (b) Insects trapped in amber. These are examples of unaltered fossil remains.

ACTIVITY 3.2 EXPERIMENT: MAKING A FOSSIL

Aim: To make fossil moulds and casts.

Apparatus

- A shell, tooth or bone
- Playdough
- Cooking spray or Vaseline
- Some plaster of paris

Risk assessment

Hazard: Chemicals.

Risk: Injury.

Precaution: Wear safety goggles.

Method

1. Spray your object lightly with the cooking spray or smear it with a thin coating of Vaseline.
2. Make a mound of playdough about the same size as the palm of your hand and gently press your object into it (slimy side down).
3. Being careful not to disturb the playdough, remove your object to observe your mould.
4. Pour some plaster of paris into your mould and leave it to set to make your cast.
5. You can also make a second mould of the other side of your object if time permits and when it has set put both halves together.

Questions

1. How is a mould different from a cast?
2. Did your plaster fossil resemble the actual object closely? What differences can you notice? Would these differences be the same in the case of a real fossil?

Figure 3.12 The largest dinosaur footprint in the world (a trace fossil 1.7 m long) was recently discovered in Western Australia. (Steve Salisbury)

Figure 3.13 Wood fossils The process of permineralisation is how petrified wood fossils form.

Figure 3.14 Carbonised fossils Fossils such as these *Glossopteris* leaves have had all their original molecules except for carbon removed. This carbon is what gives them their distinctive black colour.

Figure 3.15 Recrystallised fossils Marine molluscs often construct their shells from a mineral called aragonite. Once buried, this less stable form of calcium carbonate changes into calcite, a more stable form of calcium carbonate. This ammonite shell is made of yellow calcite and is an example of a recrystallised fossil.

Figure 3.16 Replacement fossils These ammonite fossils have had all of their original shell minerals replaced with iron pyrite (also known as fool's gold). This mineral is common in replacement fossils.

Past communities – Cretaceous dinosaurs

A unique dinosaur community from the Cretaceous (95 million years ago) is preserved at Lark Quarry, 110 km south of Winton is central Queensland. There are a series of tracks preserved in clay from what may have been the edge of a small lake. From the numbers of footprints it is believed there were around 150 dinosaurs present. The size of the footprint, the depth to which it sank into the mud can help identify the animals. The stride tells us if they were walking or running.

Figure 3.40 Lark Quarry dinosaurs (a) A moment in time recorded in tracks preserved in mud. (b) The dinosaur predator and prey.

It appears there were three dinosaur types present, possibly drinking at the edge of a lake (Figure 3.40). The smallest were carnivores that walked on two legs and were about 20 cm at the hip. Next largest were some herbivores that grew in size from a chicken to that of an emu when adult. Stalking these smaller dinosaurs was a large carnivore about 8 metres long and 2.5 metres at the hip and with a stride of around 2 metres. While the smaller dinosaurs were walking when near the water, the tracks show them running from the large carnivore.

ACTIVITY 3.7 INVESTIGATION: WEIRD BUT TRUE

Aim: Who can find the biggest, smallest and most weird?

Use the internet to find information and images of trilobites and/or dinosaurs. See who can find:

- The biggest.
- The smallest.
- The one that looks most strange.

Past communities – Pleistocene megafauna

If we could somehow go back to the world of the Pleistocene, around 2 million years ago, we would find the vegetation reasonably familiar. Most of the major evolution of flora had taken place in the Tertiary. However, although you would recognise much of the fauna, it would be obvious there was something different. They were big! Called the **megafauna**, it included very large kangaroos, wallabies, wombats, the huge *Diprotodon*, giant running birds and a giant python (Figure 3.41).

The oldest known fossil monotreme is an opalised platypus-like jaw from around 110 million years ago. It was found at Lightning Ridge, New South Wales. Other fossils of platypus and echidna from around 20 million years ago have been found in New South Wales. The fossil remains of the last remaining monotremes – the platypus and echidna – were until recently quite rare! However, new finds in 15 million years old limestone at Riversleigh near Mount Isa in Queensland has changed all that.

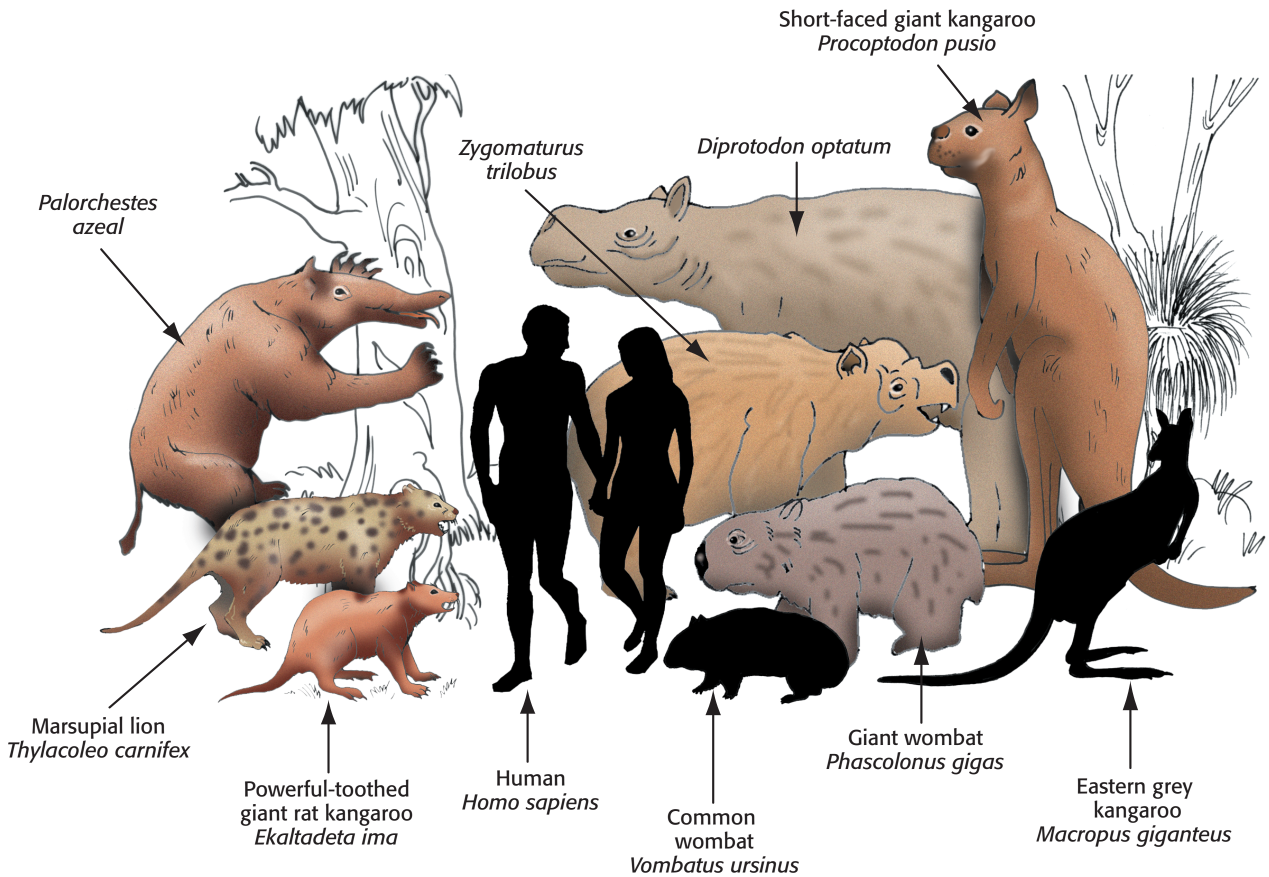


Figure 3.41 Megafauna.

Riversleigh has also been the source of many marsupial fossil finds. Kangaroos and wallabies, bandicoots, possums and other herbivores were present at this time. But so too were giant kangaroos and wombats. One of the largest herbivores was the huge *Diprotodon*, a lumbering marsupial that was the size of a present-day hippopotamus. Another large herbivore was the cow-sized *Palorchestes* with its short tapir-like snout. They all served as prey for an equally large group of carnivores.

Rather startling is the idea of 'killer kangaroos'. Yet this is what fossil evidence has indicated – giant kangaroos with a diet that included meat. Related to present day musky rat kangaroos, the powerful-toothed giant rat kangaroo (*Ekaltadeta ima*) probably walked on all fours. Musky rat kangaroos weigh 1 kg, while the giant rat kangaroo is estimated to have weighed anything from 15 to 20 kg. Other giant rat kangaroos weighed up to 60 kg.

If marsupial prey escaped from 'killer kangaroos', then they had to be careful in the forests as well. A 130 kg or more marsupial 'lion' could drop from a branch. There are at least eight known species, related to present day wombats and koalas! Also present were the marsupial 'wolves', dog-like animals of the forest floor. The last surviving member of the group was the thylacine, or Tasmanian 'tiger' which became extinct in 1936.

Megafauna murder mystery
http://qr.w69b.com/g/qMicAzlmM

SCIENCE SKILLS

1. Young children are often fascinated by trilobites, megafauna and especially dinosaurs. Using appropriate language levels, present a page of information and illustrations to help youngsters to understand the nature of these living things.

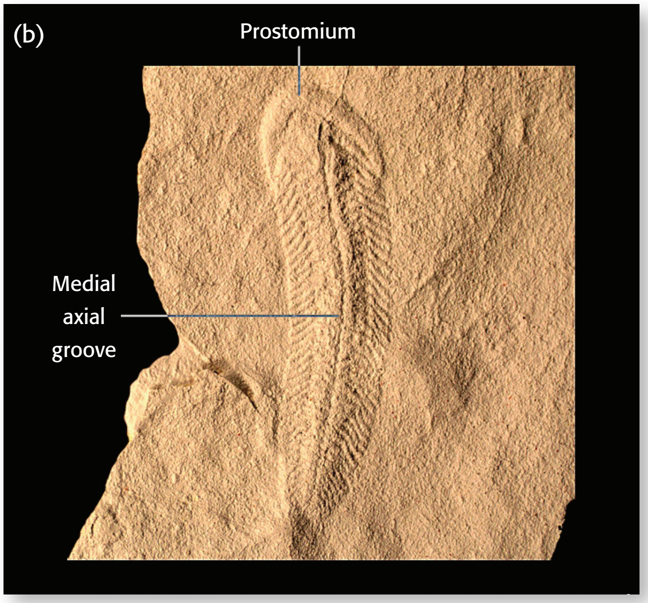


Figure 3.43 Ediacaran fauna (a) *Dicksonia* is around 50 cm long and seems to be a large flat sheetworm. (b) *Spriggina* is about 4 cm long and was thought to be a segmented worm, but may be an early type of arthropod.

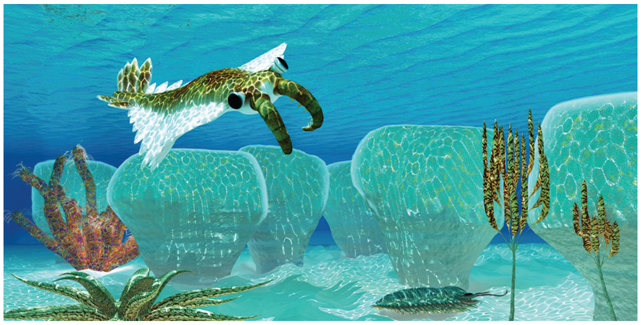


Figure 3.44 Cambrian explosion Some of the organisms in Cambrian seas after the Cambrian explosion.

The puzzle facing geologists may have several answers. Evidence shows that oxygen levels had risen in the atmosphere prior to the Cambrian and that some of this oxygen had slowly reached the bottom of the oceans. Plate tectonics saw large areas of shallow seas appear that were suitable for life. Another reason may be the appearance of hard parts such as shells and exoskeletons that are more readily fossilised. Perhaps there were many soft bodied organisms prior to this period that were never fossilised.

All fossils from this period were marine – as far as we can tell there was no life on land. Most of these Cambrian animals were extinct by the end of the Permian. The famous trilobites were extinct by this time. Brachiopods reached their zenith in the Devonian but relatively few species survived the Permian extinction and today survive in polar regions and at great depths. There are also a number of unusual fossils of strange animals that have all become extinct.

The Cambrian explosion
http://qr.w69b.com/g/t71JNnNAc

The big five mass extinctions
http://qr.w69b.com/g/pJeclRVRu

The Cretaceous mass extinction

There have been several mass extinctions in geologic history of which the Cretaceous extinction around 66 million years ago is best known. This is because it saw the extinctions of the dinosaurs. However, other mass extinctions were more devastating.

The one at the end of the Permian about 250 million years ago saw 96 per cent of all marine species become extinct. Figure 3.45 shows the major mass extinctions in the geologic record. It is estimated that more than 99 per cent of species that have ever lived are now extinct.

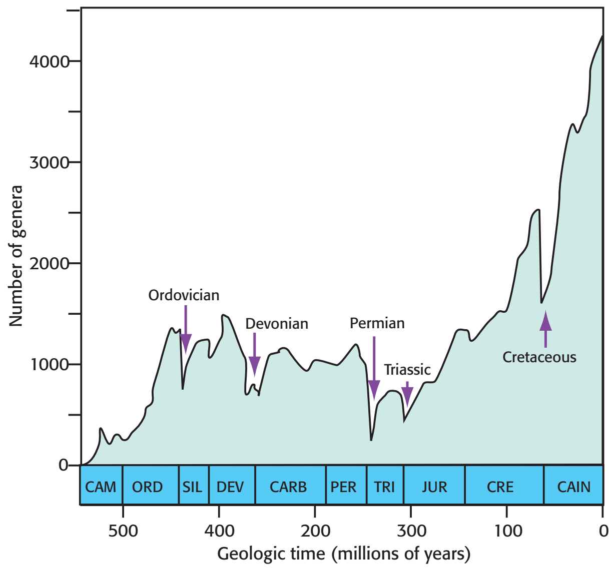


Figure 3.45 Mass extinctions The graph shows the number of genera that became extinct at various times in the geologic record.

The Cretaceous mass extinction is often called the K-T extinction as it occurred at the end of the Cretaceous and the beginning of the Tertiary. However, many organisms other than the dinosaurs also perished at the end of the Cretaceous including most species of plankton, the ammonites and other marine invertebrates, many flowering plants and the last of the flying reptiles (pterosaurs) and sea reptiles (Figure 3.46).

Figure 3.46 The K-T extinction Many organisms became extinct.

Many groups had been in decline for several million years before the final event that destroyed them all. It is suggested that the decline was due to flood basalt eruptions in what is now India called the Deccan Traps affecting the world's climate. Another factor may have been plate tectonic movements with resulting effects on climate. Then a huge asteroid or comet struck the seabed near the Yucatan Peninsula in Mexico which saw the final end of the dinosaurs and other species. There is a huge crater 180 km across that would have generated huge tsunamis and ejected huge amounts of rocks and dust into the atmosphere. This dust would have cut solar radiation reaching the Earth causing a massive drop in world temperatures.

The K-T extinction
http://qr.w69b.com/g/oqpKbVkWY

Human extinction?

Many scientists believe that the sixth mass extinction is in progress right now. Animals are going extinct 100 to 1000 times faster than at the normal background extinction rate, which is about 1 to 5 species per year (counting all organisms such as insects, bacteria, and fungi, not just the large vertebrates we are most familiar with). Many researchers claim that we are in the middle of a mass extinction event faster than the Cretaceous-Tertiary extinction which wiped out the dinosaurs. Unlike past mass extinctions, caused by events like asteroid strikes, volcanic eruptions, and natural climate change, the current crisis is almost entirely caused by we humans.

Rates of extinction

The easiest to obtain evidence comes from large animals such as mammals and birds. Starting with mammals and using the fossil record for the last 65 million years, we find that the extinction rate is a little under two species per million years. That's 130 species in total. But in the past 500 years, at least 80 of 5570 species of mammals have gone extinct. And even larger numbers of mammals are endangered. Birds present a similar picture. At least 150 species of birds have gone extinct in the last 500 years alone.

We can't begin to know how may reptiles, amphibians or fish have gone extinct. We know that coral reefs are under threat with the many thousands of species there. As far as the world's invertebrates and plants are concerned, we often have less knowledge. Instead we must extrapolate from known statistics to estimate the numbers that have gone extinct or are threatened.

ACTIVITY 3.8
EXTINCTION

Aim: To prepare a database of known extinct plants and animals.

Table 3.5 lists the known extinct marsupials, nearly all from Australia. Either create a database, or use one from previous years, and make a record of all known extinct plants and animals in one particular group, e.g. marsupials, eagles. You will need fields for the name, classification, year it went extinct and the country, and cause of extinction (if known). Save the database so that it can be used in future years.

Table 3.5 Extinct marsupials.

Name	Year	Country
Broad-faced potoroo	1875	Australia
Eastern hare wallaby	1890	Australia
Lake Mackay hare wallaby	1932	Australia
Desert rat kangaroo	1935	Australia
Thylacine	1936	Tasmania, Australia
Toolache wallaby	1943	Australia
Desert bandicoot	1943	Australia
Lesser bilby	1950s	Australia
Pig-footed bandicoot	1950s	Australia
Crescent nailtail wallaby	1956	Australia
Red-bellied gracile opossum	1962	Argentina

Figure 3.47 Modern extinction The last dodo was seen in 1662.

Causes of extinction

The best known cause of extinction is climate change. Climate change is being accelerated by the high amounts of greenhouse gas emissions (primarily carbon dioxide, methane, and nitrogen oxides). Acting like a greenhouse, these gases trap heat from the Sun. Not only does climate change increase temperatures, but it increases extreme weather events. Taking the Great Barrier Reef, increased numbers of cyclones damage the reef and extreme temperatures cause coral bleaching. Combined with direct human impact on the reef, the results can be devastating.

However, other human activities such as habitat destruction in combination with climate change are making the situation only worse. Increasing temperatures may force species to move towards their preferred, and generally cooler, climate range. Thus, if in time those habitats are destroyed, then the species are not be able to escape the climate change and will go extinct. As well, the new invading species may outcompete the resident species causing them to become extinct.

Humans can release new species into natural environments and displace native species through predation, competition, and disease organisms. We have seen in Australia the effects of foxes, native cats, rabbits and cane toads (Figure 3.48).

Figure 3.48 Causes of extinction (a) Introduced foxes. (b) Bush meat.

Increased human population is adding to pressures that may contribute towards the sixth mass extinction. Humans take up more land for farming, housing, water storage and roads. Pollution increases in the air and in rivers and oceans. Overharvesting of wood from forests, hunting of animals for sport or as 'bush meat', as well as overharvesting fish from the ocean all contribute towards extinctions (Figure 3.48).

The question must be asked: Will humans themselves become extinct because of their own destructive activities?

SCIENCE SKILLS

1. In Table 3.5 we have listed a range of marsupials that we believe have become extinct. Yet, from time to time we find examples of animals that are thought to be extinct in remote locations. By the time you use this textbook, perhaps one of the above is found not to be extinct. Using that example, or one from an earlier time, use the internet or other sources of information to **evaluate** a scientific or media text's claims and conclusions by considering the quality of available evidence.
2. The idea that humans may cause their own extinction is quite controversial. Using the internet or other sources of information, **evaluate** a scientific or media text's claims and conclusions by considering the quality of available evidence.

TO THINK ABOUT

Set 1

1. **Identify** where the first fossils of multicellular fauna have been found.
2. **Explain** why we use the term 'explosion' to describe the fossil record from the early Cambrian.
3. **Outline** reasons why the Cambrian explosion took place.
4. **Describe**, using the internet or library if you need to, how a trilobite was adapted to its habitat.
5. **Identify** a group of animals that existed in the Cambrian and still exists today.

Set 2

6. **Identify** the most massive extinction event in the geologic record.
7. **Describe** three reasons why there was a massive extinction at the end of the Cretaceous.
8. **Compare** the current rate of extinction with that from the geologic past.
9. **Identify** three human activities that are leading to the extinction of many living things.
10. **Discuss** the question above: Will humans themselves become extinct because of their own destructive activities?

Chapter 4

ENERGY FOR EARTH PROCESSES

Interactive vocabulary
http://qr.w69b.com/g/uiBErrgQg

The energy of the Earth
http://qr.w69b.com/g/ula7qDhG8

In physics, the **law of conservation of energy** states that the total energy within an isolated system remains constant. Energy can transform from one type to another, but in total, no energy is created or destroyed. The **first law of thermodynamics** is the same law but modified to describe thermodynamic (i.e. 'heat changing') systems. All changes on our planet are the result of transfers of matter and/or energy, and therefore this law permeates through all of Earth science. Every concept you study in this course can be explained in terms of the law of conservation of energy and the first law of thermodynamics. These concepts include:

- Planetary formation – Earth's internal structure – plate tectonics.
- Hydrospheric and atmospheric processes – volcanic eruptions and earthquakes.
- Interactions between living things – biogeochemical processes.

Why perpetual motion machines never work
http://qr.w69b.com/g/oaSjOLdgA

Unsustainable (second law) – muse
http://qr.w69b.com/g/qZW7gVuWA

Earth and environmental processes all involve energy. Energy is needed to throw ash and stones into the atmosphere when a volcano erupts (Figure 4.1). Enormous amounts of energy are released when an earthquake shakes an area. When flowing water erodes away a river bank, energy is involved. We will be looking at this energy is this chapter.

Figure 4.1 Energy Energy in an erupting volcano differs from the Sun's energy used by plants.

The Sun's energy is needed to move water through the water cycle. The Sun's energy is needed for winds to blow and for ocean currents to flow.

Energy from the Sun is needed for life on Earth to exist. Photosynthesis traps this energy and converts it into plant matter that serves as food for animals and humans alike (Figure 4.2). We will look at this in Chapter 6.

Why is Earth's interior molten?
http://qr.w69b.com/g/mHG9E5ExG

4.1 Energy and the geosphere

Energy can be neither created nor destroyed. However, it can be transformed – changed from one form to another. Some of the main types of energy are listed in Table 4.1. Moving objects have **kinetic energy**. When a volcano throws stones into the atmosphere, the moving stones have kinetic energy (Figure 4.1). **Thermal (or heat) energy** from within the Earth is transformed into kinetic energy. As the stone gains height, the kinetic energy is transformed into **gravitational potential energy** – energy due to its height in the Earth's gravitational field. As the stone falls back to the Earth the gravitational potential energy is transformed back into kinetic energy as it gains speed.

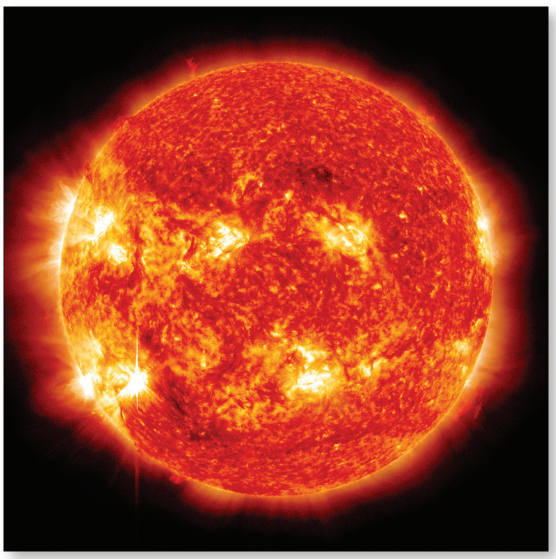


Figure 4.2 Energy being transformed In the Sun, nuclear energy is transformed into light energy and thermal energy.

Inside the Sun, **nuclear energy** is transformed into **light energy** and thermal energy (Figure 4.2). The process involves nuclear fusion. The thermal energy from the Sun then evaporates water from the Earth and is transformed into kinetic energy and gravitational potential energy as the water vapour rises into the atmosphere. When the water falls to the Earth, the gravitational potential energy is transformed into the kinetic energy of falling raindrops and then kinetic energy of a flowing stream as it erodes away the stream bank.

How does fusion power the Sun?
http://qr.w69b.com/g/n1wQR2lLa

Energy from within the Earth

That the interior of the Earth is a source of thermal energy is easily seen in volcanic eruptions (Figure 4.3). Not only are red-hot ash and rocks thrown into the atmosphere, but red hot lava can sometimes be seen flowing down the volcano (Figure 4.1). The puzzle is to explain where this energy is coming from. Energy is also released during an earthquake. Hot thermal springs also show rocks beneath the ground are hot (Figure 4.2). Some very deep mines, such as a 3.9 km deep mine in South Africa, have to be air conditioned so that the miners can work. Rocks become hotter as we go deeper into the Earth.

Table 4.1 Types of energy.

Type of energy	Description	Examples
Chemical	Energy stored in chemicals	Photosynthesis stores energy in plant matter
Elastic potential	Energy stored in bending rocks	Energy stored along fault lines that can be released in an earthquake
Electrical	Energy due to an electric current	Lightning
Gravitational potential	Energy stored due to height in a planet's gravity	Rocks on a hillside; rain in a cloud
Kinetic	Energy due to motion	Falling rock; flowing stream
Light	Energy in particles of light	Light from the Sun or a volcanic eruption
Thermal	Heat energy	Energy from the Sun or released in volcanic eruptions

Figure 4.3 Heat from inside the Earth Hot flowing lava obtained its heat from inside the Earth.

Where does this energy come from? You may recall from Chapter 1, that Lord Kelvin estimated the age of the Earth from how long it would take to cool. He assumed that the Earth was originally molten and calculated that it cooled gradually over 20 to 30 million years. So part of the Earth's energy comes from how it was formed.

The Earth and other planets are the result of the accretion of rocks orbiting the Sun (Chapter 1). As Earth developed in size and mass, its gravity also grew and attracted a hail of meteorites. This period of meteorite bombardment melted the rocks of the young Earth and allowed the molten ingredients to differentiate according to density. The densest materials, such as iron and nickel, sank to the centre while the less dense materials, such as oxides and sulfides, were pushed to the surface. The Earth began to cool and formed a solid surface, but the centre remained hot.

Figure 4.4 Thermal springs Hot boiling water from deep in the Earth at Rotorua, New Zealand.

Since **radioactivity** had not been discovered it meant that Lord Kelvin got the wrong answer. Radioactive elements deep in the Earth undergo **nuclear fission** – nuclear energy is transformed into thermal energy. This energy then moves towards the Earth's surface where it is transformed into kinetic, light and thermal energy during volcanic eruptions and earthquakes. It is estimated that more than half of the heat reaching the surface now comes from radioactive sources.

Measuring the Earth's temperature

Before we can measure the energy released from the Earth, we need to know its internal temperature. This was initially done using the principle of **extrapolation**. Figure 4.5 shows how temperature changed with depth for a very deep borehole drilled on the Kola Peninsula in Russia. They had to stop drilling when the rocks became too soft for drilling. As we can see, if we extrapolate the graph beyond the 12 000 metres drilled, we would get a temperature of around 100 000°C at the centre of the Earth. Since we know from seismic data that the core is solid iron-nickel alloy, its temperature cannot be much greater than the melting point of such an alloy, around 5500°C. For some reason, the rate the temperature increases must be lower when deeper inside the Earth.

The increase in temperature with depth is known as the **geothermal gradient**, and can be measured in °C per kilometre. Near the surface it is often around 25°C/km, but this can vary. Within 100 m of the surface it can vary with climate and water content. Below that the value can depend on location. Near the edges of tectonic plates it can be as high as 100°C/km. Under mountain ranges with very thick insulating crust, it can be as low as 10°C/km.

Recent advances have allowed a much more accurate reading of internal temperature. It has required the **cooperation** of many branches of science, including seismologists, geochemists, and computer programmers. The advance relied on laboratory studies of what happens to minerals under the extreme pressures and temperatures found deep in the Earth. These minerals are squeezed into crystal structures not seen on the surface, except in a few research labs. These new minerals transmit seismic waves at different speeds compared to other minerals (Figure 4.6).

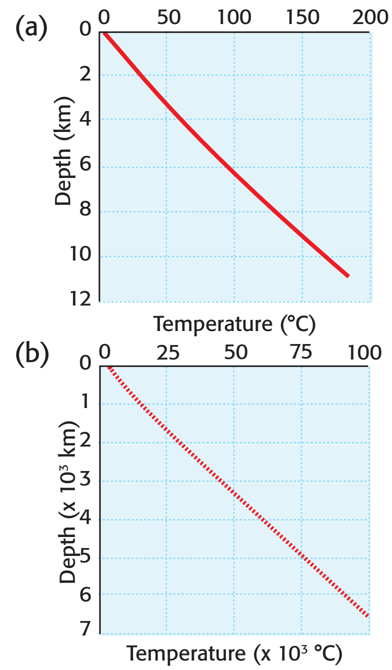


Figure 4.5 Geothermal gradient (a) Change in temperature with depth on the Kola Peninsula, Russia. (b) Extrapolating the data.

Seismologists recorded the seismic signals which were then analysed by supercomputer to show how the speed of the signals changed. From the speed, the pressure could be determined and hence the temperature at that depth. From this, the heat flow to the surface could be measured. The value is quite small compared to the heat from the Sun. Energy from the Sun is around 4000 times bigger than that from inside the earth. Energy from inside the Earth will have negligible effect on climate change.

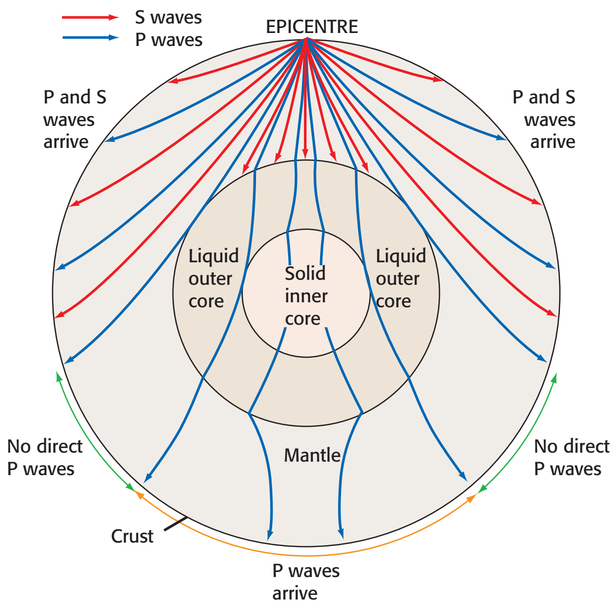


Figure 4.6 Seismic waves Travel through the Earth at varying speeds.

How energy moves inside the Earth

There are three ways to transmit energy from inside the Earth (Figure 4.7). While **radiation** is important for energy of the Sun to reach the Earth, it has little importance for heat reaching the surface from inside the Earth. Radiation occurs through air and the vacuum of space. Again, there is no movement of matter.

Heat **conduction** mainly occurs through solids. As the heat moves through the solid, no matter is moved. Since rock is a poor conductor, the rate at which energy reaches the surface is quite slow.

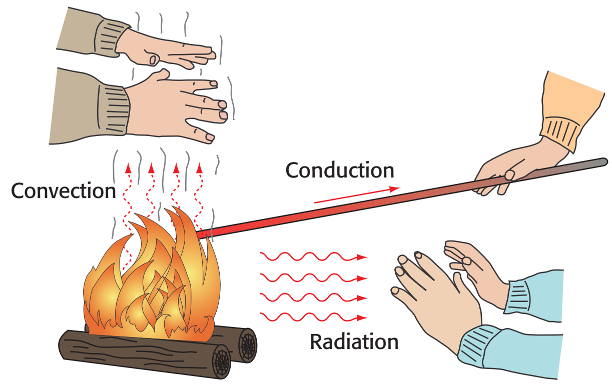


Figure 4.7 Heat transfer Radiation, conduction and convection.

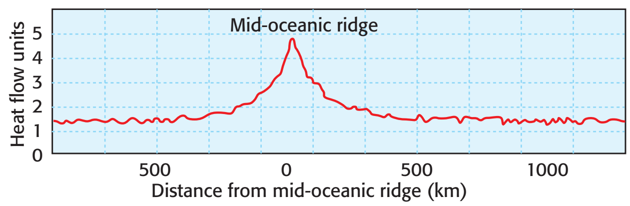


Figure 4.8 Heat flow Heat flow is high at mid-oceanic ridges and gradually declines away from the ridge.

When temperature was measured along the ocean floor in the 1950s, it was found to reach a peak along mid-oceanic ridges (Figure 4.8). Volcanic activity in such regions implied that magma was rising beneath the ridge. This movement of magma suggested that heat was being moved by **convection**. With convection, the heat is carried along by moving matter. As we will see in the next unit, moving magma provides a mechanism for moving oceanic and continental crust.

ACTIVITY 4.1 EXPERIMENT: CONDUCTION OF HEAT

Many high schools have specific equipment to demonstrate heat conduction through different metals. After your teacher shows you this equipment, design an experiment to test one of the following hypotheses:

- Is there a correlation between heat conduction and the melting point of a metal?
- Is there a correlation between heat conduction and the density of a metal?
- Is there a correlation between heat conduction and the darkness of colour of a metal?

SCIENCE SKILLS

1. Use the graph in Figure 4.9 to answer the questions below.
   (a) **Calculate** the thermal gradient.
   (b) **Determine** the temperature at the base of the solid crust. Would the rocks still be solid at this temperature?
   (c) **Determine** the temperature at the centre of the Earth. **Discuss** if this temperature is reasonable.

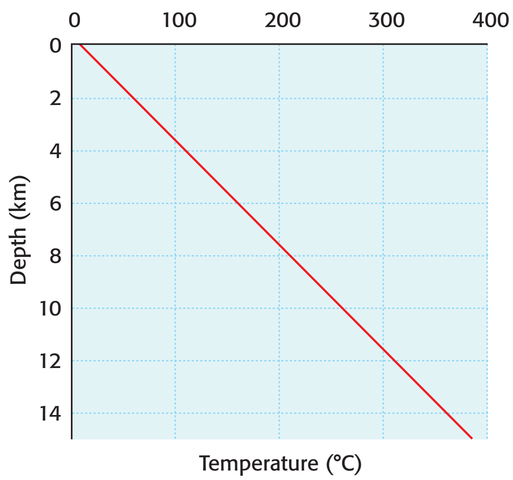


Figure 4.9 Thermal gradient.

2. Table 4.2 provides data from the measurement of temperature with depth in a deep borehole.
   (a) Graph the data on suitable axes. If needed, use a line of best fit.
   (b) **Measure** the thermal gradient.
   (c) **Suggest** the type of crust where the borehole may have been located.

Table 4.2 Borehole temperatures.

Depth (km)	Temperature (°C)
0	20
10	155
20	292
30	457
40	611
50	739
60	892
70	1061

TO THINK ABOUT

Set 1

1. **Define** kinetic energy.
2. **Identify** the two ways in which nuclear energy can be transformed.
3. **Identify** the two sources of the Earth's internal energy.
4. **Identify** the three ways energy can be transferred.
5. What does it mean to extrapolate?

Set 2

6. **Distinguish** between gravitational potential energy and elastic potential energy.
7. **Explain** how ancient geologists knew that the Earth had a very hot interior.
8. The thermal gradient for a location is 18°C/km. **Calculate** the temperature at a depth of 350 km.
9. **Compare** how Lord Kelvin estimated the age of the Earth with how modern scientists found ways to accurately measure the temperature inside the Earth.
10. Would a modern Jules Verne be able to write a book such as *Journey to the Centre of the Earth*? **Explain** your answer.

4.2 The hydrologic cycle

An **environmental cycle** is any series of processes by which a particular substance is cycled through different parts of nature. Although the amount of any substance in the environment is limited, a cycle ensures that each source of the substance is continually being replenished by other sources.

The **hydrologic cycle** (or **water cycle**) refers to processes that transfer water between the various spheres of the Earth (Figure 4.10). Liquid water is evaporated by the Sun's heat to form water vapour. As water vapour rises in the atmosphere it cools and condenses, creating rain, hail or snow. This liquid or solid water can remain suspended in clouds by convection currents in the atmosphere for some time. Eventually, the rain, hail or snow becomes too heavy to remain suspended and falls as **precipitation**.

Most of the water that falls as precipitation makes its way into larger bodies of water, such as lakes or oceans. This can happen quickly via surface run-off into rivers or by direct precipitation. The larger bodies of water are also refilled slowly by water either moving through the ground or stored within living things, glaciers and ice caps. Water can also be evaporated directly from living things.

Evapotranspiration is the movement of water from roots to leaves (transpiration) followed by evaporation from the leaves. This process increases humidity and lowers surface temperatures in areas with good vegetation cover. Once it is back in liquid form and exposed to the atmosphere, water is again subject to evaporation and the cycle continues.

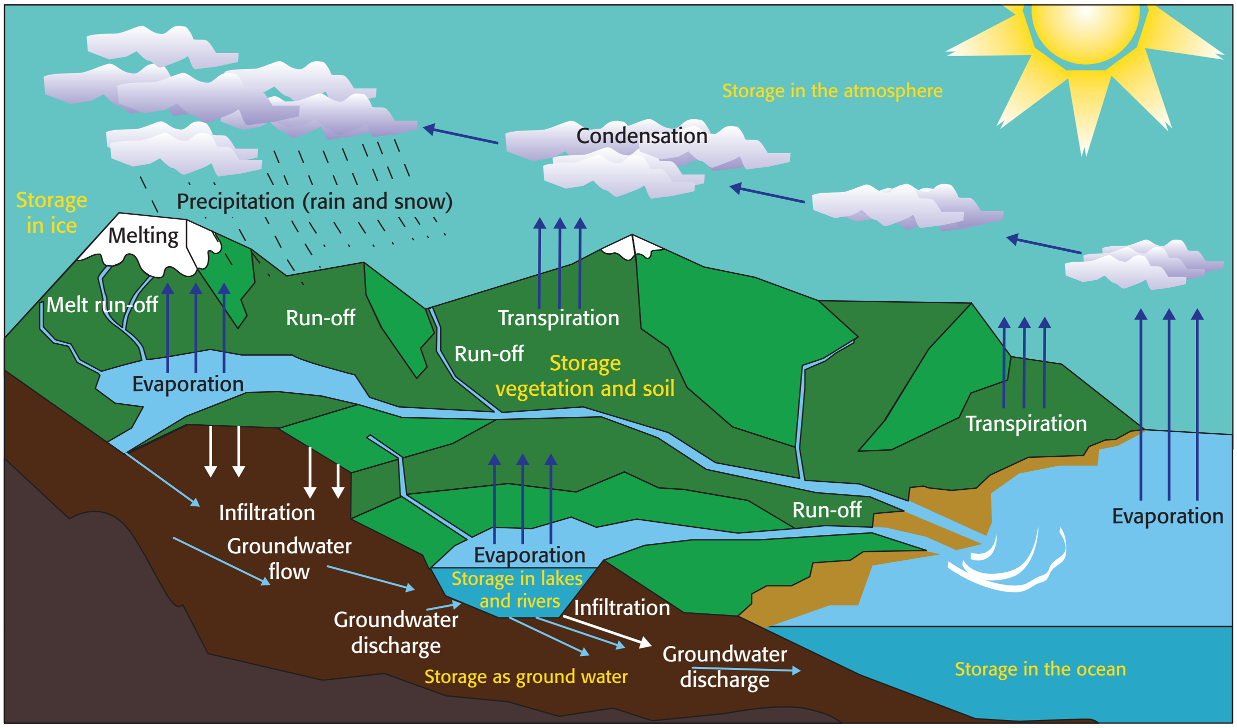


Figure 4.10 The hydrologic cycle This cycle is powered by solar energy and gravity. It connects the atmosphere, hydrosphere, biosphere and geosphere. (Nancy Gladstone)

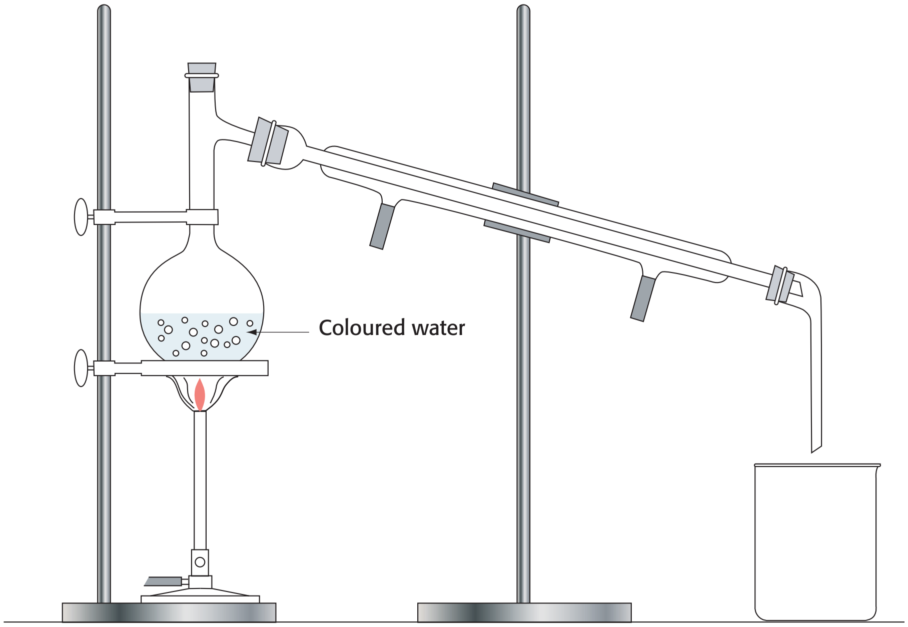


Figure 4.11 Simulated hydrologic cycle How could this model be improved?

Direct measurement

With the advent of such technologies as computers, laser measurement and satellite remote sensing, the slow movement of the Earth's plates can be measured directly (Figure 4.30). By calculating the distance between two points on either side of a plate boundary, the rate and direction of relative movement can be determined. Figure 4.31 shows the direction and speed of movement in centimetres per year of the Earth's main tectonic plates. The fact that they move in different directions means they sometimes collide, sometimes separate and sometimes rub past other plates (Unit 4.4).

Note that while individual plates have one general direction of movement, the rate at which different parts of that plate move can vary considerably. These variations cause the tearing or folding of the plates, where the pressures are greatest or the rocks are weakest. Such forces generate fault lines in the interiors of the plates. For example, the Newcastle earthquake, which killed 13 people and caused over $1500 million damage in 1989, was caused by rock movement along such a fault line.

Figure 4.30 Measuring plate movements The movement of the Earth's plates can be determined with the help of laser measurements.

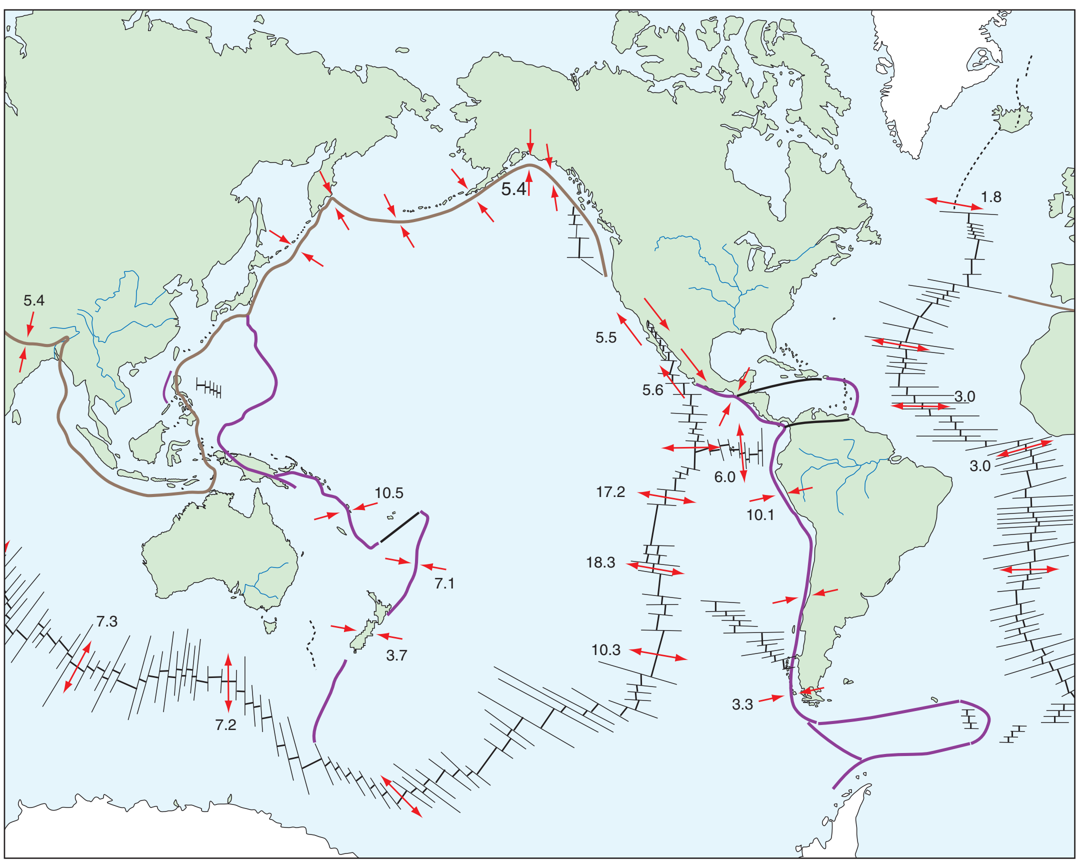


Figure 4.31 Earth's crustal plates There are seven major plates and many smaller ones. The directions of movement are shown as arrows. The values shown are in centimetres per year.

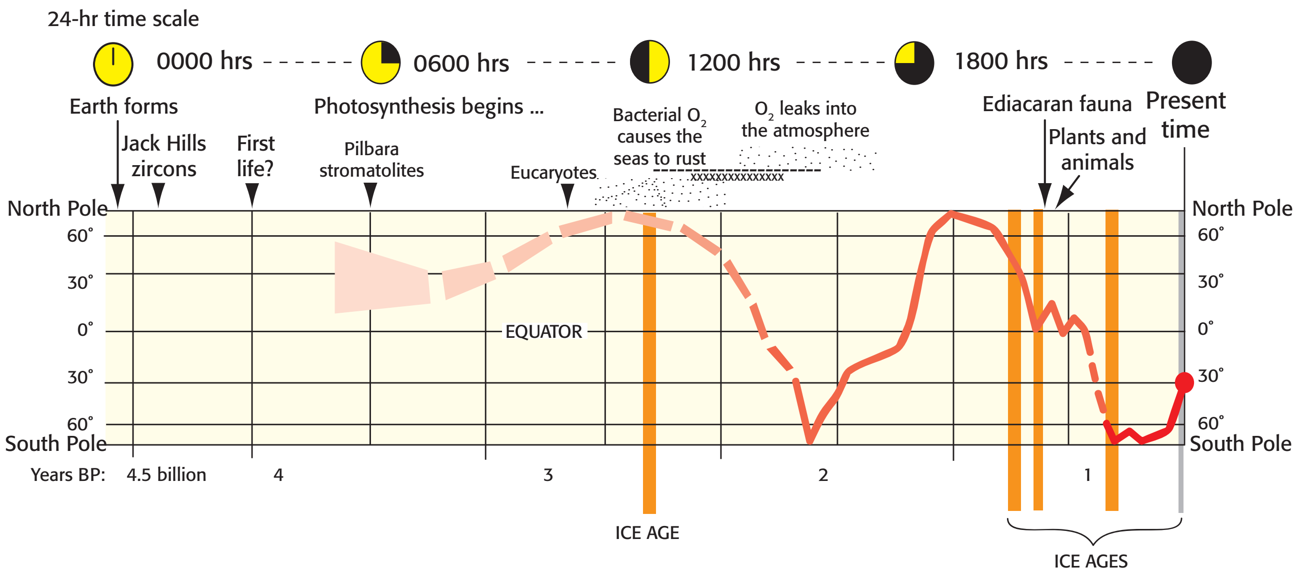


Figure 4.33 Movement of Australia Our own continent has wandered between the north and south poles throughout geologic history.

Future continents

It has taken 200 million years for the supercontinent Pangaea to break up into the widely dispersed landmasses of today. While this is an unimaginably long period of time for humans to grasp, it represents less than five per cent of the Earth's life span – roughly equivalent to eight months in the life of a 16 year old. This transition from congregation to segregation is believed to be part of a regular cycle known as the **tectonic supercycle**. Given the current rate and direction of movement of the continents, another supercontinent is likely to form in around 250 million years (Figure 4.34).

Figure 4.34 Future continents What the Earth may look like 250 million years from now.

Despite the inevitable modifications that will occur to the theory of plate tectonics over time, the continents will continue to drift. At oceanic ridges, lava will carry on erupting and forming new oceanic crust. This new crust will take only 150 to 200 million years to travel across the width of the plate, only to be forced beneath another plate and reabsorbed into the mantle.

The less dense and therefore more buoyant continental crust that makes up most landmasses will not suffer the same inevitable destruction as the oceanic crust. Since continental crust is too buoyant to be forced into the mantle, it will remain at the surface and will continue to be rearranged, welded together and torn apart. Thus oceanic crust stays eternally young through continual birth and death, whereas continental crust continues to age, becoming worn down and altered and so appearing quite different from the crust it once was.

Chapter 5

ENERGY FOR ATMOSPHERIC AND HYDROLOGIC PROCESSES

Interactive vocabulary
http://qr.w69b.com/g/roMKx7we4

Life on Earth as we know it is totally dependent on the Sun. While a small amount of energy comes from within the Earth (Chapter 4), by far the majority comes from the Sun. The Sun's energy is needed to make the Earth habitable for life. The energy from the Sun is trapped by the atmosphere's *natural greenhouse effect* so that the planet is habitable. The ozone layer in the upper atmosphere helps protect us from ultraviolet light.

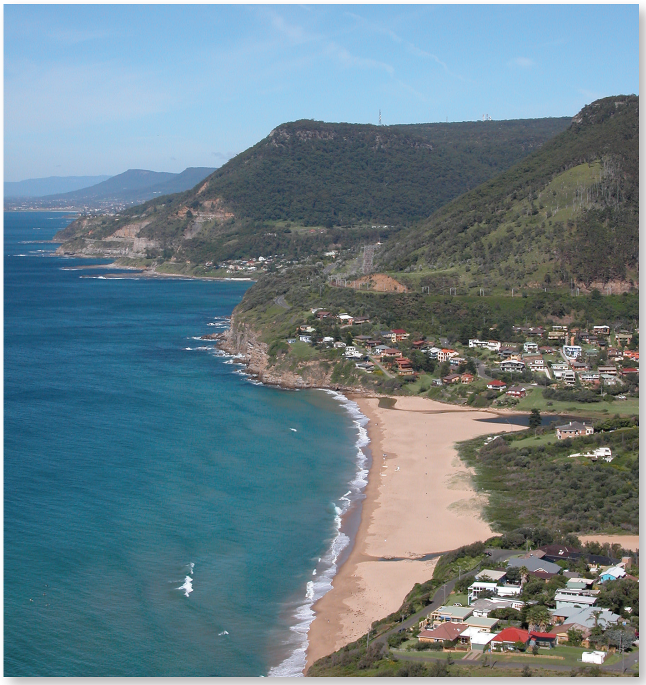


Figure 5.1 Air and water Transferring energy from the Sun around the Earth.

Human activity is interfering with these natural processes. The release of greenhouse gases such as carbon dioxide has resulted in the *enhanced greenhouse effect*. The result is global warming with melting glaciers and ice caps, rising sea levels and extremes of weather. The release of gases called CFCs has damaged the ozone layer that helps protect us from ultraviolet radiation.

Energy from the Sun is primarily distributed around the Earth by the movement of the atmosphere. Part of this movement is due to the movement of warm air at the equator towards the poles. Part is due to the rotation of the Earth. Moving weather systems are a major way in which heat is transferred. Some heat is transferred by the currents in the oceans, but their major effect is to store heat energy. However, human activity is having a major effect on both atmosphere and oceans. El Niño and La Niña weather patterns are becoming more extreme.

5.1 Energy and the atmosphere

The Sun's energy causes evaporation of water that feeds moisture into the hydrologic cycle – also called the water cycle. It also powers transpiration as water moves through plants. Of course, the Sun provides the energy needed for photosynthesis.

There is a fine balance between the energy arriving from the Sun and the energy that is lost back into space. Human use of fossil fuels is interfering with the natural balance leading to the enhanced greenhouse effect and global warming.

The Sun's energy

The Sun's energy is produced by nuclear fusion (Figure 5.2). In the centre of the Sun there are huge pressures as well as enormous temperatures of more than 15 000 000°C. These cause hydrogen nuclei to travel so fast that, when they collide with each other, they fuse together to form helium nuclei. The energy released during this process moves slowly to the surface of the Sun where the temperature is around 5500°C.

Figure 5.2 Sunlight Radiation from the Sun is essential for life but too much can cause harm.

The energy released from the Sun is mostly in the form of electromagnetic radiation. The electromagnetic spectrum (Figure 5.3) allows us to see the many types of radiation that differ in their wavelength.

Of the radiation that reaches Earth, the short wavelength ultraviolet light can be dangerous (Unit 5.2). Visible light and infra-red (heat) radiation is what mainly warms the Earth.

The Sun also emits many charged particles such as protons and electrons – the solar wind. The Earth is surrounded by a magnetic field that protects us from such particles. The energy from these particles is minor.

When radiation reaches the Earth

Only a small fraction of the Sun's radiation reaches planet Earth. The spherical Sun gives off its energy in all directions and only a small amount reaches the tiny sphere of Earth in the vastness of space. As well, the Earth is a long way from the Sun, around 150 million kilometres.

Earth is at just the right distance for life to exist. If we were much closer to the Sun, it would be too hot – any further away it would be too cold.

When the Sun's radiation reaches Earth, it may be reflected or absorbed. The **albedo** (Latin for 'whiteness') of the Earth is the fraction of light which reaches Earth that is reflected (Table 5.1). Ever wondered why the asphalt of the school playground is so hot to sit on? It's albedo is around 0.12 – most heat from the Sun is absorbed making it very hot.

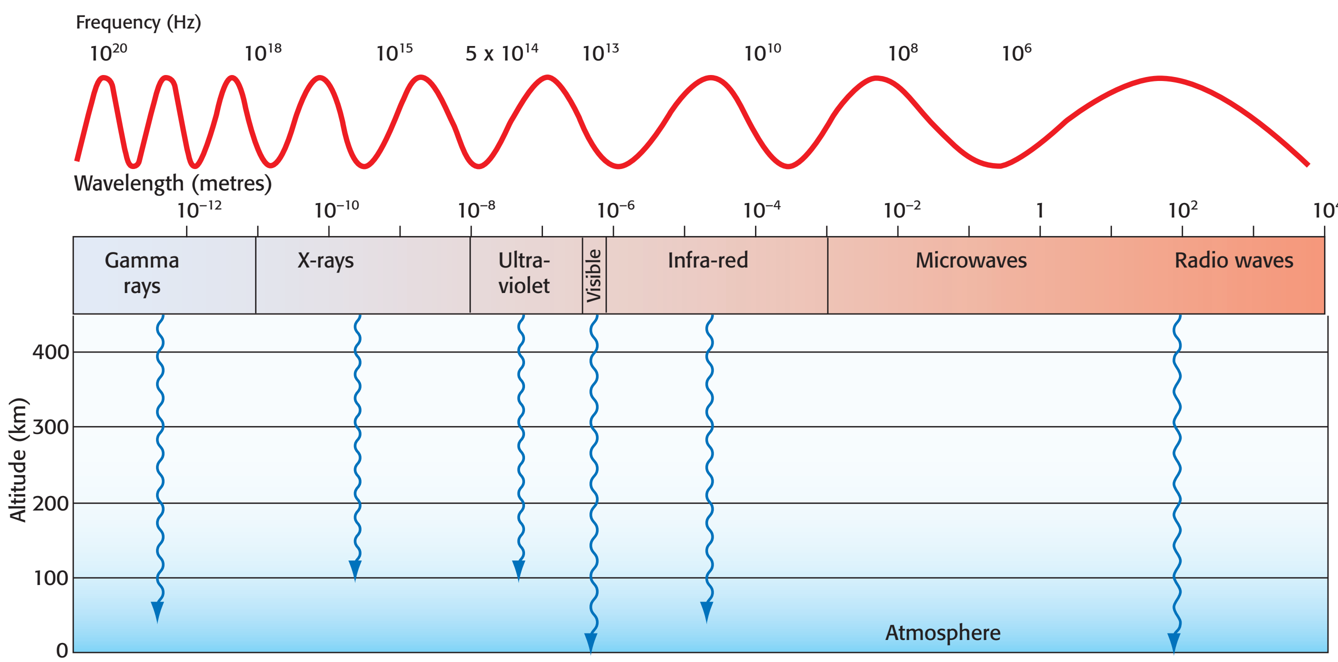


Figure 5.3 Sun's electromagnetic spectrum Radiation from the Sun varies in wavelength.

Nearby grass has an albedo of around 0.25 and is cooler to sit on as much more light is reflected. The ice on the polar ice caps has an albedo of around 0.6 while that of fresh snow can be as high as 0.9.

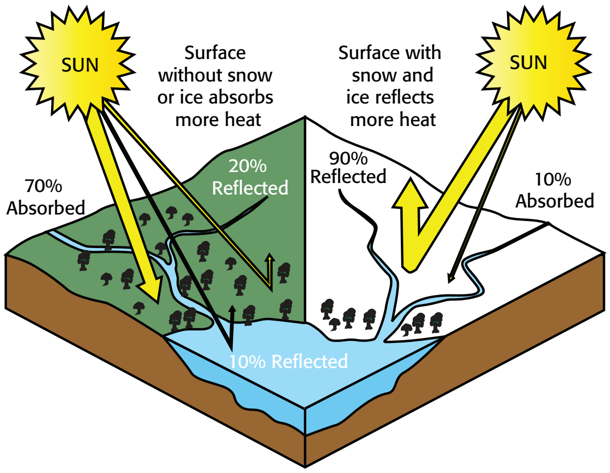


Figure 5.4 Albedo Snow covered regions have a higher albedo than regions covered by vegetation.

The Earth's average albedo is around 0.3 so that 30 per cent of the radiation that reaches the Earth and is reflected back into space (Figure 5.4). The value does vary with the region and the season. Desert regions with little vegetation have a fairly high albedo that changes little as the seasons are often fairly constant. Tropical regions with significant cloud cover have a high albedo as radiation is reflected by the clouds. When forests are cut down, the albedo drops and the region becomes much hotter as more heat is absorbed.

Polar regions in winter are mostly covered with snow and ice. Near the North Pole where the sea ice melts, the albedo can vary from 0.4 in summer to 0.7 in winter. The variation is not as great at the South Pole as the land remains covered with ice. With global warming melting more sea ice, the albedo will drop also increasing the amount of heat absorbed. That will cause more snow and ice to melt, and so on. We call this the snow temperature **feedback**.

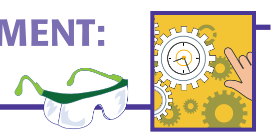
Albedo is also affected by clouds, aerosols and particles in the atmosphere. Major volcanic eruptions can send huge amounts of ash and aerosols into the atmosphere. These particles reflect light back into space, thus lowering Earth's temperature. When in 1991 Mount Pinatubo erupted in the Philippines, huge amounts of dust and aerosols were sent high into the atmosphere and circulated around the globe. In 1992 and 1993, the average temperature of the entire planet was cooled 0.4°C to 0.5°C.

Human activities are also increasing the amount of aerosols in the atmosphere. Dust from moving vehicles, aerosols from vehicle exhausts, and vapour trails from high flying aircraft all increase the number of particles reflecting radiation back into space. All these activities help cool the atmosphere and help slow global warming.

Table 5.1 Selected albedos.

Surface	Range of albedo
Fresh snow	0.80 to 0.90
Old/melting snow	0.40 to 0.80
Ocean ice	0.5 to 0.7
Desert sand	0.40
Grassland/grass	0.25
Deciduous trees	0.15 to 0.18
Coniferous forest	0.08 to 0.15
Tundra	0.20
Soil – bare	0.17
Asphalt	0.12
Ocean	0.07 to 0.10

ACTIVITY 5.1 EXPERIMENT: SURFACE ALBEDO



Aim: To investigate how the colour of a surface influences its albedo and heat absorption.

Apparatus

- Light sensor
- Temperature probes
- High intensity lamp (or strong sunlight)
- Different coloured paper, including black and white
- Mirror, similar size as paper
- Metre ruler
- Large protractor

Risk assessment

Hazard: Hot equipment.

Risk: Burns.

Precaution: Allow lamp time to cool before packing up.

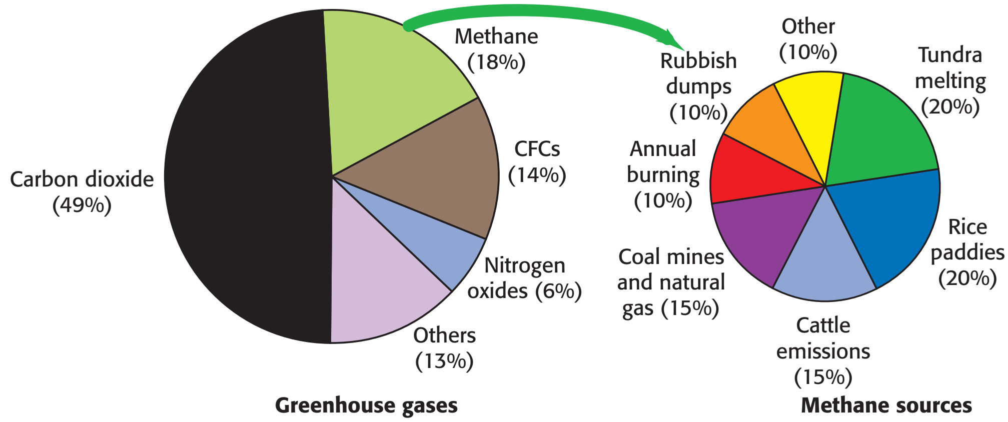


Figure 5.19 Greenhouse gases The sources of methane gas, including that from ruminants.

Water vapour makes up between 0.1 and 3 per cent of dry air, varying with the location, season and altitude. It is the most abundant and powerful of all the greenhouse gases, causing about 60 per cent of Earth's naturally occurring greenhouse effect.

Other compounds such as sulfur dioxide, nitrous oxide and halocarbons add to the total greenhouse gases.

Figure 5.20 Tundra lakes Lakes like these form when permafrost melts.

SCIENCE SKILLS

Refer to the pie charts in Figure 5.21 to answer the following.

1. The nitrous oxide total is given as 17 Tg/y and the methane total is given as 565 Tg/y. What does Tg/y mean?
2. How many times larger are the methane emissions compared to the nitrous oxide emissions? **Show** all working.
3. For the nitrous oxide sources, classify each source as either natural or anthropogenic in a data table. **Justify** your choices for each.
4. Use the data provided to calculate the total natural emissions and total anthropogenic emissions for nitrous oxides in Tg/y.
5. Repeat Question 3 for methane sources.
6. Repeat Question 4 for methane sources.

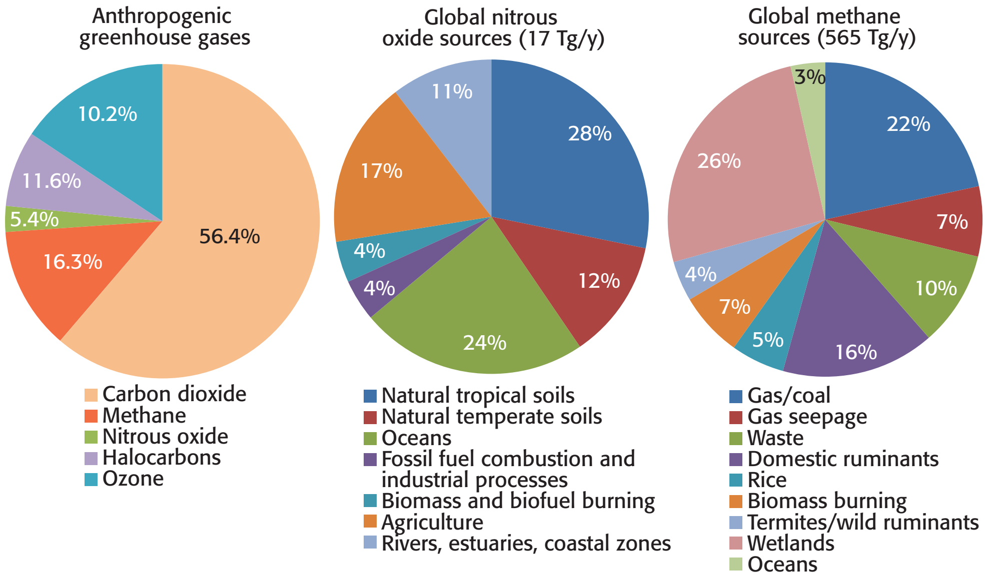


Figure 5.21 Gases in the atmosphere Sources of anthropogenic greenhouse gases (NASA) and sources of nitrous oxide and methane emissions. (IPCC)

Figure 5.22 Human activities that contribute to global warming (a) Transport emissions. (b) Deforestation.

Therefore, climate change cannot be avoided. What can be done is to limit the extent of climate change so as to minimise its harmful effects. Minimising climate change has become an imperative not just for environmentalists, but also for groups as diverse as business leaders, religious leaders, insurance agencies, economists, military planners, ethicists, and everyday families and individuals.

A plan for action

Global carbon emissions are projected to double between the years 2005 and 2055. This will be *triple* the level of carbon dioxide in the atmosphere from pre-industrial levels of around 275 parts per million (ppm) to around 825 ppm. As you can see in Figure 5.23, such an atmospheric carbon dioxide level is 'off the chart' and would result in the catastrophic worst case scenarios of possible consequences.

In order to minimise global warming and its consequences, scientists have recommended that emissions be reduced in stages so that they will be back down to 2005 levels by 2055. While this is still almost double the pre-industrial carbon dioxide levels, it will avoid the worst consequences of global warming.

Figure 5.23 shows two different scenarios. If we continue with our current rate of emissions increase (referred to as the 'business as usual' scenario) we will have tripled carbon dioxide levels by 2055. If we meet the recommended reduction targets, we will remain at double the pre-industrial carbon dioxide levels. The difference between these two scenarios is called the **stabilisation triangle**. It is in this area of the graph where governments, industry and individuals need to reduce emissions by 7 billion tonnes per year by 2055.

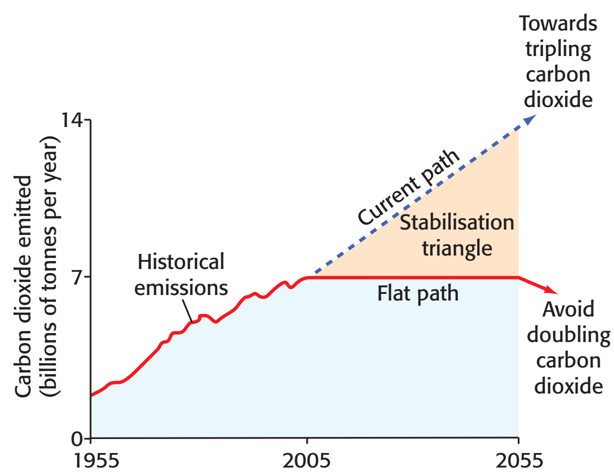


Figure 5.23 Predicted carbon dioxide levels If we continue 'business as usual' emissions, the predicted carbon dioxide levels are shown by the dotted black line. The proposed emission target for 2055 is shown in orange. In reality, this line will not be flat. Rather it will rise after 2005 to a point then fall back to 2005 levels by 2055.

Experts have divided the stabilisation triangle into seven individual wedges, each representing approximately one billion tonnes (Figure 5.24). The potential carbon savings can come from a variety of sectors. By strategically planning how to target these sectors individually, it is hoped that the necessary reductions can be made.

2. What does the term greenhouse gas mean? **Identify** the main greenhouse gases.
3. For one of the gases mentioned in Question 2, **describe** its main sources of emission.
4. Ice cores offer scientists invaluable insights into past climates. **Explain** how they are obtained and how they provide evidence for ancient atmospheres.
5. **Outline** one other source of evidence for past climates.

Set 2

6. **Describe** the link between atmospheric carbon dioxide levels and average global temperatures.
7. **Draw** a diagram that explains the natural greenhouse effect.
8. **Identify** two different sources of data about past climates. Compare these in terms of what is measured and what the measurements indicate.
9. **Evaluate** the possibility for humans to reduce the proportions of carbon dioxide gases in the atmosphere.
10. **Evaluate** claims of a relationship between changing carbon dioxide concentrations and changes in average global temperatures.

5.4 Atmospheric circulation

Figure 5.25 Flooding The Brisbane floods of 2011 were due to a strong La Niña event. (Courier Mail)

One of the major controlling factors of our weather is El Niño and La Niña. The massive Brisbane floods of 2011 were due to a strong La Niña event (Figure 5.25). To understand how this system works we need to grasp how the circulation of heat through the atmosphere affects our weather. In the next unit we will see how the circulation of ocean currents also transfers heat. Then in Unit 5.6 we will look at how El Niño and La Niña affect our weather.

The Sun heating the Earth

The Sun does not heat the Earth evenly. The axis of the Earth is tilted by around 23° to the plane of the Solar System, and the amount of radiation the Earth receives changes during a **revolution** of the Earth around the Sun. In the southern summer we are closer to the Sun than we are in winter. Due to the tilt of the Earth on its axis, the Sun's rays are more concentrated at the equator when compared to the poles (Figure 5.26).

The overall effect is that the equator is on average much warmer than are the poles. At sea level, the average is around 30°C both summer and winter while at the South Pole the average temperature at sea level is around –65°C in winter and –30°C in summer. For the North Pole the average is 0°C in summer and –40°C in winter. As we know, heat moves from regions of high to regions of low temperature. As a result, heat moves from the equator to the poles thus helping keep the Earth's climate in balance.

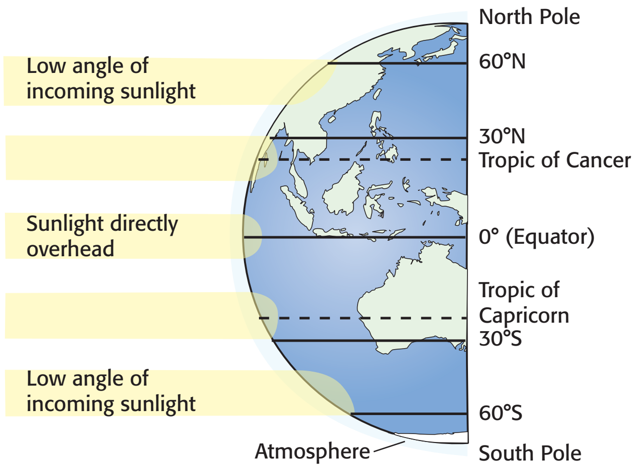


Figure 5.26 Uneven heating of the Earth The Sun's rays are more concentrated at the equator when compared to the poles.

ACTIVITY 5.8
READING SYNOPTIC CHARTS

Use the synoptic chart in Figure 5.30 and research to answer the following questions.

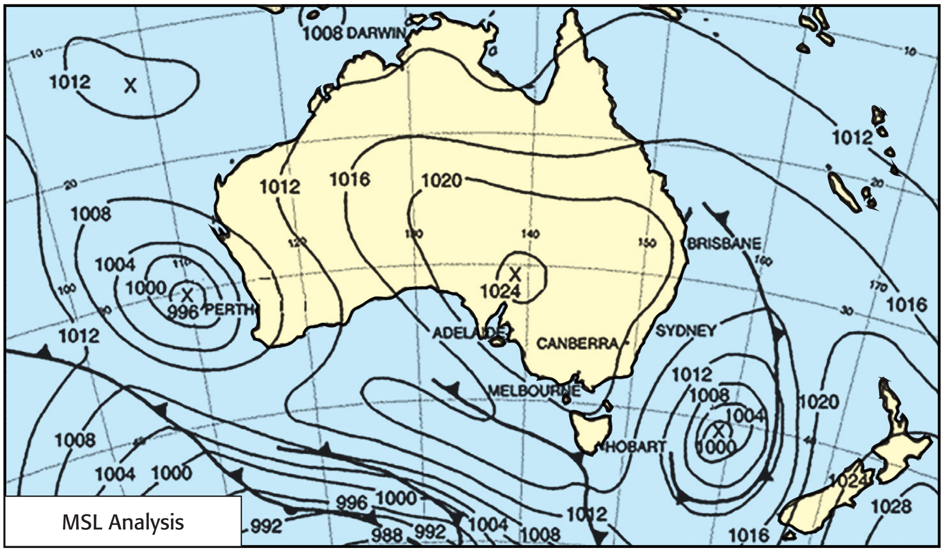


Figure 5.30 Synoptic chart. (BOM)

1. How many pressure cells are visible on this chart?
2. What is the unit of pressure used for the isobars on this chart?
3. What other numerical data is shown here?
4. Just west of Brisbane is a circular isobar labelled ‘1020’. What does every location on this line have in common at the time this chart was made?
5. Estimate and record the air pressure at each ‘X’ in the centre of pressure cells.
6. Label the centre of each pressure cell as high or low.
7. Use a pencil to draw the directions of air/wind movement across this chart, keeping in mind two things:
   - The direction in which air moves around pressure cells in the Southern Hemisphere.
   - The fact that air moves parallel to isobars, not across them.
8. The closer the isobars are together, the stronger the pressure difference and the faster the winds will be. Use this information to compare the wind speeds between:
   (a) Perth and Darwin.
   (b) Brisbane and Sydney.
9. Construct a data table to display the following information at the time this chart was made:
   - Each labelled Australian locality.
   - Air pressure.
   - The direction the wind is blowing from.
10. Research what are the world’s record highest and lowest surface air pressures and where they occurred. Explain how the locality influenced these extreme high or low pressure readings.

Atmospheric circulation

As we know, hot air rises. As the humid air of the tropics is heated by the Sun, it expands and becomes less dense and rises into the atmosphere. The rising air creates a region of low pressure. This is because pressure is due to the weight of air above – the less air the less weight and the lower the pressure.

It was originally felt that this rising air then moved to the poles, cooling along the way. As it cooled, it contracted and became more dense. At the poles the cooler, denser air then sank to create regions of high pressure (Figure 5.31 (a)).

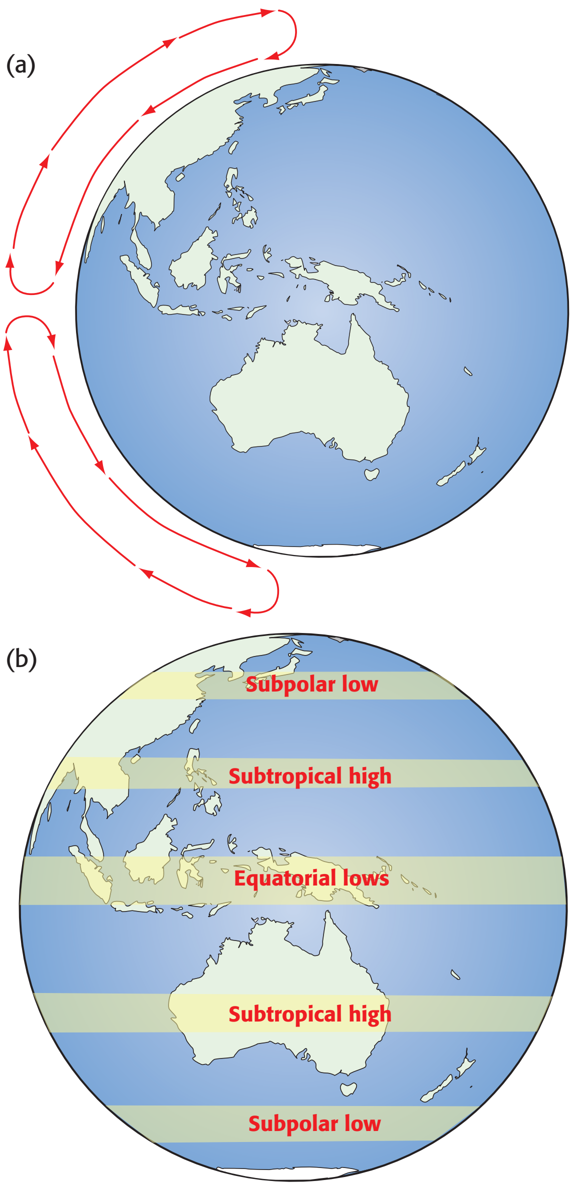


Figure 5.31 Circulating atmosphere (a) One circulating atmospheric cell. (b) Regions of high and low pressure between the poles.

This cool air then moved across land and sea until it reached the equator and the cycle started again. Such a circulation is called a **Hadley cell**.

This simple picture has to be discarded when measurements of air pressure showed there were regions of high and low pressure between the north and south poles (Figure 5.31 (b)).

Atmospheric circulation
http://qr.w69b.com/g/r3HYkEQXC

Three atmospheric cells

We now believe there are three atmospheric cells between the equator and the poles (Figure 5.32). The first cell rises at the equator and carries warm air to latitudes of around 30°N and 30°S. By this stage it has cooled, losing heat along the way. The cool air sank and returned to the equator. Another major cell is located closer to the poles carrying heat from around 60°N and 60°S to the very poles themselves. Both of these atmospheric cells have a simple circulation.

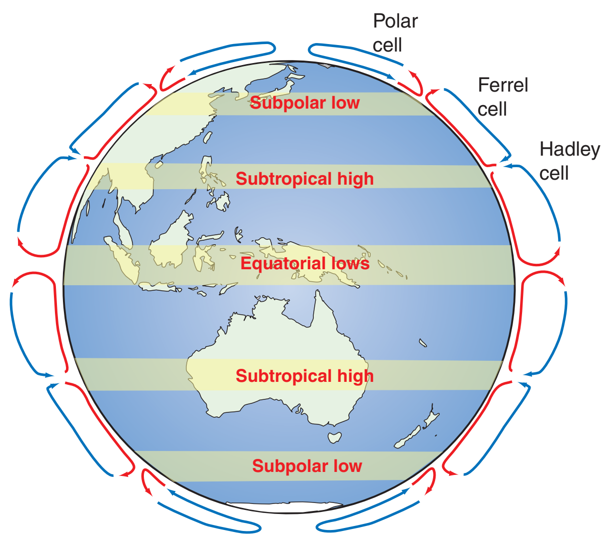


Figure 5.32 Three cell circulation Heat is transferred by convection through three cells from the equator to the poles.

Between these two cells lies a third cell with a much more complex circulation. There is enough heat around 30°N and 30°S to cause the air to rise and move towards the poles. However, while some of the air sinks and returns to its starting region, other air continues towards the poles.

Making use of the moving atmosphere

In the era of sailing ships, the route from say Europe to Australia had to be chosen carefully. When you sailed close to the equator, you entered the **doldrums** – a region with often very little wind but intense thunderstorms (Figure 5.33). We now know that heat from the Sun causes this air to rise and move towards the poles – the first of the atmospheric cells. Hot moist air rising would begin to cool and thunderstorms would result. Sailors had to cross the doldrums off the west African coast and could on occasion remain nearly stationary for up to three weeks.

When sailing from Europe to America, sailors took a rather long route. By moving south towards the equator they were able to take advantage of ocean currents and **trade winds** (Figure 5.33). This wind is part of the atmospheric cell that starts at the equator where it causes the doldrums. When the air descends at around 30°N or 30°S, it then travels over the ocean towards the equator thus creating trade winds used by sailors. In the Southern Ocean, ships sailed south and used very strong trade winds called the roaring forties to carry them from Africa to Australia.

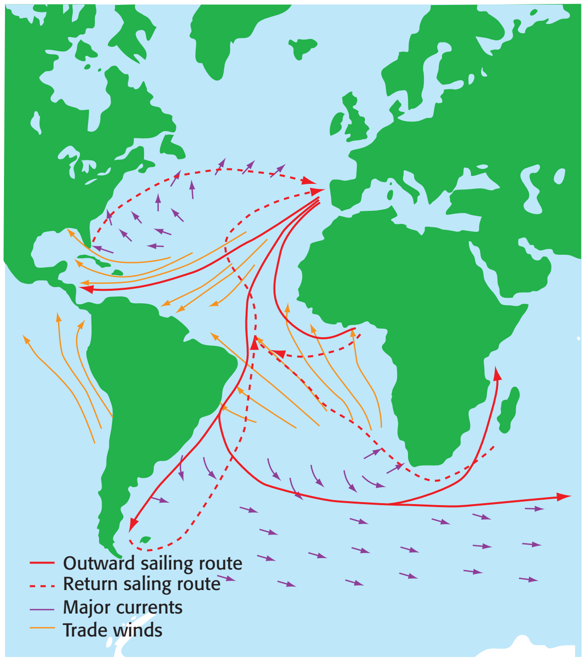


Figure 5.33 Sailing the oceans Trade winds helped sailors cross the Atlantic and sail from Africa to Australia. Crossing the doldrums could take weeks.

Have you ever been on an aeroplane flight and found that you arrived much earlier than expected? Perhaps your were told the pilot was able to take advantage of the **jet stream** (Figure 5.34). Between the atmospheric cells we can have some very fast moving winds at high altitudes. They help distribute heat around the Earth. If they are moving in the right direction, a pilot can take advantage of this fast moving air, arriving early and saving fuel. When flying in the opposite direction they are avoided.

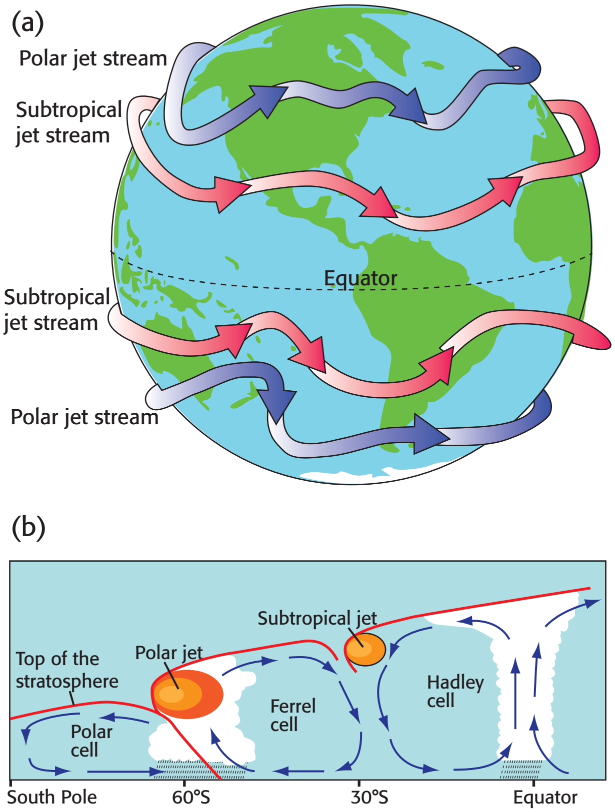


Figure 5.34 Jet stream High speed winds between atmospheric cells can help aircraft but can also change weather patterns.

The jet stream can also influence the weather. Fast moving air helps keep high and low pressure weather systems on the move. If the jet stream remains in the same position, it can result in severe weather events. It can block the movement of weather systems causing heatwaves in some locations or extreme floods in other locations. If the jet stream changes direction it can bring unusually severe weather to a region.

The hot air over land rises and is replaced by cooler and moist air from the Southern Ocean. This moisture is then released as rain over the northern continent as the summer **monsoon**. This air then flows back over the Southern Ocean and the cycle is repeated.

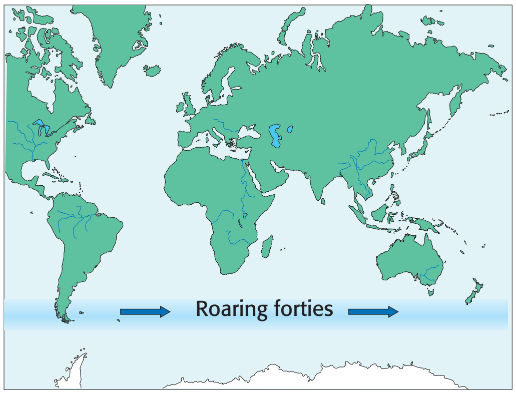


Figure 5.37 Continents and circulation The flow of atmosphere around Antarctica is much smoother due to lack of continents.

There is also another *monsoon* during the southern summer. During this season, the Australian continent becomes very hot causing the air above to rise. Ocean currents prevent the waters in the Indonesian region from leaving and they absorb a lot of heat. This creates very humid air that under the right conditions moves south to replace the air rising over Australia. This moisture falls as rains over northern Australia as our summer monsoon.

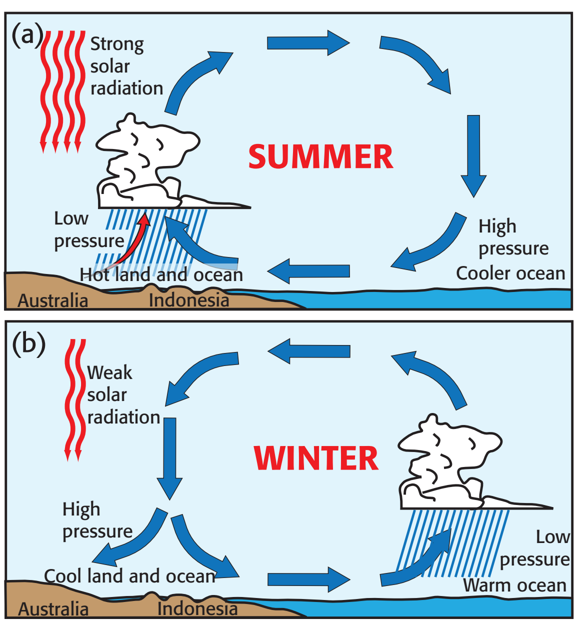


Figure 5.38 Monsoons (a) Asian monsoon in the northern summer. (b) Indonesian and Australian monsoon in the southern summer.

ACTIVITY 5.9
CORIOLIS EFFECT

There are a number of demonstrations of the Coriolis effect to be found on the internet. Here are some at the time of writing.

Coriolis effect 1 http://qr.w69b.com/g/q1hpoqf60	

Coriolis effect 2 http://qr.w69b.com/g/rQoaWeveM	

Coriolis effect 3 http://qr.w69b.com/g/o9qWvpw2s	

View the video and answer the questions.

1. As far as a person who is stationary on the rotating platform is concerned, how does the ball travel?
2. As far as a person who is stationary above the rotating platform is concerned, how does the ball travel?
3. As far as a person who is sitting on the rotating platform is concerned, how does the ball travel?
4. Which of the three experiments best matches what happens to we humans on the rotating Earth?

SCIENCE SKILLS

1. Sailing ships of the early 1800s had no motors and relied on sails. Clipper ships carried tea from China to Britain with a prize for the fastest passage. **Explain** why such sailing ships carried as much sail as possible.

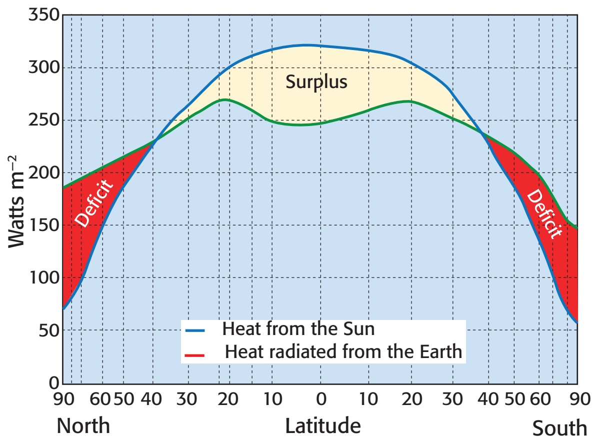


Figure 5.39 Heat arriving at Earth Heat arriving from the Sun at the equator compared to the poles.

2. The graph in Figure 5.39 shows the heat arriving at the equator and at the poles.

(a) **Identify** the latitudes of the poles and the equator.

(b) **Measure** the heat that arrives at both the poles and the equator.

(c) **Explain** why one answer to (b) is larger than the other.

(d) **Identify** the latitudes where the heat lost balances the heat that arrives.

TO THINK ABOUT

Set 1

1. **Identify** the region of the Earth that receives the most heat per unit area from the Sun. Identify the region that receives the least heat per unit area.

2. **Distinguish** between trade winds and the doldrums.

3. **Describe** how the rotation and revolution of the Earth helps distribute heat around this planet.

4. **Explain** why hot air rises.

5. **Describe** what the Coriolis effect has on winds in the Southern Hemisphere.

Set 2

6. **Explain** why heat is transferred from the equator to the poles.

7. **Describe** how heat is transferred to the poles.

8. **Justify** the long route taken by ships as they sailed from Europe to America. **Investigate** how they returned from America to Europe.

9. **Outline** how the monsoon forms in northern Australia.

10. **Explain** why airline pilots avoid flying into a jet stream but will fly along with a jet stream.

5.5 The global ocean heat conveyor

If you live near the ocean, a lake or even a river, you will know that the presence of water helps moderate the local temperature. Each kilogram of water can absorb five times the heat of one kilogram of granite to produce a 1°C increase in temperature. Thus on hot days, the presence of water helps reduce the local temperature as it absorbs heat. On cold days, the water releases heat helping to warm the area. Of course, local breezes also help transfer the heat between water and land.

Figure 5.40 Heat sink Water can absorb five times the heat compared to nearby land for a 1°C rise in temperature.

Thus the oceans act as an enormous **heat sink** (Figure 5.40). The oceans acting as a heat sink have helped moderate global warming. The heat absorbed by the oceans near the equator can also be distributed towards the poles. In the last unit, we have seen how the atmosphere distributes heat towards the poles. In this unit we will see how ocean currents are also involved in making the Earth habitable. Cold water from the poles can move towards warm regions at the equator in the form of deep currents (Figure 5.41). As well, the prevailing winds can drive warm surface waters towards the poles.

Deep ocean currents

When ocean water in the Antarctic freezes, the ice that is formed is nearly salt free. This means that the cold water that remains is much saltier – we say that it is **saline**. Cold saline water is denser and sinks to the bottom. When it reaches the bottom of the ocean, it moves away from the Antarctic towards the equator. Something similar happens in the Arctic except landmasses and shallow straits mean most of this cold saline water enters the northern Atlantic. Currents of water that depends on temperature and density of water is called **thermohaline** circulation.

Thermohaline circulation
http://qr.w69b.com/g/qODqA9d1m

This constant movement of water away from the poles has to be replaced. This replacement water ultimately comes from the tropics where it has been warmed. This warm layer is only around 100 metres thick, extending to the **thermocline** where temperature drops rapidly. As it travels towards the poles the thin layer of warm water gradually loses heat, helping to maintain constant temperatures.

If warm water is moving towards the poles, it too must be replaced. Somehow the cold saline water deep in the oceans has to return to the surface. Part of this process involves the tides. As the water in the oceans move back and forth with the tides, deep cold water mixes with water above. Over time this mixing sees the cold water move to the surface. But perhaps the main route back to the surface are regions of **upwelling** where deep currents reach shallow water around the continents and are forced to the surface (Figure 5.42).

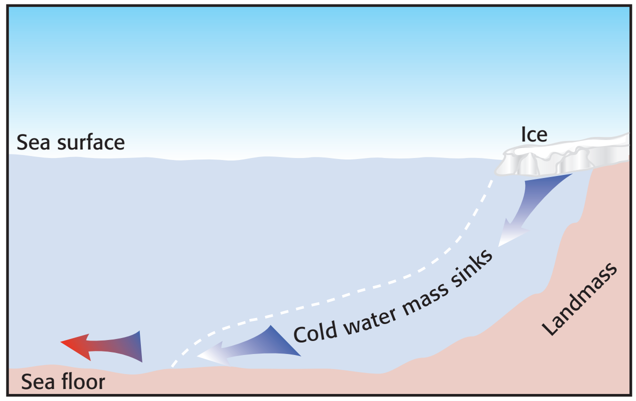


Figure 5.41 Cold water sinks Oxygen rich saline water sinks and spreads out over the ocean basin from the poles.

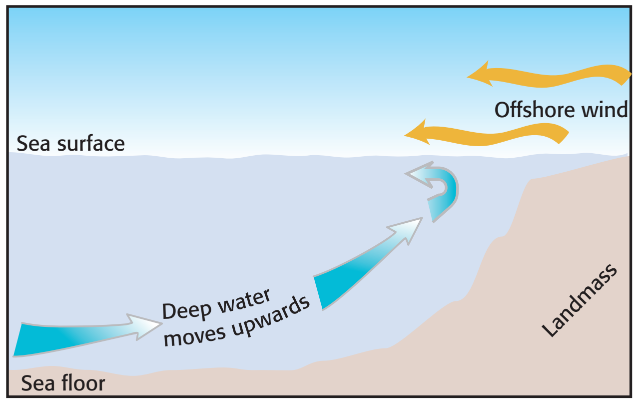


Figure 5.42 Upwelling Cold bottom water comes to the surface when it reaches shallow water.

This deep ocean water is both oxygen and mineral rich. Cold water dissolves more oxygen than does warm water. So the cold water that sinks to the bottom and makes up these deep ocean currents is rich in oxygen. Little is used by the organisms that live in these cold depths. Along the way it also dissolves minerals including those from deep ocean vents. Upwelling water that is oxygen and mineral rich supports a diverse population of marine life.

Thermohaline demonstration
http://qr.w69b.com/g/qODqA9d1m

Wind driven surface currents

When wind blows across the surface of water frictional forces between wind and water will result in the movement of surface waters. This movement or water current extends down to around 100 metres.

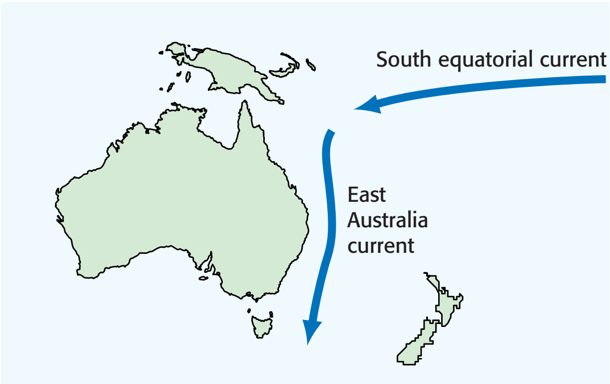


Figure 5.43 Wind driven currents The net direction of water movement is at right angles to the wind.

Since the trade winds near the equator blow in a westerly direction, this tends to force the surface currents in the same direction. However, the moving water is subject to the Coriolis effect just as much as moving air. The overall effect is that the net direction of water movement is perpendicular to the wind – to the left in the Southern Hemisphere and to the right in the Northern Hemisphere (Figure 5.43).

Let's see the effect this has on currents in the Pacific Ocean. Water moves west just south of the doldrums along the equator until it reaches Australia. Because the net force is from the north-west, the current swings down the east coast until it reaches the Antarctic circumpolar current and heads east to South America. The net force is now from the south-west and the current moves up the coast of South America to rejoin the currents at the equator (Figure 5.44).

We can now see how wind driven ocean currents can distribute heat around the globe. The current from Antarctica that heads north up the coast of South America carries cold water to warmer equatorial regions. The current down the east coast of Australia carries heat from the equator down towards the Antarctic. We can also see how water that has travelled along the ocean floor towards the equator returns to the poles. It is carried along with the wind driven surface waters.

Similar patterns of ocean current can be found in other parts of the world (Figure 5.45). We can also see why the fastest passage when sailing from Europe to America meant sailing towards the equator and picking up the trade winds and the ocean current meant a faster journey than sailing directly across the Atlantic.

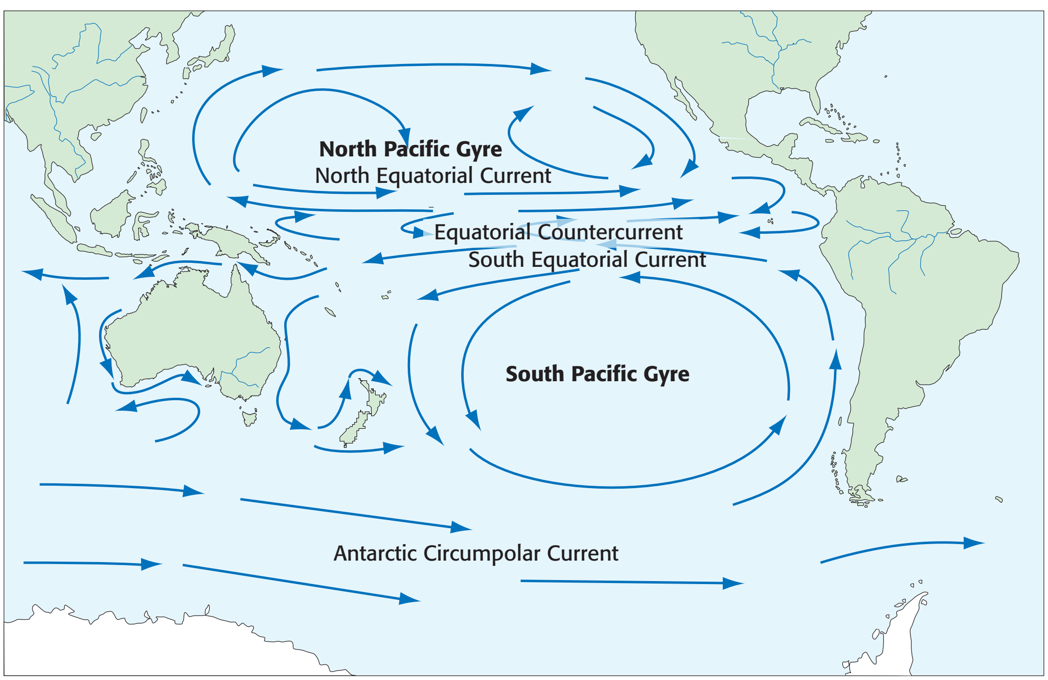


Figure 5.44 Pacific ocean currents The current is clockwise around the south Pacific Ocean.

On the return journey, they would have joined the warm Gulf Stream to speed their journey home. The warm waters of the Gulf Stream are one of the factors that make it possible for people to live in Iceland and northern Europe.

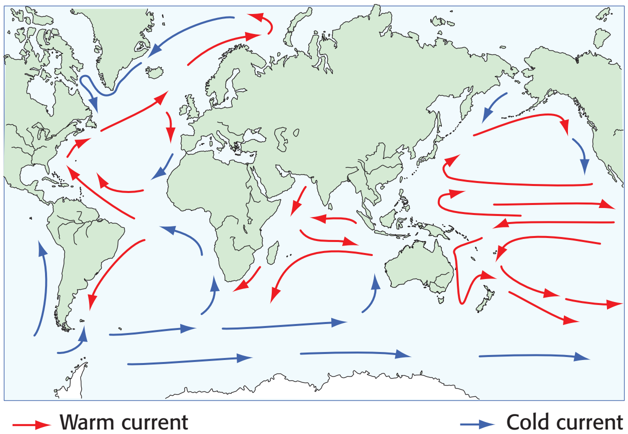


Figure 5.45 Ocean currents Major wind induced current in the world.

The global ocean heat conveyor model

While there are many currents in the world's oceans, there is one major system that helps transport huge amounts of energy around the Earth. All together, water currents distribute around half of the heat arriving at the equator to other regions of the Earth. But a word of warning – this is a simplified version of the much more complex **global ocean heat conveyor model** (Figure 5.46).

Let's begin at Antarctica. As the deep ocean current moves past Antarctica, the water is cooled and it sinks deeper to the sea floor. The current splits with part moving into the Indian Ocean and part into the Pacific Ocean. As the deep water current travels for thousands of kilometres it is gradually warmed until it rises to the surface. This surface current then travels back across the equator, around Africa and up into the north Atlantic. Here it is cooled and sinks to the bottom, travels back down the Atlantic as a deep current and is cooled again as it passes Antarctica.

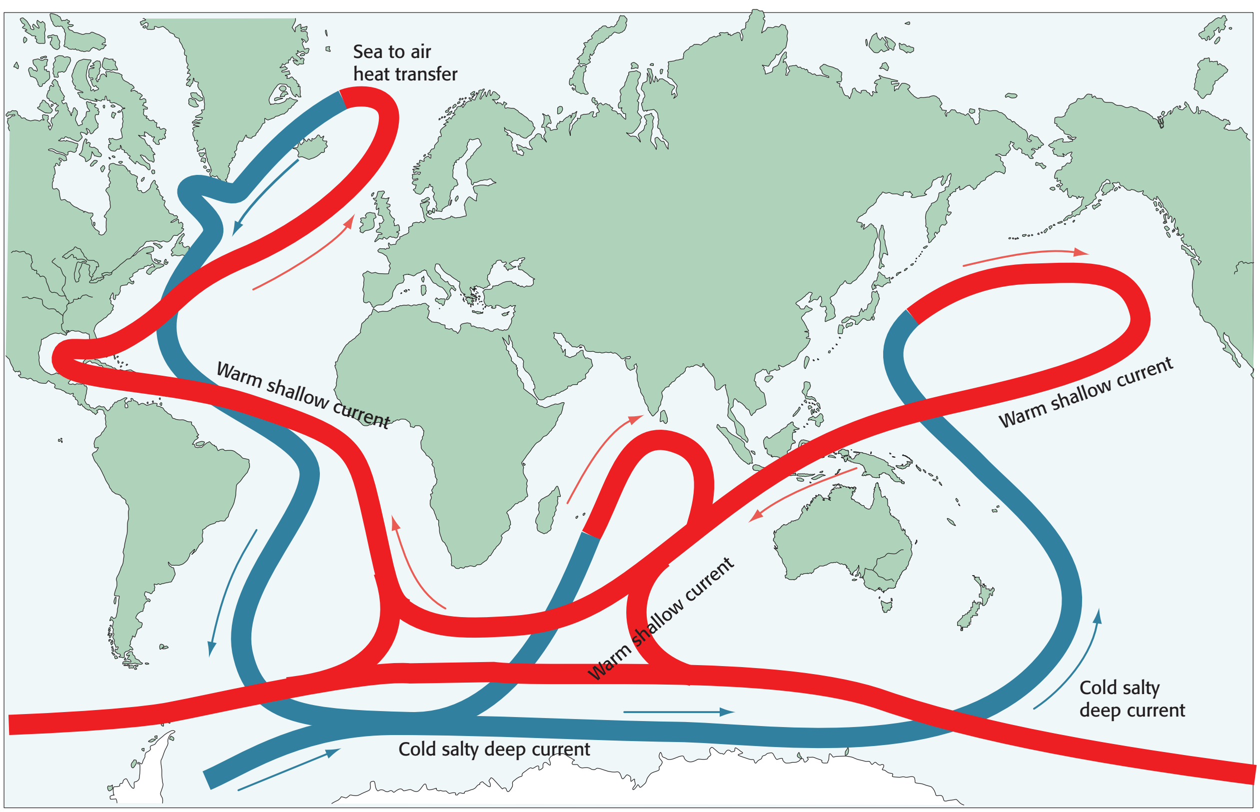


Figure 5.46 Global ocean heat conveyor model A simplified version of how currents move energy around the Earth.

5.6 El Niño and La Niña

Australia is a continent surrounded by oceans. Long term weather changes in Australia are in part due to changes in the temperatures of these oceans. In Unit 5.4 we learnt about the circulation of the atmosphere. In Unit 5.5 we learnt about the circulation of the oceans. In this unit we will learn how wind and current combine together to produce long term weather changes in Australia. While we know a lot about the influence of the Pacific Ocean, we are still learning about the influence of the Indian Ocean.

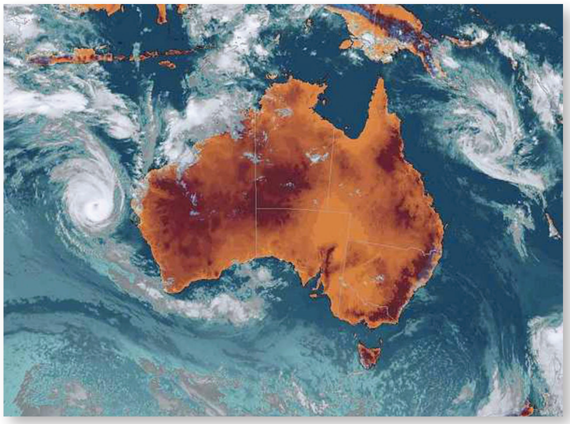


Figure 5.47 Surrounded by oceans Changes in the oceans surrounding Australia strongly influence our weather.

Walker cells

In most years a strong current brings relatively cold water northward along the west coast of South America from Antarctica (Figure 5.44). Under the influence of trade winds, the cold water then flows westward along the equator and is heated by the tropical Sun (Figure 5.48). These normal conditions form a large **warm pool** of water near Indonesia and Northern Australia that is about 3°C to 8°C warmer than the eastern Pacific. As well, the water along eastern Australia can be 0.4 m higher than along western South America. The thinner surface layer along the west coast of South America allows upwelling of cold nutrient rich waters that supports extensive wildlife and commercial fishing.

Along with the warm water, the trade winds bring warm moist air towards the Indonesian region. Here, moving over normally very warm seas, moist air rises to high levels of the atmosphere (Figure 5.48). The rising air is associated with a region of low air pressure, and the towering clouds bring tropical rain. The air then travels eastward in the upper atmosphere before sinking over the cooler eastern Pacific Ocean forming what is called a **Walker cell** (after the man who discovered it). This results in drier conditions in the Americas.

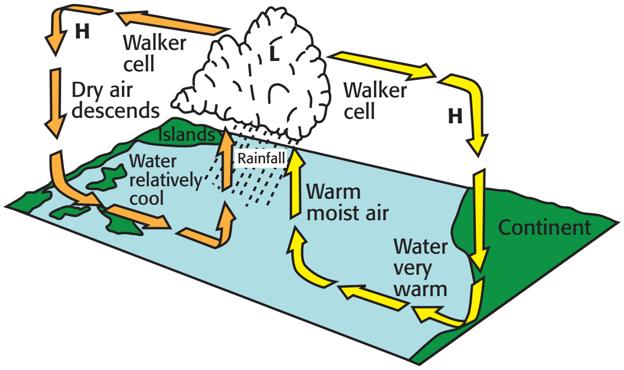


Figure 5.48 Walker cells The atmosphere is circulating along and above the equator in the Pacific.

La Niña and El Niño

Every three to seven years the normal pattern is upset. If the winds along the equator are very strong the process reaches an extreme. Thick layers of warm water evaporating and rising into the atmosphere can bring floods to parts of Australia and is called a **La Niña** (Figure 5.49). The major floods in eastern Australia in 2010 were the result of one of the strongest La Niña events on record.

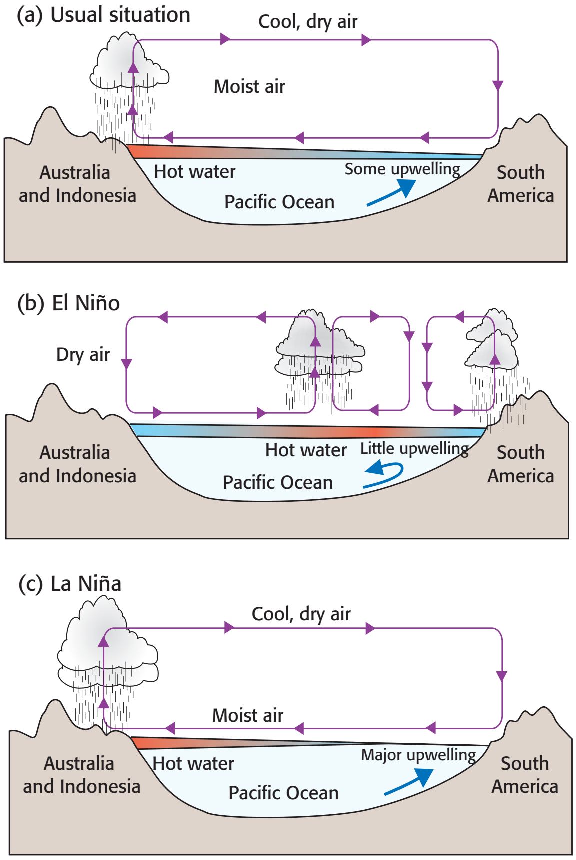


Figure 5.49 El Niño (a) During a La Niña, warm moist air rises over Indonesia bringing rain. (b) During an El Niño warm moist air rises over the Americas bringing rain.

The **El Niño** is the opposite extreme. The westerly trade winds can weaken (maybe even reverse) for reasons that we do not fully understand. When this happens, the force of gravity on the high water levels along eastern Australia pushes warm water in the west towards the east. The warm water accumulates in the middle of the Pacific Ocean and along the west coast of the Americas (Figure 5.50). The build-up of thick layers of warm water prevent the upwelling of cold nutrient rich water with devastating effects on wildlife and commercial fishing.

El Nino and La Nina animated
http://qr.w69b.com/g/n6H0ZTsUE

With cooler water in the Indonesian region less evaporation occurs. This produces little rain and drought and subsequent forest fires occur throughout Australia and Indonesia. In contrast, the western Americas are bathed in warm water with increased evaporation. As a result, there are often extensive rains and floods in these regions.

This movement of warm water back and forth across the Pacific is called the Southern Oscillation. When combined with El Niño we get El Niño-Southern Oscillation or **ENSO** for short.

ENSO outlook
http://qr.w69b.com/g/mM1Ep535m

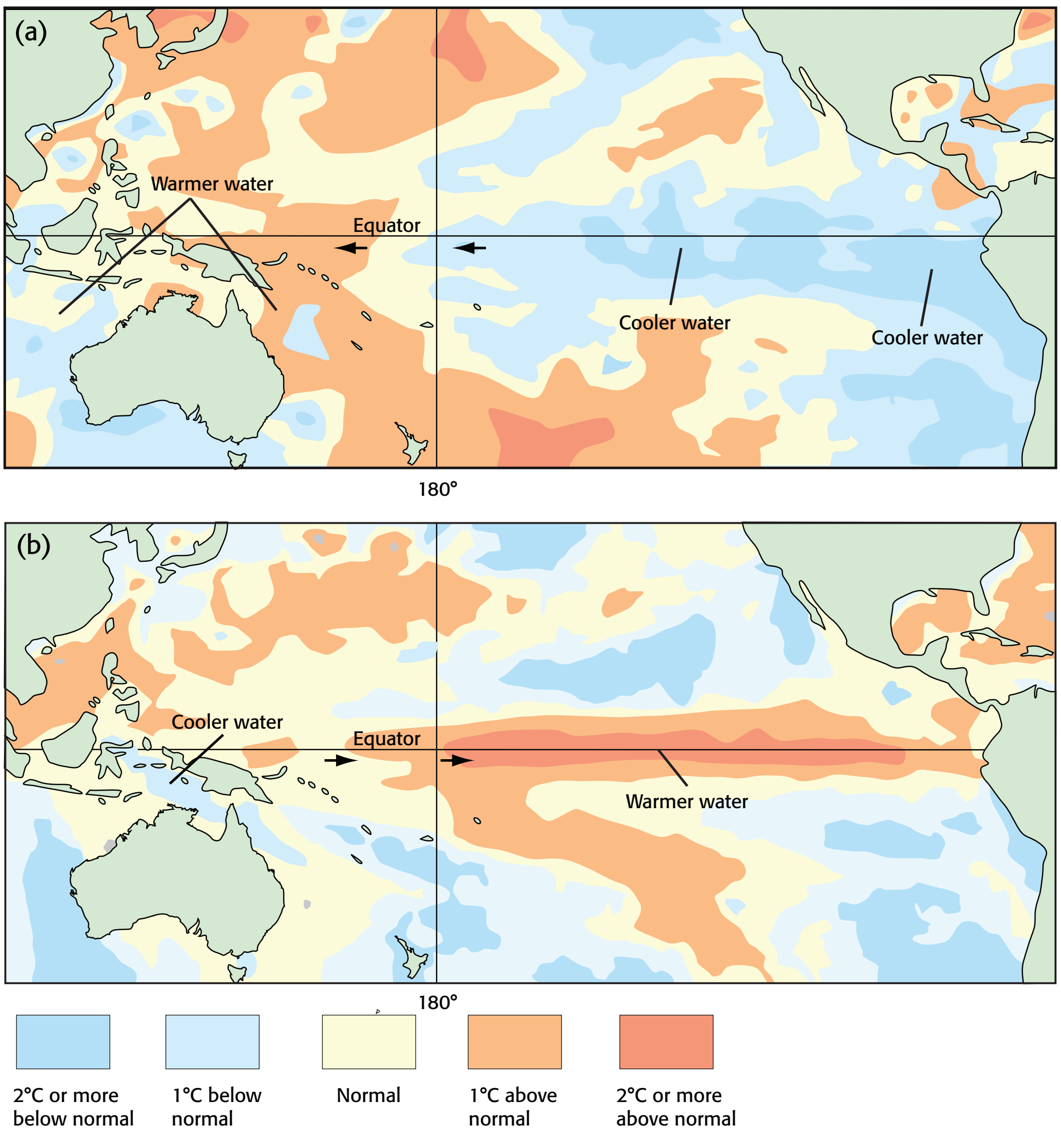


Figure 5.50 Surface temperatures (a) During a La Niña, warm water moves towards Indonesia. (b) During an El Niño, warm water moves towards the Americas.

The Indian Ocean dipole

But this cannot be the full story for Australia. During the decade long drought of the early 2000s the La Niña events did not bring extensive rain – it remained dry. Recent research has revealed that the Indian Ocean plays a major role in our weather.

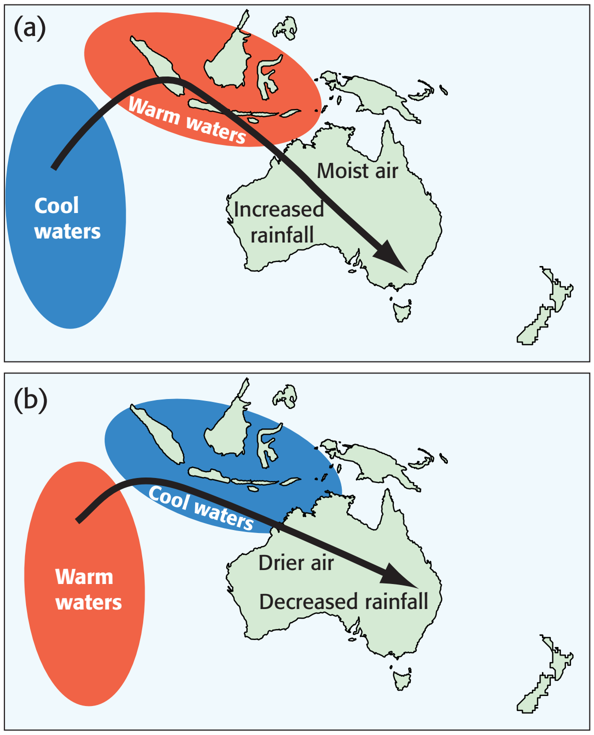


Figure 5.51 Indian Ocean dipole (a) Cool Indian ocean water pushes moist warm air over Australia and brings normal rain. (b) Warm Indian Ocean water leads to weaker, drier winds and less rainfall.

In one weather pattern, there is cool Indian Ocean water west of Australia (Figure 5.51). This generates winds that pick up moisture from the warm Timor Sea to the north and then carry the moisture down towards southern Australia to bring wet conditions. In the other pattern, the ocean temperatures are reversed and the weakening winds travel over a cooler Timor Sea to bring less moisture to be transported across Australia. So the south-east misses out on its usual amounts of rain. This shifting back and forth of conditions is called the **Indian Ocean dipole**.

Indian Ocean dipole explained
http://qr.w69b.com/g/qXa5wiBHO

It is thought that the Indian Ocean dipole has a link with La Niña/El Niño events through an extension of the Walker cells to the west. Hence, dry air from the Indian Ocean when combined with El Niño leads to extreme dryness. Moist air combined with La Niña results in extreme wet. When dry Indian Ocean air combines with La Niña, or moist Indian Ocean air combines with El Niño, they tend to cancel each other out to produce neutral conditions. Research in this area is ongoing.

ACTIVITY 5.11
MAPPING THE PACIFIC

For each of the two maps of surface water temperature in Figure 5.52, predict if we are dealing with an El Niño event or a La Niña event, or perhaps normal ocean temperatures. **Justify** your answers.

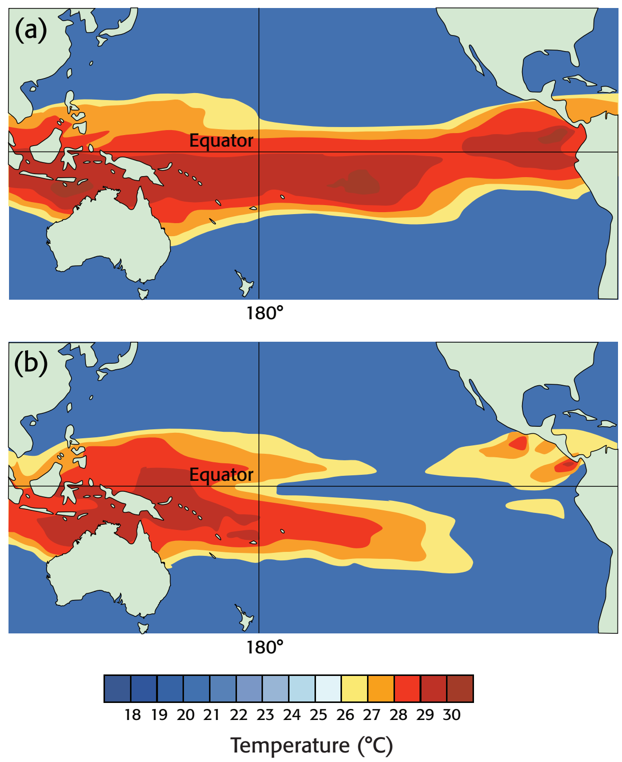


Figure 5.52 Pacific surface temperatures.

Chapter 6

ENERGY FOR BIOGEOCHEMICAL PROCESSES

Interactive vocabulary
http://qr.w69b.com/g/qo55v8VfG

As you watch grasses and trees swaying gently in the breeze, it is hard to imagine that inside the leaves things are very busy. The leaves of plants have been likened to a factory, powered not by electricity but by the ultimate source of energy – the Sun. Plants can use sunlight and simple, inorganic compounds from soil and air to make the complex molecules they need. The Sun's energy is **transformed** into chemical energy stored in the molecules of the plant.

Figure 6.1 Transforming energy Plants transform the Sun's energy into chemical energy.

The energy stored in plants is passed along food chains to animals that eat the plants and then to those animals that eat other animals. There is a limit to the numbers of plants and animals that can be supported in a community. This depends on the energy trapped by plants but also on the water and minerals that both plants and animals need to survive.

6.1 Net primary production

Organisms that can make their own food are called **autotrophs** (*auto* means 'self'; *troph* means 'food' or 'feeding'; *autotroph* means 'self-feeding'). Such organisms are also called **primary producers** because they are the first producers of complex compounds. Not all living things are autotrophs – many organisms are **heterotrophs**. They depend, directly or indirectly, on plants for energy.

Autotrophs: obtaining energy from the Sun

Plants of all types carry out **photosynthesis** (Figure 6.2). Inside the plant cells, the green pigment chlorophyll captures solar energy and converts carbon dioxide and water into energy-storing compounds known as carbohydrates. The word carbohydrate comes from *carbo* meaning 'containing carbon' and *hydrate* meaning 'containing hydrogen and oxygen'.

We can summarise the photosynthesis reaction with a word equation.

$$\text{Carbon dioxide} + \text{water} \xrightarrow{\text{In the presence of chlorophyll and sunlight}} \text{glucose} + \text{oxygen}$$

The balanced chemical equation for photosynthesis is:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

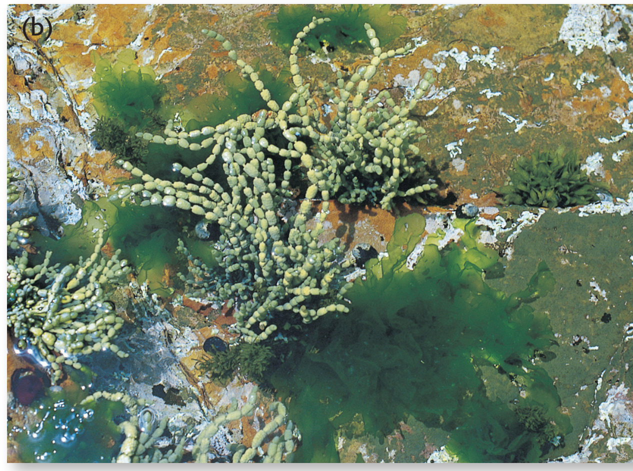


Figure 6.2 Photosynthesis in different types of plants (a) Moss. (b) Seaweed.

The simplest and most important carbohydrates are the *sugars*, such as glucose. The energy that plants store in glucose molecules can be released by breaking those molecules back down to carbon dioxide and water in the presence of oxygen. That is what happens in living cells – both animals and plants provide energy for their life processes by using glucose as fuel in the process known as **respiration** (Figure 6.3).

Figure 6.3 Energy for movement Respiration powers many cellular processes as well as providing the energy for muscle movement.

However, when you place glucose on the table, exposed to the oxygen in the air, nothing happens. For glucose to react with oxygen in cells, *enzymes* are needed as catalysts. We can summarise them using an equation.

$$\text{Glucose} + \text{oxygen} \xrightarrow{\text{enzymes}} \begin{array}{c}\text{carbon}\\\text{dioxide}\end{array} + \text{water} + \text{energy}$$

The balanced chemical equation for respiration is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Heterotrophs: obtaining energy captured by plants

The term *heterotrophs* comes from *hetero* ('other') and *troph* ('feeding'). Heterotrophs themselves store energy as complex molecules such as fats, oils and proteins. But they must obtain that energy by eating energy rich molecules contained in other living things. There are various ways to **transfer** energy from plants to animals.

Herbivores: plant eaters

Herbivores (*herb* means 'plant'), such as rabbits and kangaroos, eat plants that have stored energy in the form of sugars, starches and other complex carbohydrates. Because they are the first living things to consume the energy and carbon that is stored by primary producers, herbivores are usually called *primary consumers*. Herbivores survive by eating different parts of different plants (Figure 6.4).

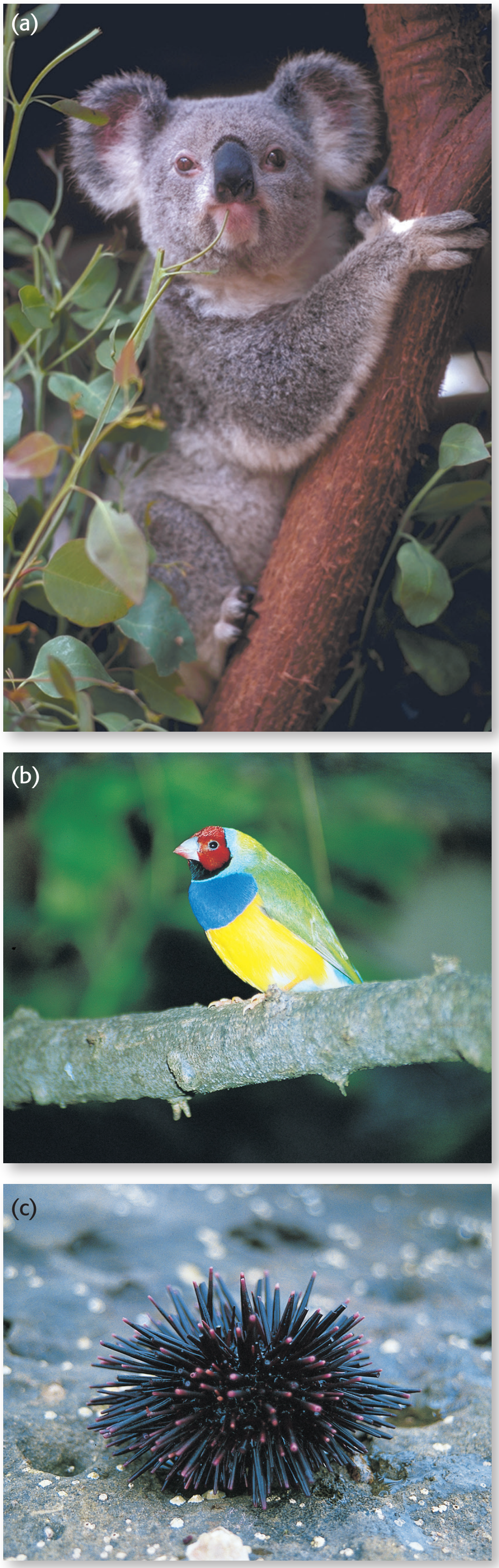


Figure 6.4 How to eat plants (a) A koala eats leaves. (b) Finches eat seeds. (c) Sea urchins graze on the thin layer of algae covering rocks.

The best known plant eaters, such as cattle and sheep, feed on the leaves of grasses. But leaves, though abundant and easily obtained, contain large amounts of hard to digest cellulose. Such animals chew leaves into a pulp with powerful grinding molars. When this pulp is swallowed, it enters the long and complex digestive system where cellulose is broken apart with the help of microbes (Figure 6.5). Even with the assistance of these microbes, grazing animals can extract only a little energy from each mouthful of food and must spend most of their lives eating (and chewing the cud if ruminants).

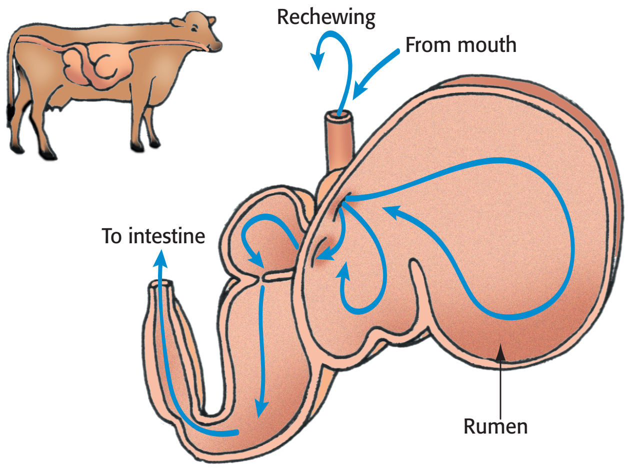


Figure 6.5 Ruminants Microbes help in the digestion of plants.

Many other herbivorous animals, including a variety of fishes, birds and mammals, feed on *seeds* and *fruit*. They contain a lot more energy per unit mass. Some, such as many finches, specialise in eating seeds of particular sizes and types (Figure 6.4). Others, such as black cockatoos, use their long, sharp bills to break open hard seeds and fruit. Fruit pigeons are common in rainforests where fruit is common.

Humans also use a lot of plant seeds and fruit as food. Most of the world's human population lives on the seeds of a single plant family – the grasses. The grasses include rice, corn, wheat, oats and barley.

Carnivores: meat eaters

Carnivores, such as quolls and dingoes, eat other animals that have stored energy in the form of fats, oils and proteins. Animals that eat herbivores are called *secondary consumers*. Carnivores that eat other carnivores are called *tertiary consumers*. Energy is *transferred* each time an animal is eaten.

Many meat eaters use up more energy than grazing animals in obtaining their food – a dingo stalking and running down a kangaroo uses a lot of energy (Figure 6.6 (a)). Other carnivores, such as net-casting spiders, lie in wait to ambush their prey by dropping a small net over it. These animals may spend much of their time waiting for prey to pass by (Figure 6.6 (b)).

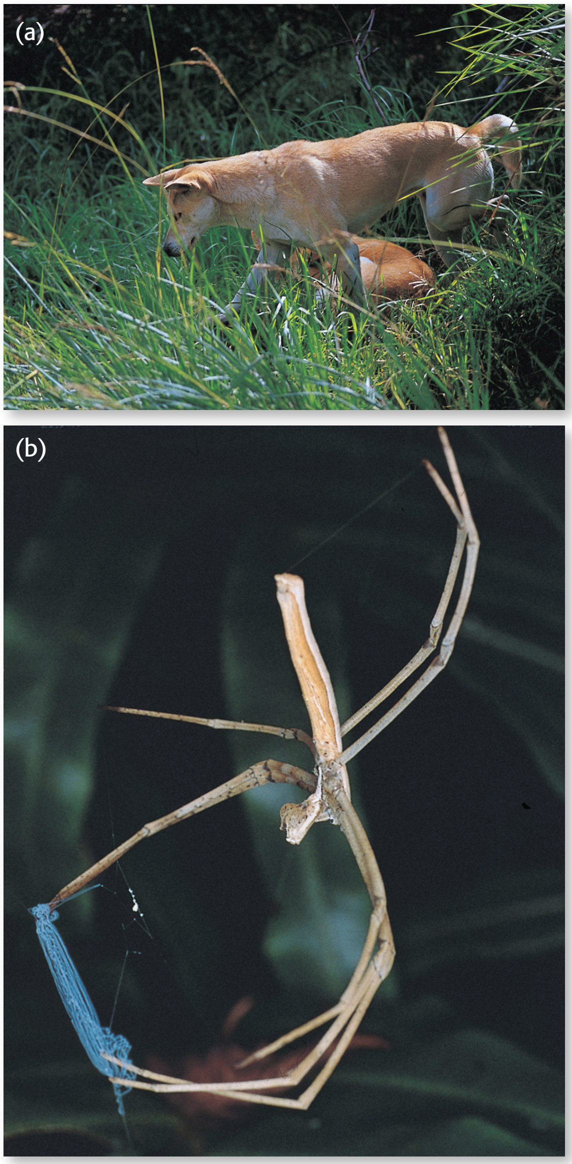


Figure 6.6 Carnivores (a) Dingo. (b) Net-casting spider.

Omnivores

Omnivores, such as humans and several other primates, eat both plant and animal material all year. Some birds, including certain honeyeaters, vary their diets depending on what is available each season. As you might expect, the teeth and digestive systems of these animals often (though not always) combine features of both carnivores and herbivores.

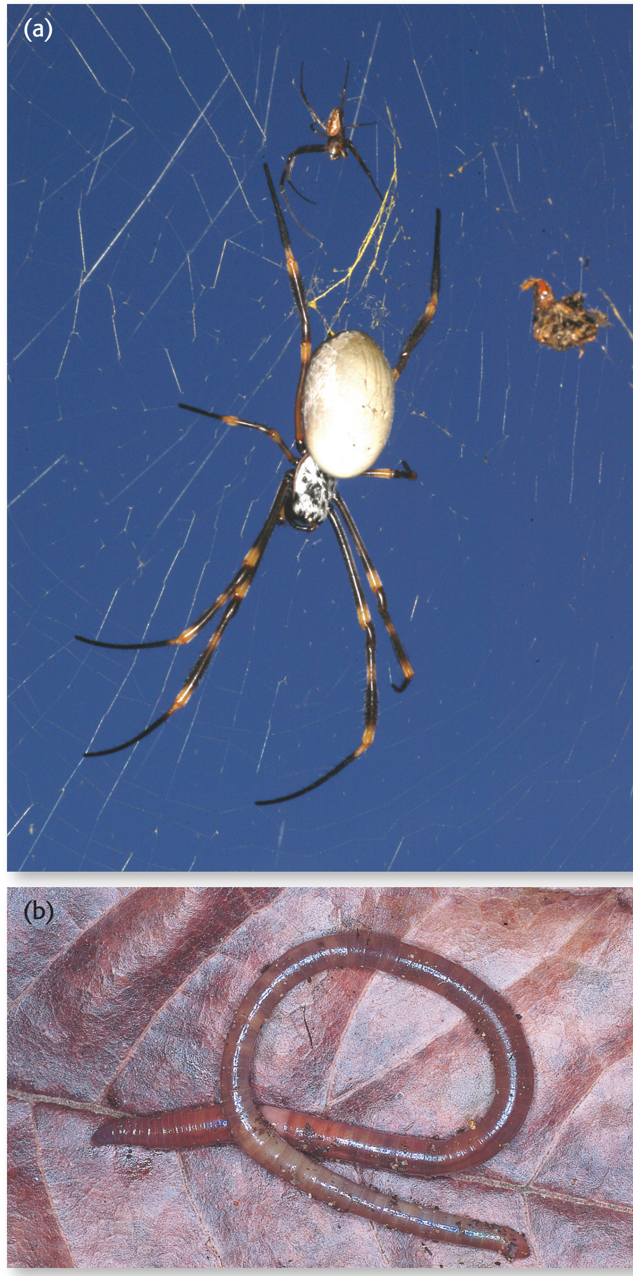


Figure 6.7 Liquid and detritus eaters (a) Spiders feed on liquids. (b) Earthworms feed on decaying plant matter.

Decomposers: organisms of decay

Fungi and bacteria obtain energy by breaking down, or decomposing the complex molecules in the decaying tissues of plants and animals to simple molecules (Figure 6.7). They are also called **decomposers**. These organisms of decay are vital to the balance of all ecosystems, for they play a crucial role in the cycling of most important nutrients. Without these invisible, yet vital, heterotrophs, bodies of dead plants and animals would be everywhere and the nutrients in those organisms would not be available to the ecosystem.

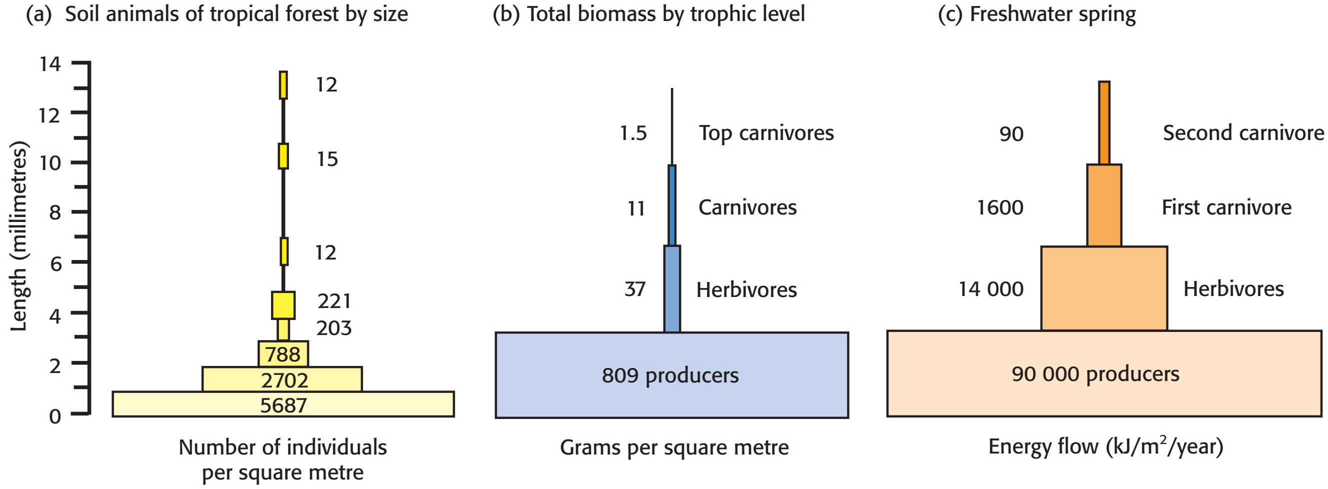


Figure 6.10 Ecological pyramids.

ACTIVITY 6.1
CONSTRUCTING FOOD CHAINS AND FOOD WEBS

When writing food chains, remember the following rules.

- All food chains start with an autotroph.
- The arrows show the direction along which energy is passed, not who eats whom.
- Food chains rarely go beyond 4 or 5 members.

1. Use the food webs in Figure 6.8 to construct six food chains.
2. Construct a food chain for each of the following environments.
   (a) Desert.
   (b) Grasslands with only a few trees.
   (c) Beach.
3. On a particular coral reef, sea slugs feed on sea anemones, sea anemones catch rockfish; copepods (small shrimp-like creatures) feed on plankton (small floating plants) and the copepods are eaten by rockfish.
   (a) Which are the producers?
   (b) Which are the top carnivores?
   (c) How do the plankton get their food?
   (d) Write down the food chain for this coral reef.

SCIENCE SKILLS

1. **Identify** the errors in the food chains and food webs of Figure 6.11.

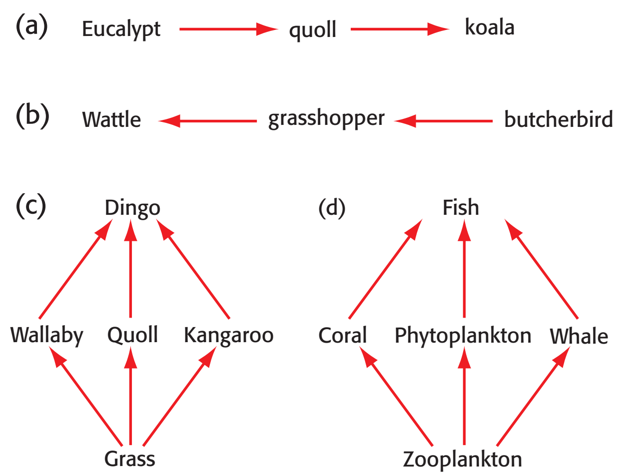


Figure 6.11 Food chains and webs.

2. **Identify** the errors in the ecological pyramids of Figure 6.12.

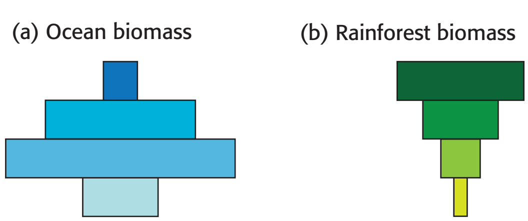


Figure 6.12 Ecological pyramids.

ACTIVITY 6.4 INVESTIGATION: POPULATION PROBLEMS

Justine was a student in an agricultural high school where high voltage power lines crossed a paddock where cattle were grazed. While herding cattle she thought that there were more four-leaf clovers (normally clover has three leaves) growing under the power lines than in other areas of the school farm. Her hypothesis was that radiation from the power lines was increasing the numbers of four-leaf clovers. She was then able to predict that the numbers of four-leaf clovers would be greater under the power lines than elsewhere in the school paddocks. She constructed a vegetation transect across three suitable areas, and took some counts in quadrats in three other areas. She found that her hypothesis was incorrect.

You job is to use what you have learnt about measuring populations to design and carry out an investigation. It is better to find your own problem, but here are some suggested problems you could try to solve.

- Does the type of lawn grass affect the types an numbers of weeds in the lawn?
- Does the type and number of insects visiting a flower depend on the variety of flower?
- Does the type and number of shrubs growing in a forest or woodland depend on the variety or size of trees present?

Figure 6.18 Four-leaf clover.

You will need to include the following.

- A map of the location being studied.
- A specific question to be answered.
- A proposed hypothesis and prediction of possible outcomes.
- The procedure/s to be followed.
- Equipment required.
- The type and amount of data to be collected.

You will also need to:

- Conduct risk assessments.
- Consider research ethics.

When you have planned your experiment, have it checked by your teacher.

Present your report in an appropriate manner.

SCIENCE SKILLS

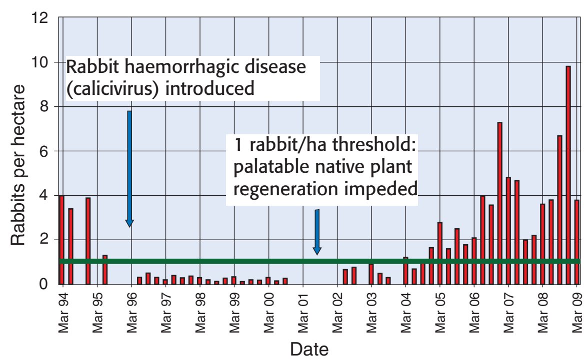


Figure 6.19 Population growth.

1. Figure 6.19 shows the population growth of rabbits in a Victorian national park after calicivirus reached the area. Calicivirus is lethal to many rabbits. The horizontal line shows the maximum population of rabbits that would not impede the regeneration of palatable native plants.

(a) **Identify** when the calicivirus virus reached the park.

(b) **Identify** the period during which palatable plants were able to regenerate.

(c) **Identify** the time when there was maximum numbers of rabbits.

(d) **Suggest** reasons why the population of rabbits is increasing again.

From organisms to the environment

When animals eat plants or other animals, they digest proteins, breaking them down into their component nitrogen-containing amino acids (Figure 6.22). Some of these amino acids are re-formed into the proteins of the animal that has eaten them. Others are broken down to release the energy they contain, also releasing nitrogen in the form of ammonia (NH_3).

Because ammonia is toxic to many cells even in low concentrations, it must be eliminated from body fluids or changed to a less poisonous form as soon as possible. Most aquatic animals eliminate ammonia continuously into the water around them. Terrestrial animals often convert nitrogen wastes into urea and concentrate it in urine before eliminating it.

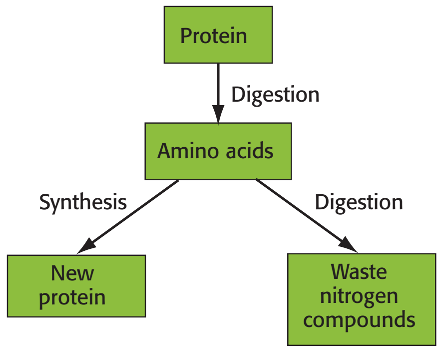


Figure 6.22 Dealing with nitrogen How animals make use of nitrogen compounds such as protein.

Micro-organisms in the environment

Nitrogen wastes in any form don't remain in the environment for long. One group, the *Nitrosomonas* bacteria, combine ammonia with oxygen and convert it into nitrite ion (NO_2^-). The nitrite may then be converted into nitrate ion (NO_3^-) by bacteria called *Nitrobacter*. These two processes together are called **nitrification**.

Although they rarely appear in food web diagrams, the bacteria and fungi of decay are vital to the **nitrogen cycle**. Nitrogen in dead animals and plants is useless to primary producers. Decomposers breakup the organic molecules in animal and plant carcasses and release their component elements in simpler form – nitrogen often ends up as ammonia (NH_3).

Completing the cycle

When nitrate ions, nitrite ions, and ammonia are released into the soil of a healthy forest or into shallow water filled with growing algae, they may be quickly reabsorbed by the primary producers. Different primary producers absorb nitrogen in different forms (Figure 6.23). Many terrestrial plants absorb nitrate ions best, which is one reason why most fertilisers contain a lot of nitrogen as a nitrate compound. Some terrestrial plants and many algae, however, pick up ammonia more readily than nitrate ions.

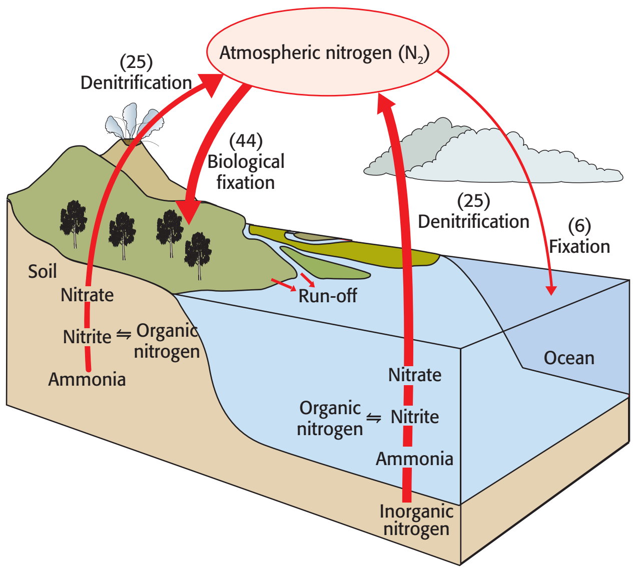


Figure 6.23 Nitrogen cycle The numbers show the quantities of carbon (in units of 10^9 kilograms) either held in reservoirs or exchanged. The width of the lines shows the relative size of the exchanges between reservoirs.

In the open sea, dead marine organisms and their nutrient rich solid wastes sink rapidly out of the surface layers. Large quantities of nutrients, therefore, end up in slowly moving currents near the ocean floor, far out of reach of photosynthetic primary producers. In certain places around the world, particular combinations of winds and ocean currents force large quantities of this nutrient laden water back up from the ocean floor into the photic zone, a phenomenon known as **upwelling** (Figure 6.24). Upwelling is not common in the waters of south-eastern Australia, except for a few small sections of coastline.

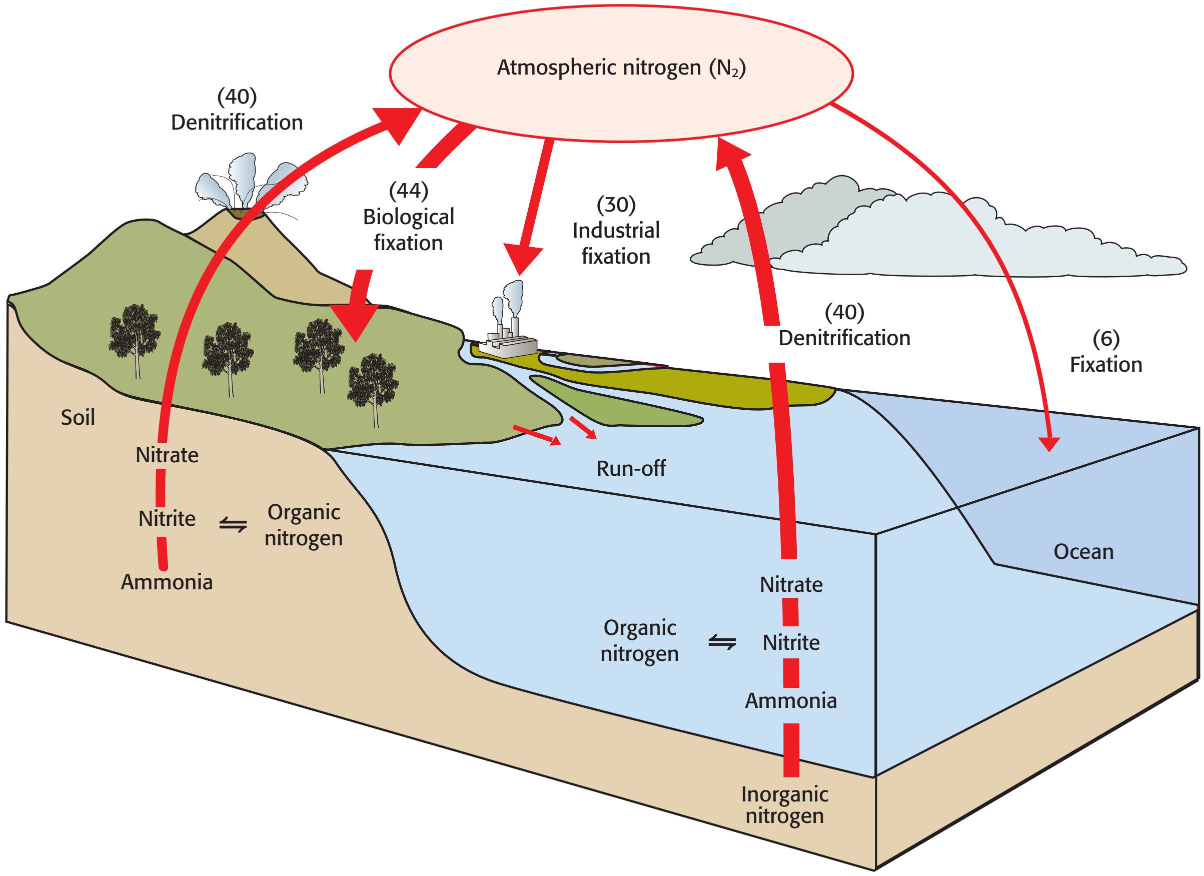


Figure 6.27 Nitrogen cycle and humans The numbers show the quantities of carbon (in units of 10^9 kilograms) either held in reservoirs or exchanged. The width of the lines shows the relative size of the exchanges between reservoirs.

SCIENCE SKILLS

1. Figure 6.28 shows the dissolved nitrogen levels in a lake along the coast of southern New South Wales.

(a) **Identify** the year that dissolved nitrogen levels were highest.

(b) **Suggest** a reason why the levels were so high at this time.

(c) **Describe** the overall trend of the readings.

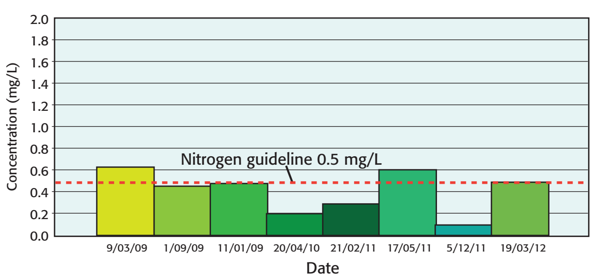


Figure 6.28 Dissolved nitrogen levels Lake along the coast of southern New South Wales.

2. Figure 6.29 shows the dissolved nitrogen levels in the lake at the mouth of the Murray River.

(a) **Identify** the year that dissolved nitrogen levels were lowest.

(b) **Suggest** a reason why the levels were so high at this time.

(c) **Describe** the overall trend of the readings.

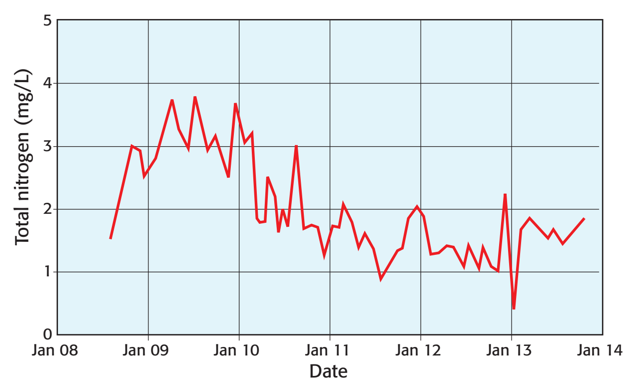


Figure 6.29 Dissolved nitrogen levels The middle of Lake Alexandrina at the mouth of the Murray River in South Australia.

Figure 6.32 Coal Long term storage of carbon.

If the original material was mostly marine plankton, then upon burial it may form **petroleum** or **oil** (Figure 6.33). The time of burial, the depth of burial and hence pressure, as well as the temperature at such depths causes changes in the buried fats, oils and proteins and converts them to **hydrocarbons**. If buried deep enough, they first become a mixture of petroleum and a thick sticky material called **kerogen**. When buried at even grater depths the kerogen can break down to form **petroleum gas** and leave behind a solid carbon rich residue. You will learn more about petroleum later on.

Figure 6.33 Petroleum Long term storage of carbon.

The buried coal, oil and natural gas are long term storage for carbon and the energy stored in its molecules. While some may be released at the surface naturally, most would remain buried without human intervention.

ACTIVITY 6.6 FOSSIL FUELS

You have been provided with a map of your state. Using your library, the internet or other information sources, identify the locations of fossil fuel resources in your state and mark the region on your map.

Carbon cycle interactive
http://qr.w69b.com/g/rV5pnGHeM

Residency and adjustment periods

The carbon cycle as shown in Figure 6.30 is a series of reservoirs or sinks connected by flows. The term **residency** refers to how long an atom of carbon is estimated to spend in a particular reservoir. The residency period is calculated based on rates of flow in and out of the sink compared to the size of the sink, therefore residency is different for each carbon reservoir.

Table 6.2 Carbon residency Times for different carbon sinks.

Carbon resevoir/sink	Estimated residence time (years)
Atmosphere	4.9
Plant biomass	9.3
Soil organic carbon	25
Surface ocean	11.3
Entire ocean	422.0

Some global warming denialists have used the short residency time of atmospheric carbon as evidence that human emissions are of little consequence to global warming. They have failed to understand or acknowledge the difference between residency time of a single carbon atom and **adjustment time**, which is how long it would take for the total changes to a carbon sink to be reversed by natural processes.

Residence time
http://qr.w69b.com/g/qs0xAe5SE

Human impacts

During the last two centuries, humans have begun to alter the carbon cycle in two ways. First, we are cutting down the world's great forests, particularly the tropical rainforests where many of the trees are then burnt (Figure 6.34). Cutting trees destroys living tissue that fixes atmospheric CO_2, and burning these trees immediately returns the carbon they contain to the atmosphere. Second, we are burning large quantities of stored carbon – fossil fuels such as coal, oil, and natural gas. These two forms of combustion return enough carbon dioxide to the atmosphere to raise atmospheric CO_2 concentrations measurably (Figure 6.35).

The carbon dioxide in the air makes the atmosphere act like a greenhouse. When light and other radiations from the Sun reach the Earth, most (about 50%) reaches the ground. This is re-radiated as infra-red radiation. The carbon dioxide in the atmosphere absorbs this radiation helping keep the Earth warm for human life. We call this natural balance the **greenhouse effect**.

When humans add increased levels of carbon dioxide to the atmosphere, more of the infra-red radiation is absorbed. This warms the atmosphere and may be causing a steady rise in global temperatures. This is called the *enhanced greenhouse effect*. World temperatures are rising, but no one knows how much is due to the enhanced greenhouse effect or how much is due to natural climatic cycles.

A steady rise in temperature could affect the biosphere in a number of ways. It would certainly cause major changes to the climate in many parts of the world. Some parts become drier, others wetter. Storms become more frequent in some areas. The increase in temperature will also cause the ocean waters to expand, and may cause the ice caps to melt. Together this would flood major coastal areas on many continents and submerge many island nations.

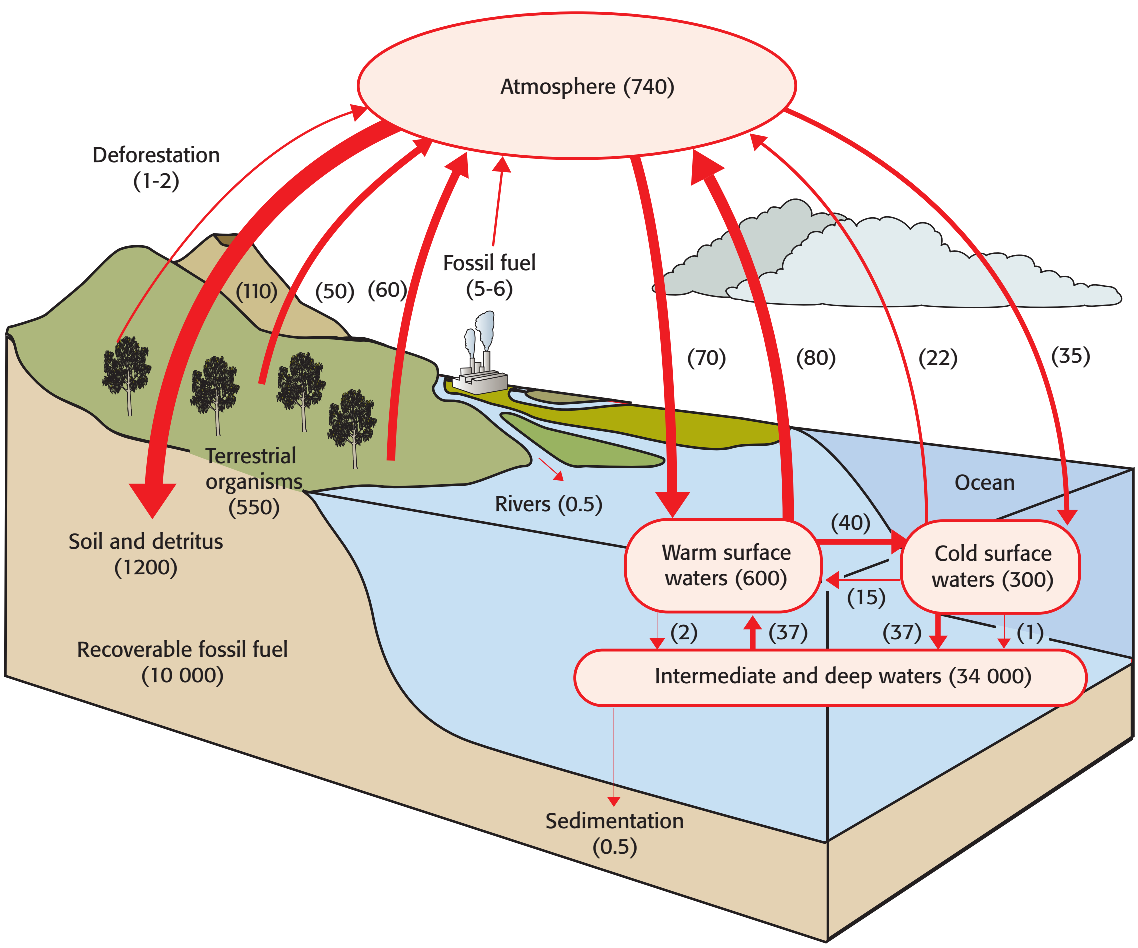


Figure 6.34 Carbon cycle and humans The numbers show the quantities of carbon (in units of 10^{12} kilograms) either held in reservoirs or exchanged. The width of the lines shows the relative size of the exchanges between reservoirs.

Chapter 7

INVESTIGATING EARTH AND ENVIRONMENTAL SCIENCE

Scientific method interactive vocabulary
http://qr.w69b.com/g/oOVHsnb3O

Figure 7.1 Student research.

When scientists carry out research, they all approach the task in a similar way. We call this the **scientific method**. Scientists do not follow this in a strict fashion, but each of the parts is usually present. Science is a creative activity, no more so than when an investigation is being carried out. Like a scientist, you will need to be asking questions, making observations, developing hypotheses to explain observations and testing these hypotheses. Sometimes scientists work as part of teams; at other times they work alone. Your teacher will tell you if you will be working as part of a team or independently. Research work is then analysed by others, so it must be communicated in an understandable way. In the same fashion, you will need to prepare a report.

At the end of this chapter, a checklist for designing and carrying out an experiment is provided in Table 7.2.

Asking questions

Questions are based usually on previous research or laboratory experiments, perhaps on observations or sometimes as a result of reading or classroom discussion. There are some questions that a scientist can attempt to answer and others that are unanswerable. Do you think a scientist could answer all of these questions?

- How can we eradicate cane toads?
- Do evil spirits live in volcanoes?
- How much lead pollution does a smelter produce?
- Does gold or silver jewellery look nicer?
- Why do some plants have spines (Figure 7.2)?
- Why are bottle trees shaped like bottles?
- Do farmers have the right to deny mining companies access to their land?
- How hard is iron ore?
- What is the best way to extract oil from oil shales?

Any question you attempt to answer in an investigation must be well defined and testable. You must be able to carry out the measurements and control the variables. That would not be possible with some of the questions above.

Figure 7.2 Spines.

Developing hypotheses

As questions are asked, scientists attempt to answer them by proposing possible explanations. Those proposed explanations are called **hypotheses**, which are tentative explanations for what we observe. If we try to answer the question, 'Why do some plants have spines?', our hypothesis might be that spines prevent the plant being eaten by animals.

For a hypothesis to be useful, it must be testable and must have the potential to be **falsified** – proven wrong. It can be proven wrong but can never be proven as true. Years after it was proposed, one experiment might prove it incorrect. In our example, we could propose this test – if the spines are removed from the test plants, more plants will be eaten.

Evidence from an investigation can only provide support for a hypothesis. In our example, if the plants without spines were eaten, we have been given support for our hypothesis. But what if the plants were not eaten? Does that disprove the hypothesis? Here are some other possible explanations.

- Maybe that plant also has a toxin that discourages animals from eating.
- Perhaps the experiment was carried out during too short a time and no animal came along to eat it.
- Perhaps the experiment is in an area where all animals that could have eaten the plant no longer exist.

Further experiments will be needed to be sure that our hypothesis is a reasonable one. It is rare that a single test will clearly support or falsify a hypothesis. Usually one has to modify the hypothesis or redo the experiment with different conditions.

Designing experiments to test hypotheses

It is rare that your first design of an experimental test of a hypothesis will be the one you finally use. Scientists refine their experimental design before they start. Here are some of the things you will need to consider.

Determining variables

The variables in an experiment must be clearly identified and controlled. There are three that you need to consider.

- Dependent variables.
- Independent variables.
- Fixed variables

A **dependent variable** is one you actually measure, count or observe. You might measure temperature, count birds visiting a nest or observe changes in animal behaviour.

An **independent variable** is one you deliberately change. If you are measuring the temperature of a compost heap, you might change the moisture levels. If you are counting birds visiting a nest, you might change the amount of food available by providing feeding sites. If you are observing the effect of the presence of other birds on the behaviour of the resident birds in a territory, you might play the song from another bird of the same species.

Fixed variables are other variables that could have been changed, but you have decided to keep the same to ensure that the test is fair. If it is the compost heap, you keep sunlight, thickness of compost, the mix of plant and food types and the covering all constant. If you are counting birds visiting the nest or observing animal behaviour in the presence of competitors, you do not want predatory birds, like hawks, around to interfere with the results.

Scientific method
http://qr.w69b.com/g/r3ZISk8og

Glossary

abiotic Non-living.

abrasion The wearing away of rock chiefly by currents of water carrying sand and other rock debris and by glaciers.

absolute dating A technique that determines the age in years for a rock or fossil.

abundance The numbers of organisms per unit area which live in a particular part of a distribution.

accretion A process in which a star gathers molecules of interstellar gas to itself by gravitational attraction.

aerobic respiration Respiration that needs the presence of oxygen to produce energy.

albedo (Latin 'whiteness') The fraction of light that reaches Earth that is reflected.

algal bloom A rapid increase in population, especially of algae, that brings about the discolouration of the water in which they are growing.

amino acid A nitrogen-containing chemical that make up proteins. Can be made by living cells or obtained in the diet.

anaerobic respiration Respiration that occurs in the absence of oxygen.

andesitic volcanism A type of silica-rich explosive eruption named after the Andes Mountains.

Antarctic The south polar region.

aquatic Relating to fresh or salt water.

Archaeobacteria Any of a class of primitive bacteria, including forms that produce methane (methanogens), that only live in very salty habitats (halophiles) and that live in harsh, hot and acidic environments (thermophiles).

Arctic The north polar region.

atmosphere The mixture of gases surrounding the Earth's surface.

autotroph A living thing that can supply its own food.

bacteria Microscopic living things (microbes) made of one cell that do not have a nuclear membrane around the 'nuclear region'.

balance The natural state where living things live together without endangering the survival of any species.

bedrock The rock underlying an environment.

Big Bang theory The theory that the Universe began at some particular instant, thus marking the origin of the Universe, and has been expanding ever since.

biofuel A fuel that is derived from biological materials, such as plants and animals.

biogeochemical cycle A cycling of materials during which a chemical substance moves through both biotic and abiotic compartments of Earth.

biomass The total mass of living matter in a given population of organisms. Usually expressed as the dry weight per unit area.

biosphere The parts of the Earth (air, land and water) where living organisms can be found.

biostorage The storage of carbon in living tissue such as the storage of carbon in forests.

biotic Having to do with living organisms; the living components of an environment.

buoyancy The upward force exerted by a gas or liquid on an object that is floating in or on it.

Cambrian The oldest geologic period whose rocks contain numerous marine fossils. First period in the Palaeozoic era on the geologic time scale.

capture-mark-recapture A statistical method for estimating the size of a population by counting captured animals and then counting them again after recapture.

carnivore Animals that feed on the flesh of other animals.

carrying capacity The carrying capacity is the number of organisms of a species that a particular environment can support indefinitely.

cast 1. To give a shape to a substance by pouring in liquid or plastic into a mould and letting it harden without pressure. 2. An object formed by this process, e.g. cast of a fossil.

catastrophism The theory that past geologic processes were much more rapid than those seen today.

CFC Short for chlorofluorocarbons. A group of substances that are chemical derivatives of methane or ethane with all the hydrogen atoms replaced by combinations of chlorine and fluorine.

chemical sedimentary rocks A rock that formed by chemical precipitation or biological activity.

chemical weathering A type of weathering where rocks and minerals are changed into new, fairly stable chemicals by dissolving and chemical reactions.

chemosphere Also called the mesosphere. Has very low concentrations of chemicals that can absorb radiation. Between the stratosphere and the thermosphere.

clastic sedimentary rocks Sedimentary rock that formed from the weathered and eroded pieces of other rocks.

cleavage How a mineral naturally breaks or splits.

climate The normal weather conditions in an area (as measured over a number of years).

coal A black or brownish-black solid that burns readily and is widely used as a natural fuel. It is formed when vegetable matter is highly heated and compressed after burial.

coal seam gas A form of natural gas extracted from coal beds.

community The populations of plants, animals and microbes found living together in a given area (habitat) and often interacting with one another.

conservation The act of preserving for future generations our natural resources, especially plants and animals, and their environments.

contact metamorphism Also called thermal metamorphism. Occurs in response to increased temperature produced by a nearby intrusion of magma. Pressure plays a lesser role.

continental crust The Earth's crust that makes up the continents is composed mostly of felsic rocks such as granite and is about 40 kilometres thick, but it can be 65 kilometres thick under mountain ranges. Beneath the continental crust is a layer of mafic rocks.

continental drift The formation and break-up of continents caused by the movement of landmasses on the surface of the Earth.

contract To become smaller in size.

control A standard against which observations and results can be checked in order to help test their validity. Used during experimental work.

controlled variable A quantity or condition kept constant during an experiment.

convection The movement that occurs in a liquid or gas caused by variations in temperature and density and by the action of gravity.

convergent boundary When two plates collide with each other.

core The centre (as in the centre of the Earth).

Coriolis effect The apparent deflection or change in direction of something that is moving in a straight line due to the rotation of the spherical Earth beneath.

correlation 1. The relationship between two sets of measurements. 2. In geology, comparing fossils and rock types to see if rocks are the same age.

cosmic background radiation The thermal radiation left over from the 'Big Bang' at the beginning of the Universe.

Cretaceous The third and last period of the Mesozoic era on the geologic time scale. Saw the end of the dinosaurs.