children's illustrated encyclopedia

Planet Earth

Orpheus

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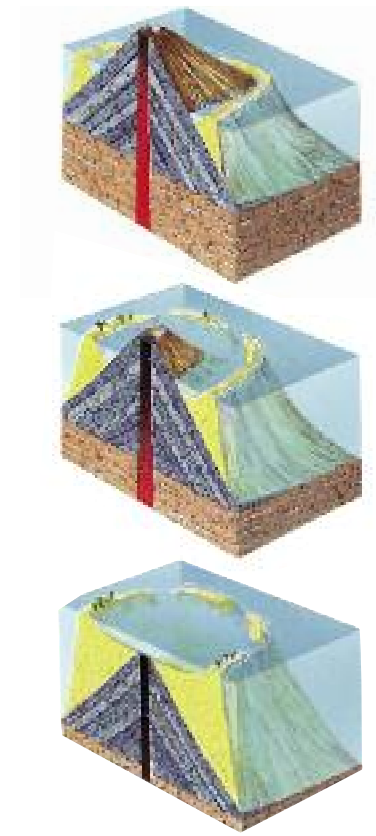

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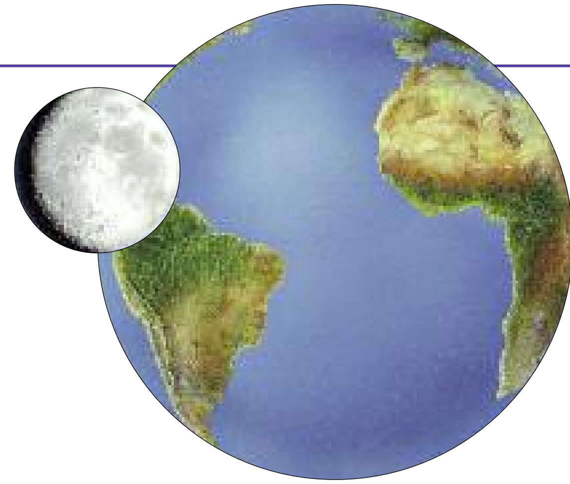
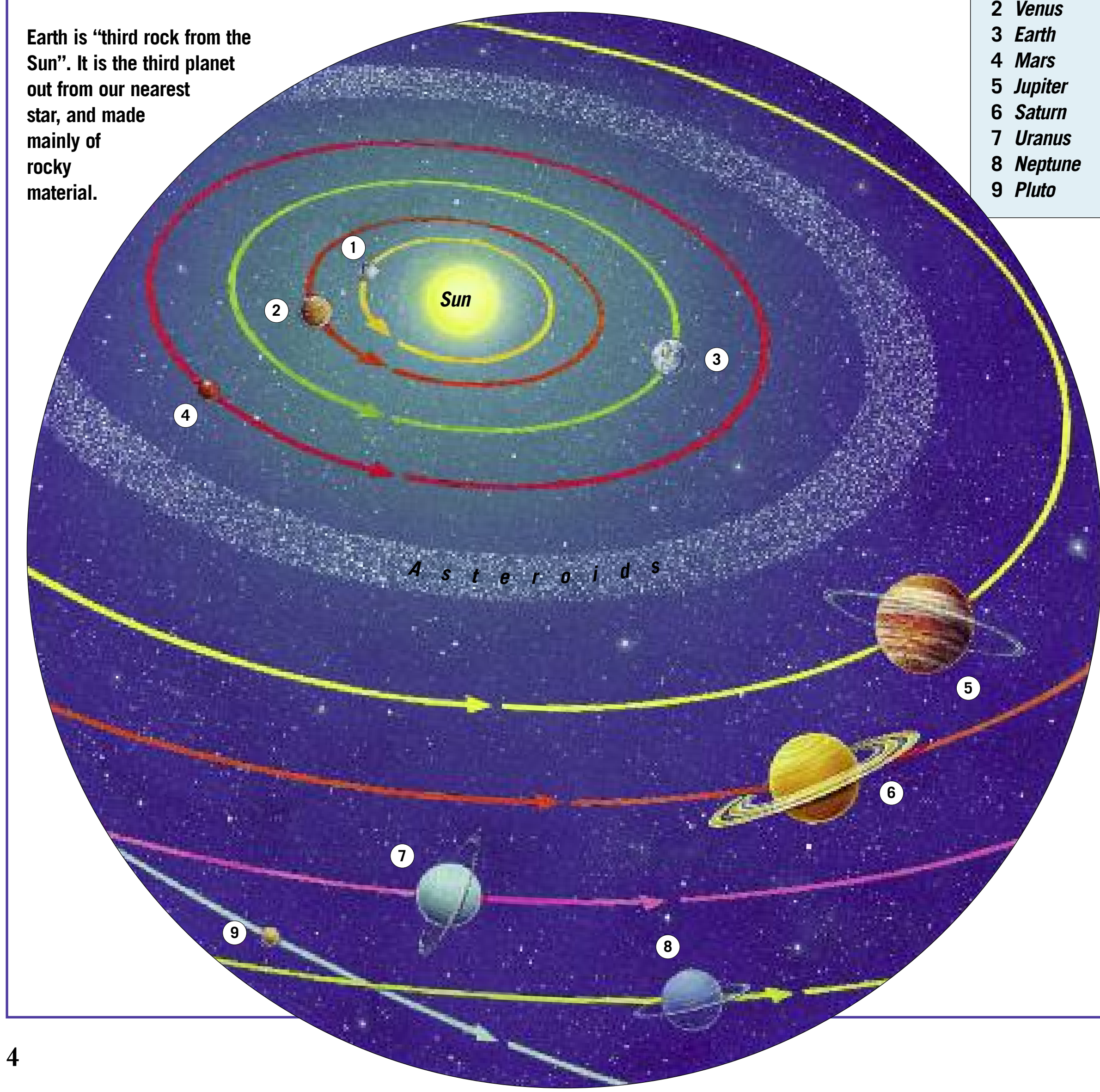
PLANET EARTH

OUR PLANET EARTH is the fifth largest of the eight planets which go around, or orbit, our nearest star—the Sun. The Earth speeds through space at about 30 kilometres every second, taking one year to complete one orbit. In addition the planet spins round like a top once every 24 hours. This makes the Sun appear to rise at dawn, pass across the sky and set at dusk, giving us day and night. The Earth is not quite a perfect ball or sphere shape. It is 12,756 kilometres across its Equator (middle) and 12,714 from Pole to Pole (top to bottom). The distance around the Equator is 40,075 kilometres, and 40,008 from one Pole around to the other and back again.



Earth's closest neighbour in space is the Moon. It is 3475 kilometres across, about a quarter the width of Earth. Its volume is around one-thirtieth that of Earth. The rocks which make up the Moon are not as heavy or dense as Earth rocks, so the Moon weighs only one-eightieth as much as the Earth.

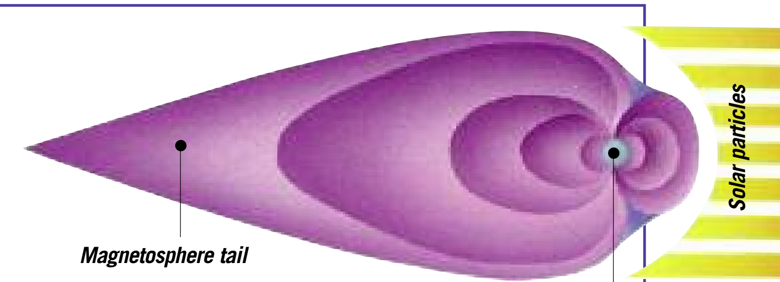
Earth is "third rock from the Sun". It is the third planet out from our nearest star, and made mainly of rocky material.



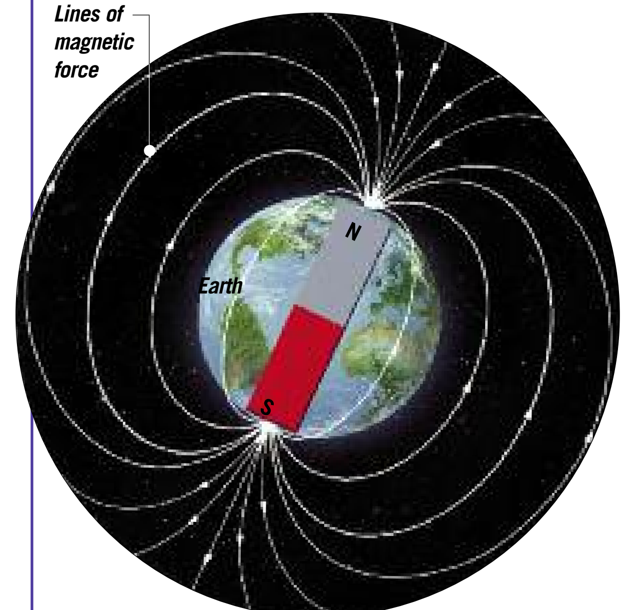
KEY
1 *Mercury*
2 *Venus*
3 *Earth*
4 *Mars*
5 *Jupiter*
6 *Saturn*
7 *Uranus*
8 *Neptune*
9 *Pluto*

MAGNETIC EARTH

THE EARTH has its own magnetism—an invisible field of magnetic force all around us. Too weak to notice in daily life, the magnetic field affects iron-based materials and other magnets. We can detect it using a magnetic compass. The compass needle is a long, thin magnet that lines itself up with Earth's magnetism to point north-south. This helps us to read maps and find our way in remote places.



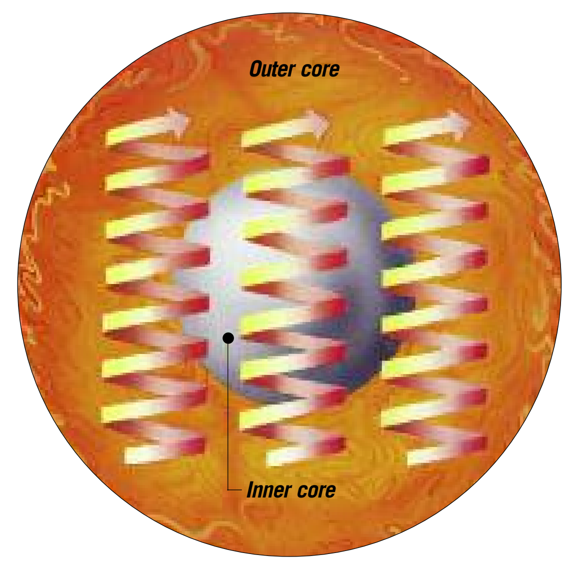
Earth's magnetism extends into space as the magnetosphere. High-energy particles from the Sun, the solar wind, "blow" against one side and make it teardrop-shaped.



The Earth's magnetic field is strongest at two places, the North and South Magnetic Poles, where it is directed straight down into the ground. It is as though there was a giant bar magnet inside the planet.

The magnetic field stretches into space and protects us from the Sun's high-energy particles. Some are attracted by the magnetic poles, however, and produce giant curtains of glowing light in the night sky, known as aurorae *(above)*.

The Earth's magnetic field is probably created by forces produced in the outer core, a layer of iron that lies some 2900 kilometres below the surface *(see page 6)*. Because of extreme pressure at this depth, it is incredibly hot—more than 4000°C. At this temperature, the iron is liquid. Heat currents cause the liquid metal to swirl around. The currents are themselves twisted by the spinning motion of the Earth into corkscrew-like patterns, called "rollers". These giant movements make electricity which, in turn, creates a magnetic field.



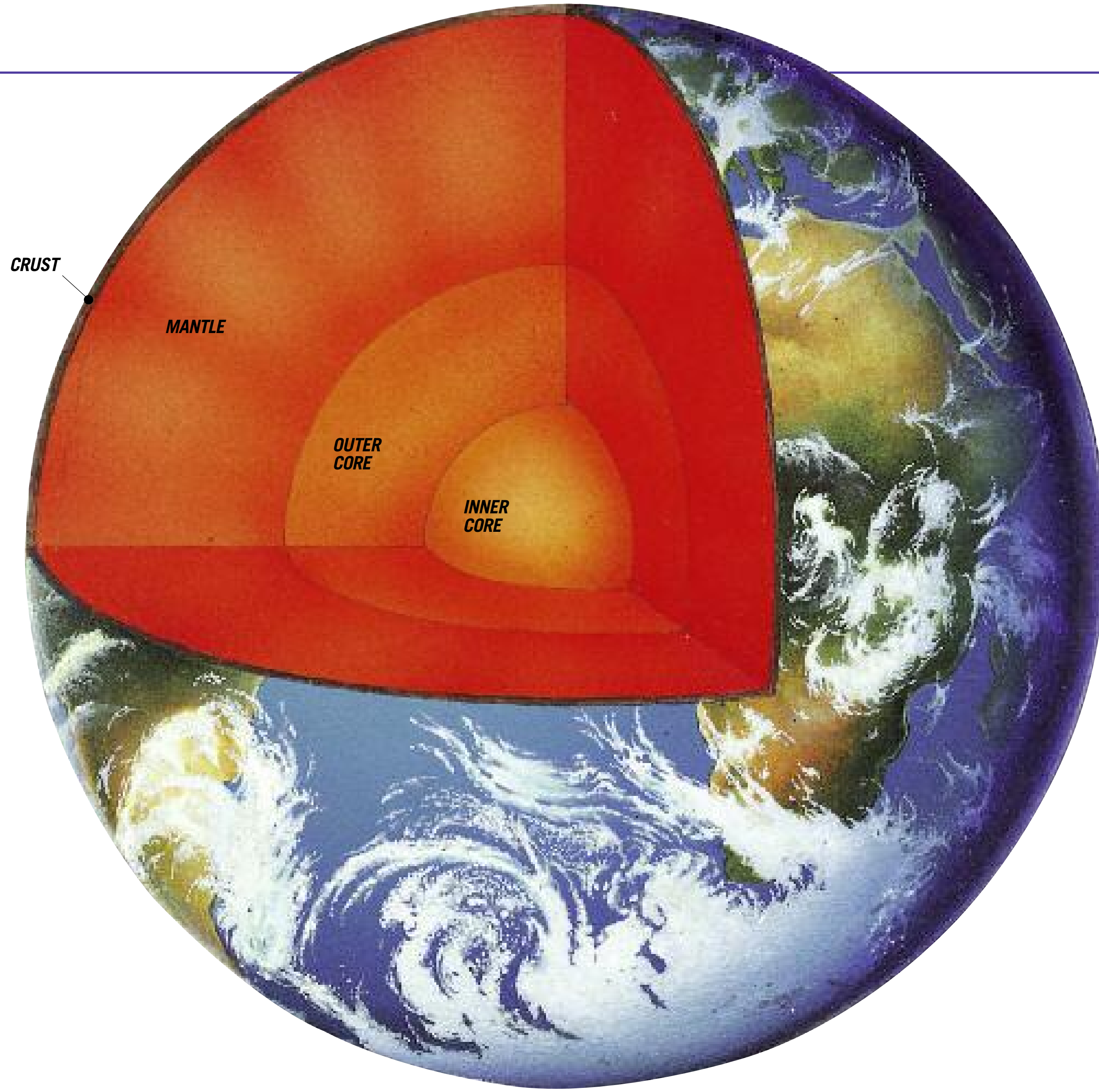
Scientists believe that massive amounts of flowing heat energy inside the Earth, combined with the planet's daily spinning motion, make the semi-liquid rocks flow in spiral patterns. These generate electricity, producing a magnetic field.

Inside the Earth

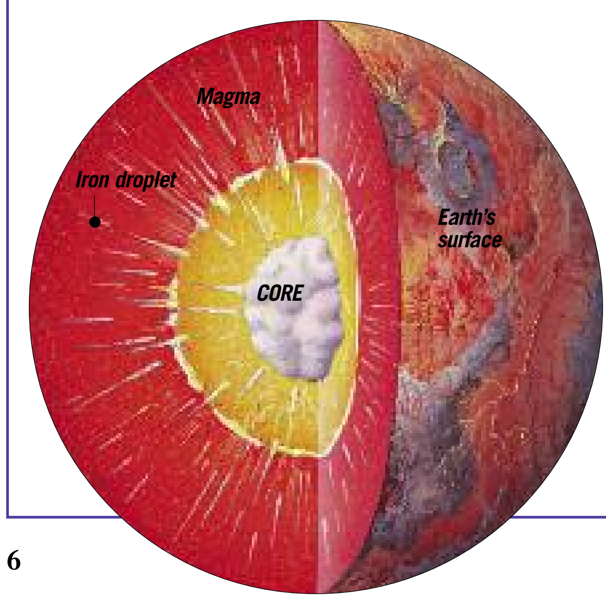
On the outside, the Earth seems hard and solid. But if you could drill a deep hole almost 6400 kilometres down to the centre of the planet, you would notice many changes as you descend. It becomes warm, then hot. The average increase in temperature is about 3°C for every 100 metres of depth. Soon it is so hot that the rocks are not solid but melted or molten. You pass through the various layers of rocky material, from the hard crust on the outside, through the very thick mantle, to the liquid outer core. When you reach the inner core at the centre there is no rock at all. The core is made of almost solid metal.

The Crust

No-one has bored a hole nearly this deep. The farthest we have drilled down is about 15 kilometres, which is part way through the crust. The crust is thinner in proportion to the whole Earth than the skin on an apple. The crust itself is solid rock and varies in depth. Under the oceans it is about 5-10 kilometres thick (with the ocean above) and made mainly of basalt-type rocks. Under the main land-masses or continents it is 35-70 kilometres thick and chiefly granite-type rocks. The taller the mountains above, the deeper the crust below. The crust is not one solid ball-shaped shell. It is cracked into large slowly-moving plates *(see page 8).*



The four main layers of the Earth *(above)* are the crust, mantle, outer core and inner core. At the base of the crust is a boundary called the Moho (Mohorovicic discontinuity). This separates the crust from the mantle and the temperature here is about 1500°C. The mantle is about 2900 kilometres thick. The next layer is the outer core which is 2200 kilometres thick. At the centre is the inner core, a solid ball of iron with a radius of about 2500 kilometres.



Some 4600 million years ago the Earth (along with the Sun and other planets) formed from clouds of gas and dust in space. Some of this matter clumped together to form the early Earth, which warmed up and glowed red hot. Iron was the heaviest substance so it began to sink through the molten magma as droplets. These collected into drops, then larger blobs. Gradually they clumped at the centre of the young planet to form the inner core *(left).*

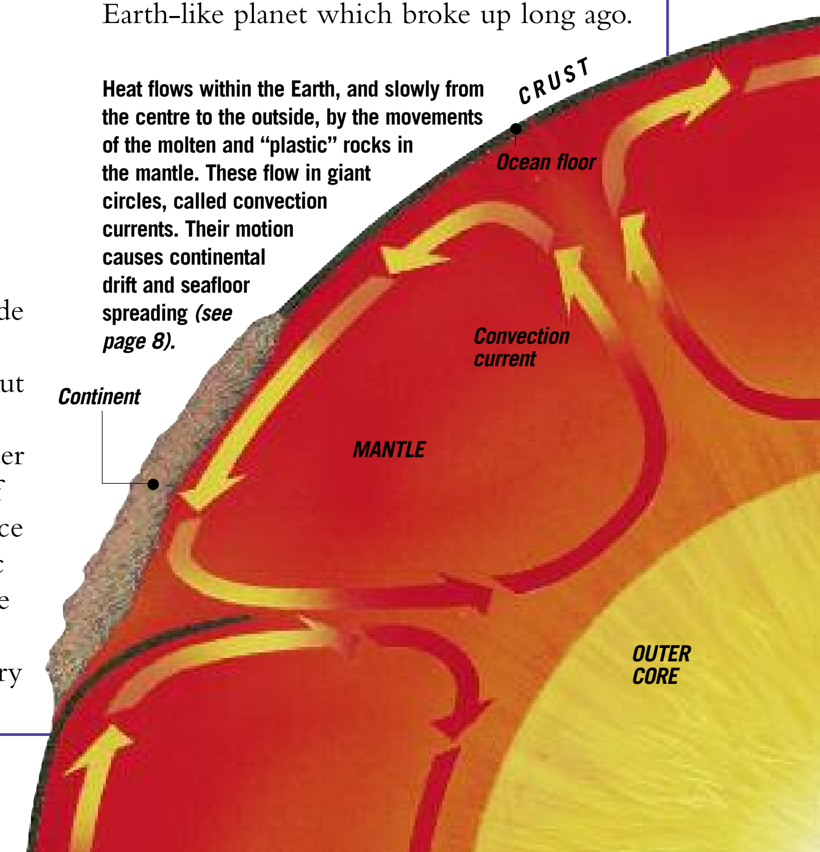
The Mantle

The mantle also has two layers. Its outer part is about 600 kilometres thick and made of crystals of rock with molten or liquid rock between them. Its temperature is about 2000°C and the molten rock, known as magma, can flow like hot tarmac. It is under great pressure and sometimes bursts out of holes or cracks at weak points in the surface of the crust, as the red-hot lava of volcanic eruptions. The pressure in the inner mantle is so great that the rock here is solid—but not completely rigid. It is "plastic" and, very gradually, moves.

The Core

At the base of the mantle, there is a sudden change. The material is no longer rock, but metal—mainly iron plus small amounts of nickel. In the outer core, the temperature rises with depth to more than 3000°C near the boundary with the inner core. The iron of the outer core is liquid, and flows in giant corkscrew-like currents or "rollers". These probably produce the magnetic field of the Earth *(see page 5).* The temperature rises still more at the inner core, to perhaps up to 7500°C at the centre of the planet. But the enormous pressure—several million times that at the surface—means that the iron crystals are squashed into a solid ball.

How do we know about the Earth's interior, if no-one has ever drilled deep into the Earth? Evidence comes from the way that shock waves from earthquakes pass around and through the Earth *(see page 13),* and from studying meteorites. Some earthquake shock waves do not travel through the outer core, telling us that this part is liquid. We know the core must be made of iron because we can compare it with the composition of iron meteorites, thought to be the remnants of the core of an ancient, Earth-like planet which broke up long ago.



Heat flows within the Earth, and slowly from the centre to the outside, by the movements of the molten and "plastic" rocks in the mantle. These flow in giant circles, called convection currents. Their motion causes continental drift and seafloor spreading *(see page 8).*

EARTH

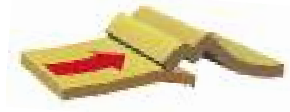
Restless Earth

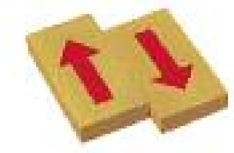
THE ATLANTIC OCEAN gets wider by about the width of your thumb every year, pushing North and South America away from Europe and Africa. The Himalayan mountains, already the highest in the world, grow taller by about the length of your thumb every year. Many other parts of the Earth are moving and changing shape, too. This is because the Earth's outer layer is divided into enormous curved pieces called lithospheric plates, which fit together like a ball-shaped jigsaw. There are six large plates and about 12-15 smaller ones, and they are continually on the move. The theory of **plate tectonics** explains how this happens.

Each plate consists of a piece of the Earth's outer layer, the crust, plus a portion below it of a thin layer of outer mantle. Together the crust and thin slice of outer mantle make up the layer known as the lithosphere. Its depth varies from 70-80 kilometres below the oceans to 100-150 kilometres where there are continents. Under the lithosphere is a slightly deeper part of the mantle about 100 kilometres thick, called the aesthenosphere. This is partly molten and allows the plates to slide about over it. In fact the slow flowing of the mantle, due to the enormous heat and pressure within, pushes the plates and makes them slide around the surface of the planet. As they do so, they carry the continental land-masses like giant rafts.

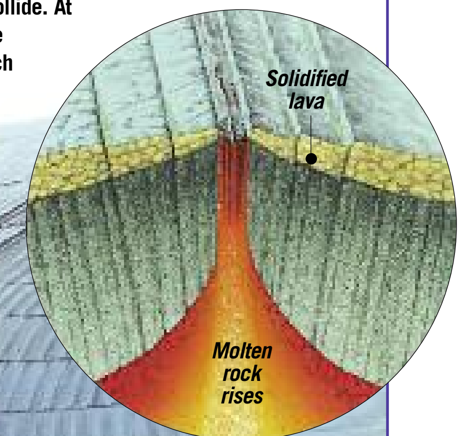
Seafloor Spreading

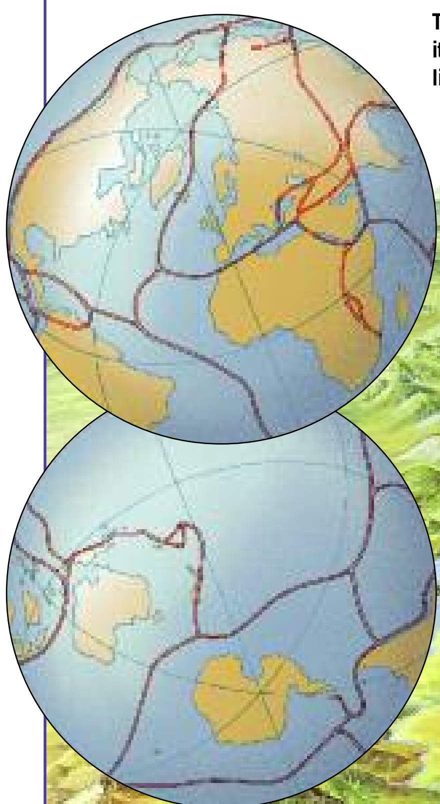
The lithospheric plates fit together tightly. As they move, they rub and grind their edges against each other. In some places the edges crash into each other and crumple, pushing up mountains. In other places, hot liquid rock wells up from deep below, into the crack or boundary between the oceanic crusts of two plates. The molten rock cools and solidifies, adding to the edges of the two plates as they move apart. This process is called seafloor spreading and it makes the whole ocean wider. The crack between the ocean plates is called the mid-oceanic ridge.



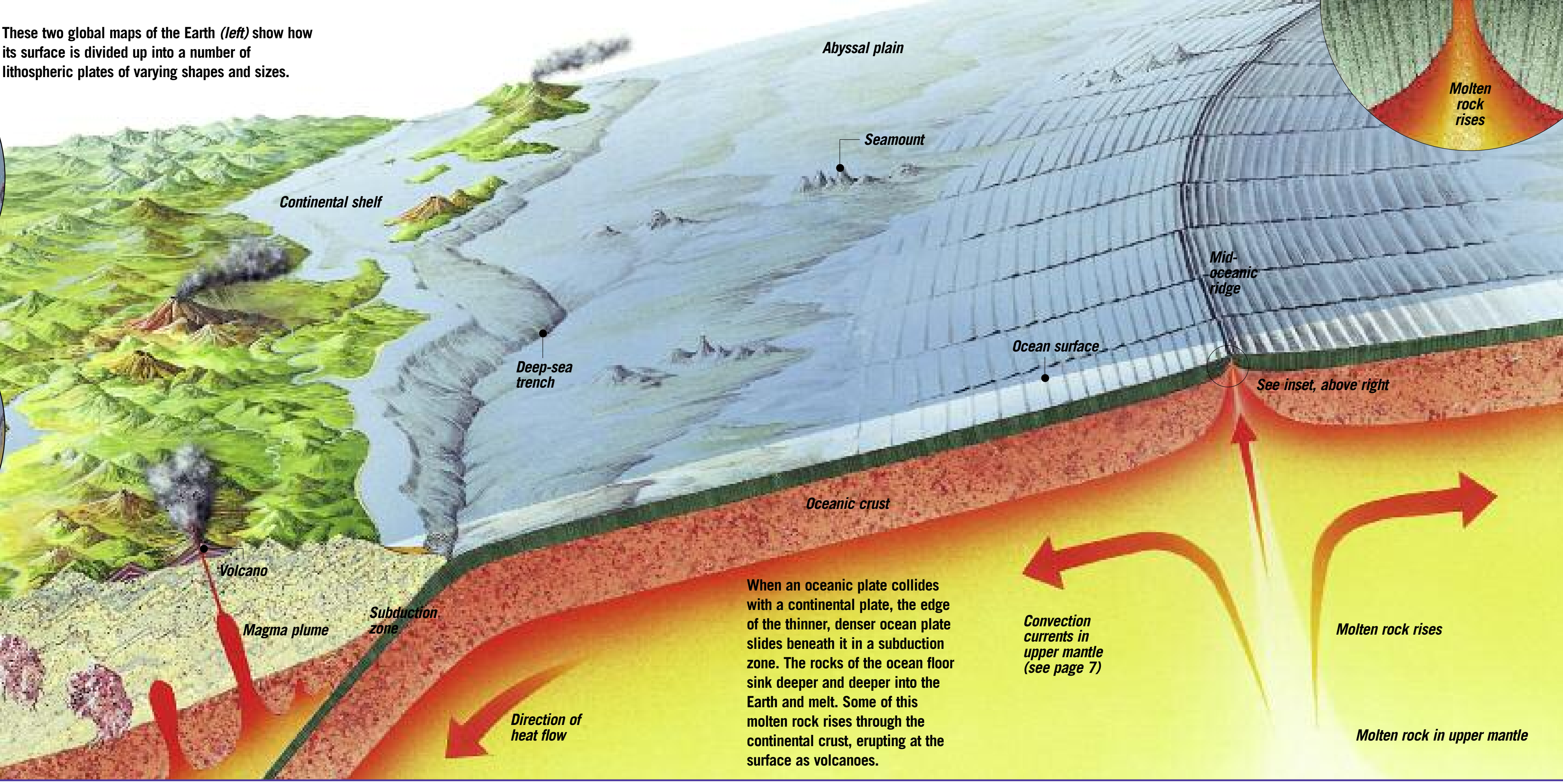


Plates meet at three types of boundaries. At a mid-oceanic ridge, new crust is made as the plates push apart. At a convergent boundary, oceanic crust is lost as a thinner oceanic plate is forced down under a thicker continental one (subduction), or is crumpled up into mountains when continental plates collide. At a transform fault, the plates slide past each other.





These two global maps of the Earth *(left)* show how its surface is divided up into a number of lithospheric plates of varying shapes and sizes.

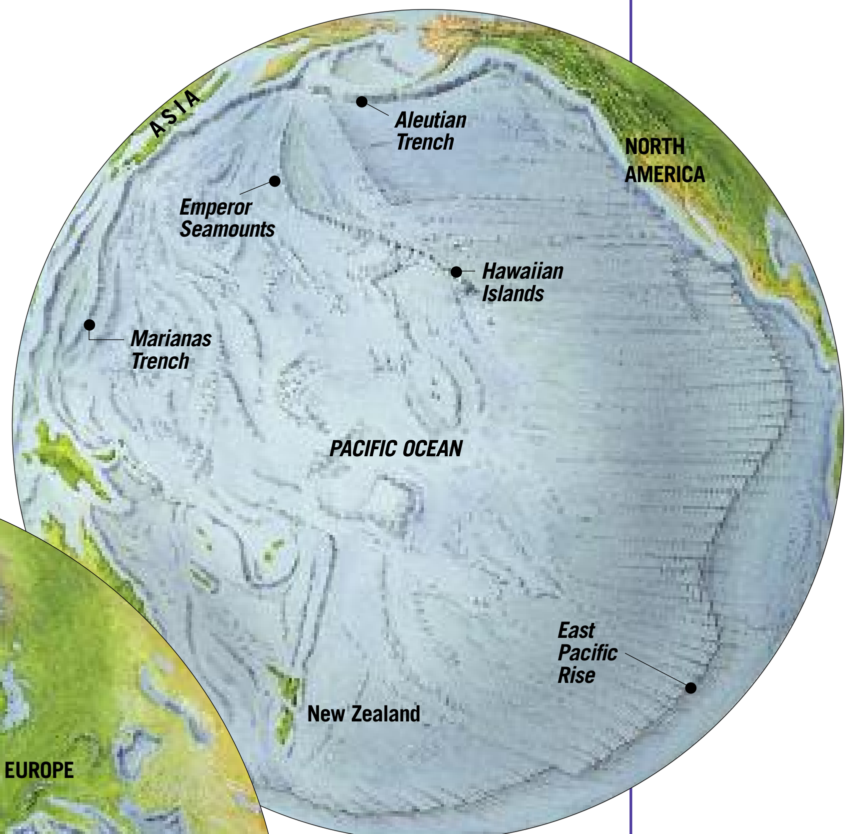


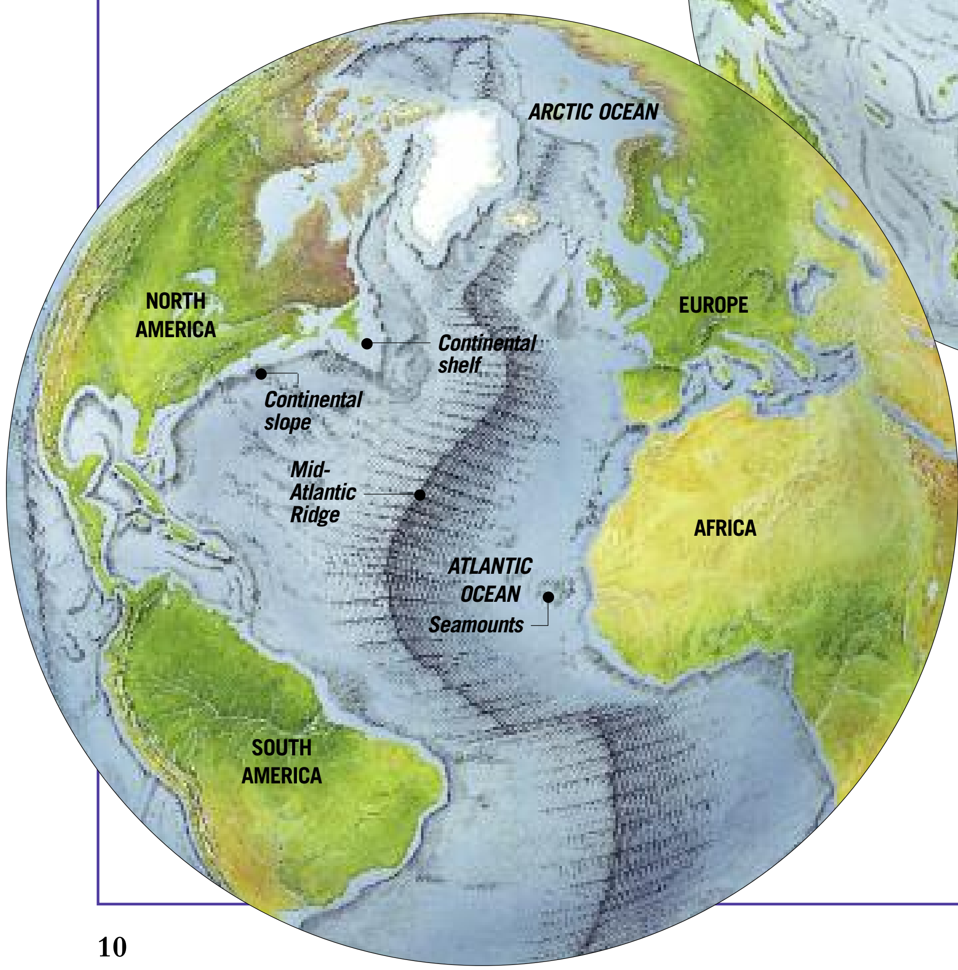
When an oceanic plate collides with a continental plate, the edge of the thinner, denser ocean plate slides beneath it in a subduction zone. The rocks of the ocean floor sink deeper and deeper into the Earth and melt. Some of this molten rock rises through the continental crust, erupting at the surface as volcanoes.

Ocean Floor

ABOUT 71 per cent of our planet is covered with water. The largest ocean is the Pacific, which covers 166 million square kilometres—almost the same area as all other seas and oceans added together. The landscape around us has tall mountains, wide plains, winding valleys and deep ravines. Under the waves the seascape has the same features but on an even bigger scale. The highest mountain above sea level is Everest in the Himalayas, at 8848 metres, but the tallest mountain from base to peak is Mauna Kea on the Pacific island of Hawaii, at 10,205 metres—with 6000 metres below the waves. Everest would disappear into the deepest part of the ocean, the narrow Marianas Trench in the north-west Pacific near Japan, at 10,911 metres deep. The average depth of the Pacific is 3950 metres. Its wide abyssal plains cover almost as much area as all the Earth's land.

The true edge of a continent is not its coastline. From here the sea bed extends about 50-100 kilometres, yet the water is less than 200 metres deep. This ledge, the continental shelf, is part of the continent. At its edge, it plunges steeply about 2000-2500 metres down the continental slope, then further down the less steep continental rise, to the main ocean floor. This is the abyssal plain, lying at 4000-4500 metres deep.



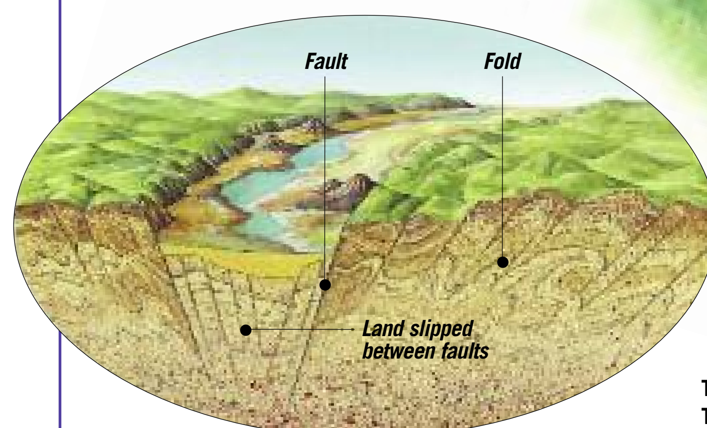


If all the ocean waters were drained away you would see the many features of the ocean floor. The continental shelf extends from the land, then dips sharply to the abyssal plain. Seamounts are underwater mountains. Peaks high enough to break the water's surface form islands. New ocean floor is forming along the mid-oceanic ridge by seafloor spreading. Old ocean floor is disappearing into the mantle along the deep trenches of the subduction zones around the Pacific Ocean.

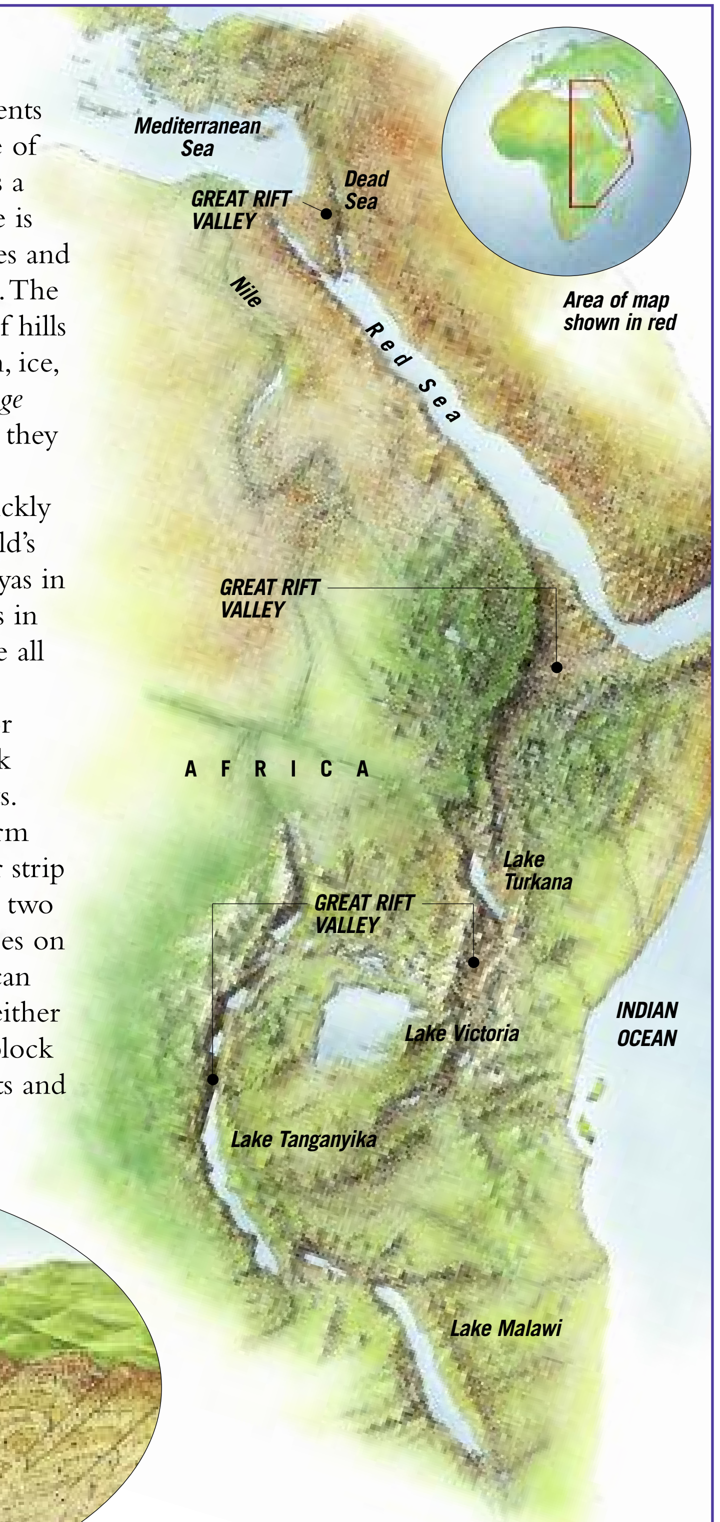
Folds and Faults

SLIDING plates and drifting continents *(see page 8)* are responsible for some of the Earth's major landscape features. As a large slab or plate of the Earth's surface is squeezed, the solid rock slowly wrinkles and crumples. Its layers become wavy folds. The land's surface is pushed up as a series of hills or even mountains. The wind, rain, sun, ice, snow and other forces of nature *(see page 18)* may wear down the folds as fast as they push up, keeping the surface low and rounded. But if the folds rise more quickly they form high, jagged peaks. The world's great mountains, including the Himalayas in Asia, Andes in South America, Rockies in North America and Alps in Europe, are all fold mountains.

In other places, rocks are stretched or bent and they crack or split along weak points. These cracks are known as faults. They may be straight or zigzag and form narrow slits or wide valleys. A block or strip of land sometimes slips down between two cracks to make a valley with steep slopes on either side, called a rift valley. Rifting can also make mountains, as the rocks on either side move in and squeeze the central block upwards. Raised blocks are called horsts and those which slip down are grabens.



A cutaway view reveals how the landscape is shaped by massive forces that crumple and crack solid rock. A wide slab has slipped down between several cracks or faults to form a rift valley with a wide floor and steep sides. To either side of the rift valley the rocks are bent into folds, with some almost tipped right over.



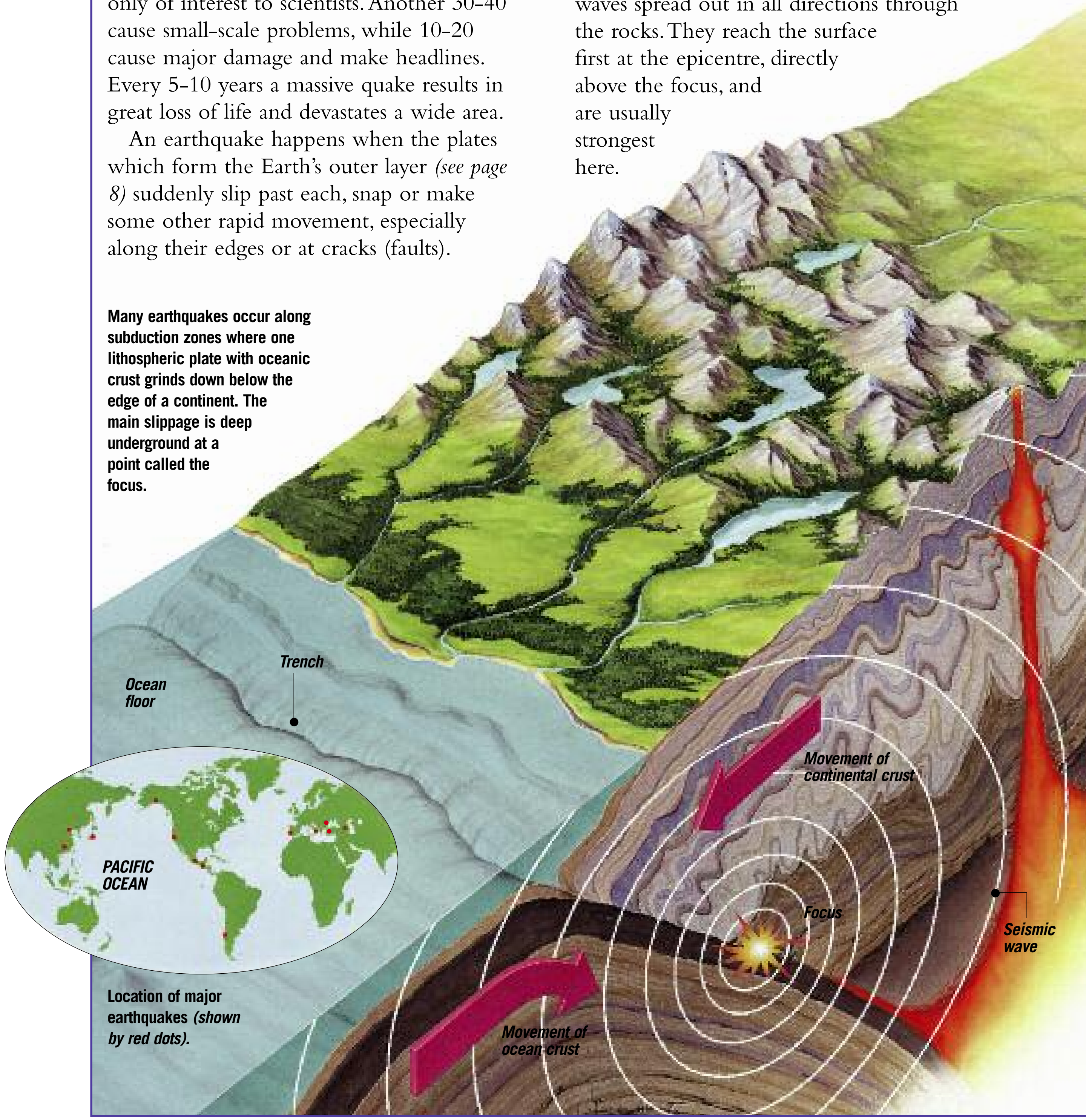
The biggest gash in the Earth's land is the Great Rift Valley. This series of rifts runs from the eastern Mediterranean south-east through the Dead Sea and Red Sea, then south across East Africa through Lake Turkana. It divides around Lake Victoria to continue south to Lakes Tanganyika and Malawi. The valley system is some 5000 kilometres long and widens by up to 2 centimetres in places each year. In millions of years the Red Sea may become a broad ocean and seawater may flood into the valley.

EARTHQUAKES

THERE ARE about 6000 noticeable earthquakes each year. Scientific devices called seismometers on continuous "quake watch" detect them all. Nine out of ten of these earthquakes are too small or occur in very remote regions so they are only of interest to scientists. Another 30-40 cause small-scale problems, while 10-20 cause major damage and make headlines. Every 5-10 years a massive quake results in great loss of life and devastates a wide area.

An earthquake happens when the plates which form the Earth's outer layer *(see page 8)* suddenly slip past each, snap or make some other rapid movement, especially along their edges or at cracks (faults).

The sudden jolt of a quake usually lasts not more than a few minutes and may be over in just a few seconds. It spreads out from a place called the focus. A shallow focus is down to 70 kilometres below the surface, an intermediate one 70-300 kilometres, and deep focus below 300 kilometres. Juddering shock or seismic waves spread out in all directions through the rocks. They reach the surface first at the epicentre, directly above the focus, and are usually strongest here.

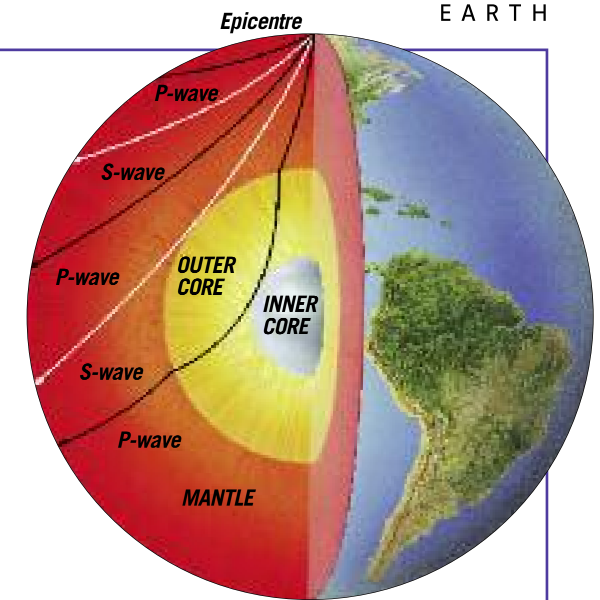


Many earthquakes occur along subduction zones where one lithospheric plate with oceanic crust grinds down below the edge of a continent. The main slippage is deep underground at a point called the focus.

Location of major earthquakes *(shown by red dots).*

Cities around the Pacific Rim suffer regular quakes. Tokyo was devastated in 1923.

The shock waves reach the Earth's surface around the epicentre, spreading out like ripples on a pond. The immensely powerful vibrations of a massive earthquake travel around and through the whole planet, making it tremble and shake for up to 20 minutes. Most earthquakes happen along the edges of the Earth's huge plates, especially where these are actively moving (often resulting in volcanoes, too). High-risk regions are the "Pacific Rim", around the shores of the Pacific Ocean, Southeast Asia (Philippines and Indonesia), from northern India west to southern Europe. Some large earthquakes also happen away from the plate edges.



There are several types of shock waves. P (primary) waves travel quickly through the Earth, although its inner layers bend them. S (secondary) waves are slower and cannot go through the liquid outer core.

Two scales measure earthquakes. The Mercalli scale shows how much damage is caused, from 1 (not felt) to 12 (total devastation), while the Richter scale measures the magnitude of the shock.

Earthquakes under the sea set off under-water ripples. These reach land and rear up to form huge waves, called tsunamis.

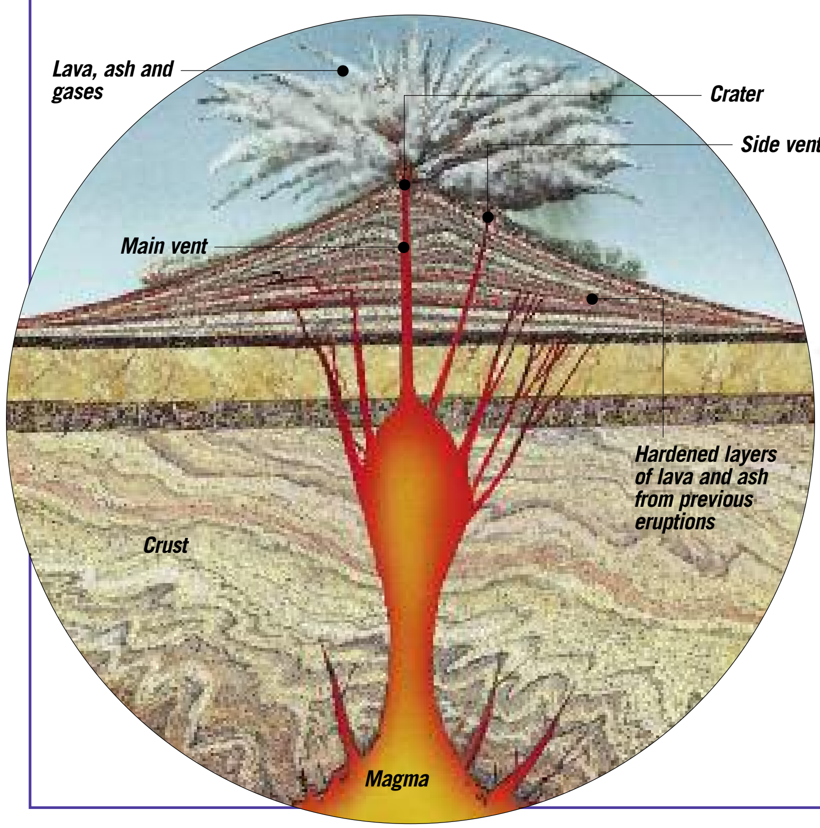
VOLCANOES

WHEN A VOLCANO erupts and hurls out its red-hot rock, this is one of the most awesome events of nature. It happens at a hole, crack or weak point in the solid rocks of the Earth's crust. Melted rock called magma from deep below forces its way up under incredible temperature and pressure. As it emerges it is called lava. When it cools and hardens, it forms a type of rock known as igneous rock *(see page 16).*

Some lava is thin and runny. It oozes like boiling syrup from the volcano and spreads over a wide area. As it cools, it turns into a "shield" of solid rock known as basalt. Each time the volcano erupts it adds to the shield, in layers of lava up to 10 metres thick. Known as shield volcanoes, the eruptions are gentle.

In explosive eruptions, lava is thick and sticky. It moves slowly and hardens near the volcano's vent or crater. As this type of volcano erupts time after time, the lava builds up to form a tall, steep-sided mountain known as a cone.

The temperature of lava erupting from a volcano can be more than 1000°C. It may take months to harden. Volcanoes eject other substances, too: gases and fumes rich in sulphur. Some give out clouds of ash or cinders that fly high in the air. The cinders may fall near the volcano and build up a cinder cone. Some volcanoes have such explosive power that they blast out huge lumps of molten rock as big as houses. These volcanic bombs crash to the ground nearby. The ash is often blown away by the wind and may fall over a very wide area.



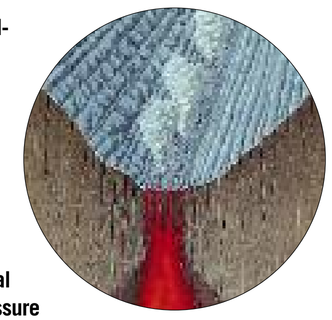
An active volcano regularly erupts lava, ash, fumes and other materials. In very active volcanoes, this happens almost continuously. In others, there are weeks or months between eruptions. When a volcano has not erupted for many years or centuries, but still might in the future, it is dormant. When there have been no eruptions for tens of thousands of years the volcano is described as extinct. Some volcanoes blast out gas and spurt red-hot lava in a spectacular eruption. Others erupt more explosively, producing clouds of ash and gas. On land, most magma oozes slowly to the surface over very long time periods without explosive power. It emerges from long cracks or fissures and spreads out to form low mounds of volcanic rock.

VOLCANIC ZONES

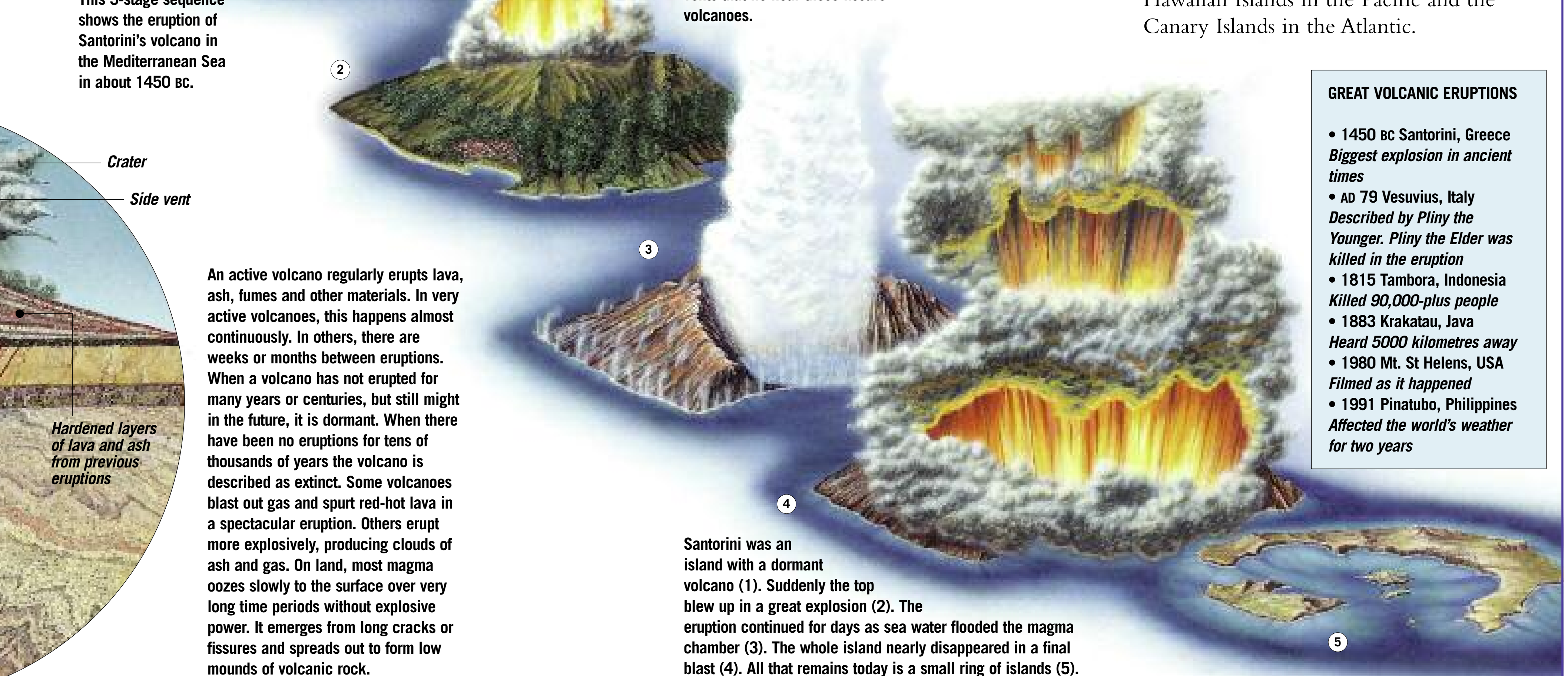
Most volcanoes are situated along the edges of the giant, jigsaw-like lithospheric plates which make up the Earth's surface *(see page 8).* The boundaries between plates have many weak points. In particular, volcanoes form along subduction zones where one plate slides down beneath another. As the lower plate melts back into the mantle its gases and lighter molten rock "boil" and force their way up through cracks with enormous pressure, causing eruptions.

Rainwater may trickle down through cracks in rocks to deeper layers where it is heated by magma. It comes blasting back out as a fountain of steam, spray and hot water known as a geyser.

The typical cone-shaped volcanoes on land may seem huge and powerful. But they make up less than one-hundredth of all the volcanic activity on Earth. Most magma oozes to the surface deep under water, along the crack-like fissures of mid-oceanic ridges *(see page 8)* or through smaller weak "holes" known as hot spots. If underwater volcanoes build cones tall enough they emerge at the surface as islands, such as the Hawaiian Islands in the Pacific and the Canary Islands in the Atlantic.



All along the mid-oceanic ridge *(right),* molten rock seeps into the ocean floor from the mantle below in a series of continually-erupting volcanoes. Hot, mineral-rich water and gas bubble from deep-sea hydrothermal vents that lie near these fissure volcanoes.

This 5-stage sequence shows the eruption of Santorini's volcano in the Mediterranean Sea in about 1450 BC.

Santorini was an island with a dormant volcano (1). Suddenly the top blew up in a great explosion (2). The eruption continued for days as sea water flooded the magma chamber (3). The whole island nearly disappeared in a final blast (4). All that remains today is a small ring of islands (5).

GREAT VOLCANIC ERUPTIONS

- **1450 BC Santorini, Greece** *Biggest explosion in ancient times*
- **AD 79 Vesuvius, Italy** *Described by Pliny the Younger. Pliny the Elder was killed in the eruption*
- **1815 Tambora, Indonesia** *Killed 90,000-plus people*
- **1883 Krakatau, Java** *Heard 5000 kilometres away*
- **1980 Mt. St Helens, USA** *Filmed as it happened*
- **1991 Pinatubo, Philippines** *Affected the world's weather for two years*

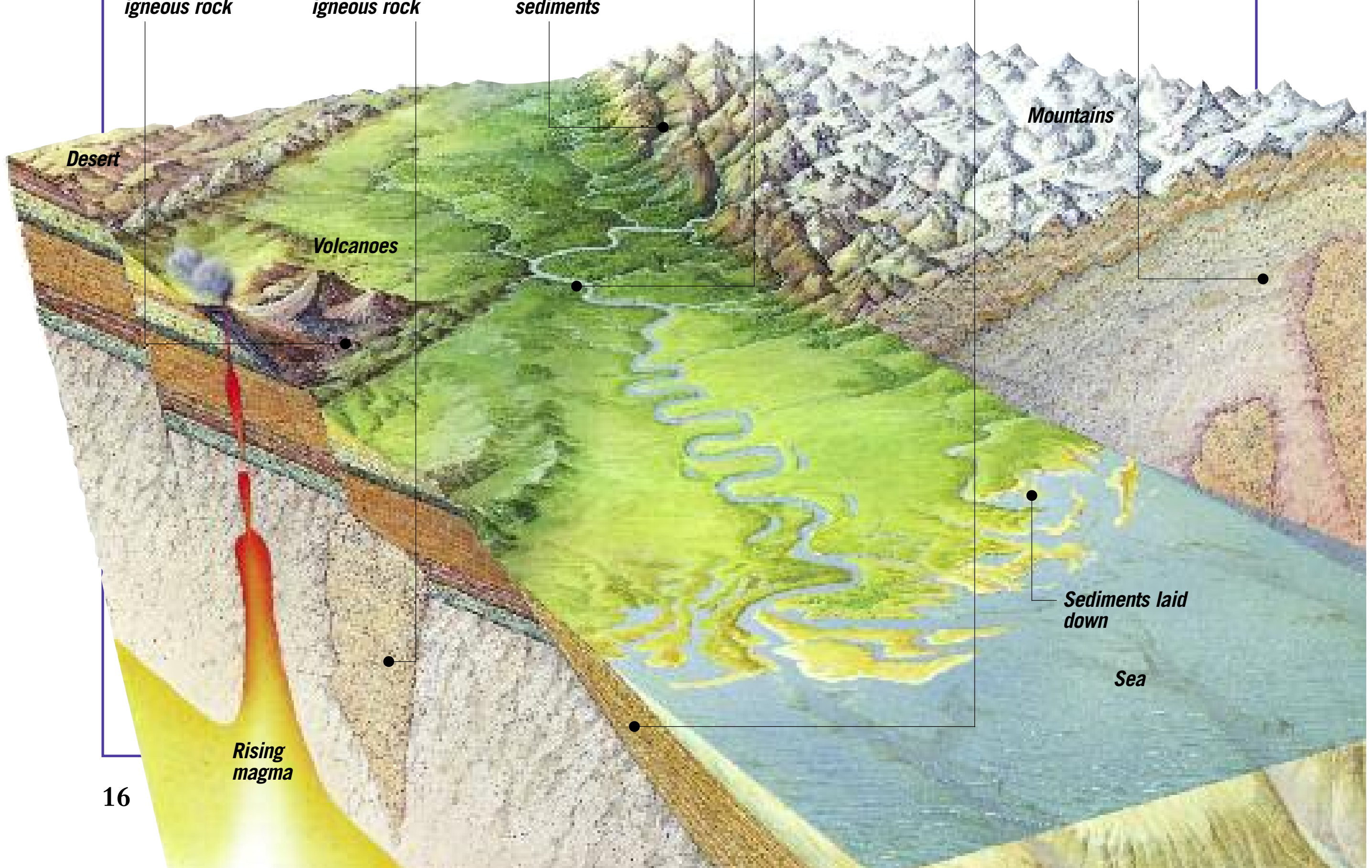
Rocks

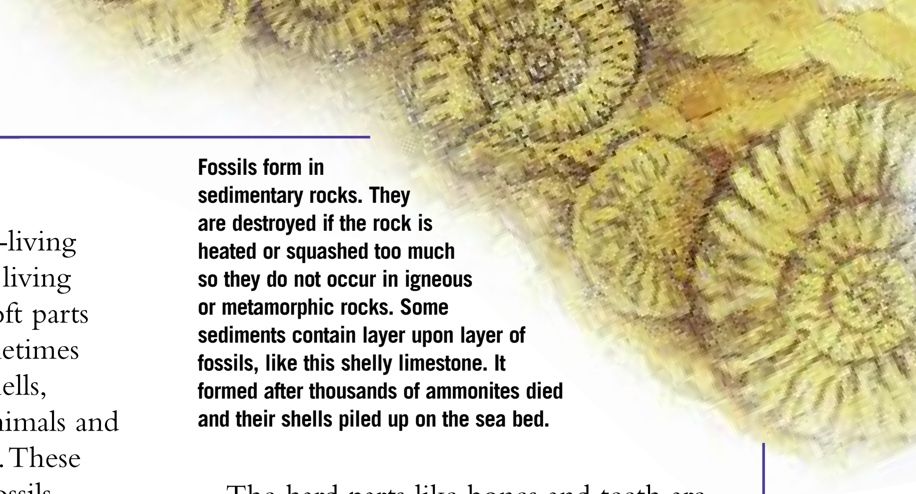
ROCK is the hard material that makes up the Earth's crust. Various combinations of minerals make up hundreds of different types of rocks. For example, the rock sandstone consists mainly of grains of sand pressed and cemented together. Sand is made mainly of the mineral quartz which consists of the chemical elements silicon and oxygen.

All rocks can be divided into three main groups depending on how they formed. **Igneous rocks,** such as granite and basalt, are formed when magma, molten rock from beneath the Earth's crust, rises, cools and solidifies. **Sedimentary rocks,** such as sandstone and mudstone, are made from sand, gravel, mud and other fragments of rock that result from erosion *(see page 18)*. These settle in layers in lakes, rivers and seas. As more layers settle on top of each other, the particles are compressed and cemented into sedimentary rock. The third group, **metamorphic rocks,** such as marble and slate, are formed when rocks are subjected to such great pressure and heat that their mineral composition is altered.

Rocks are constantly being changed. Weathering attacks all kinds of surface rocks. The eroded fragments form new sedimentary rocks which may sink into the Earth, melt, then later cool to become igneous rocks. Alternatively, they may be cooked and crushed deep in the crust, forming metamorphic rocks. This change from one type to another is called the rock cycle *(below)*.

Most magma rises slowly through the crust and turns into solid rock underground. There, like jelly in a mould, it takes on the shape of its surroundings, resulting in ledges, columns, domes and other shapes.



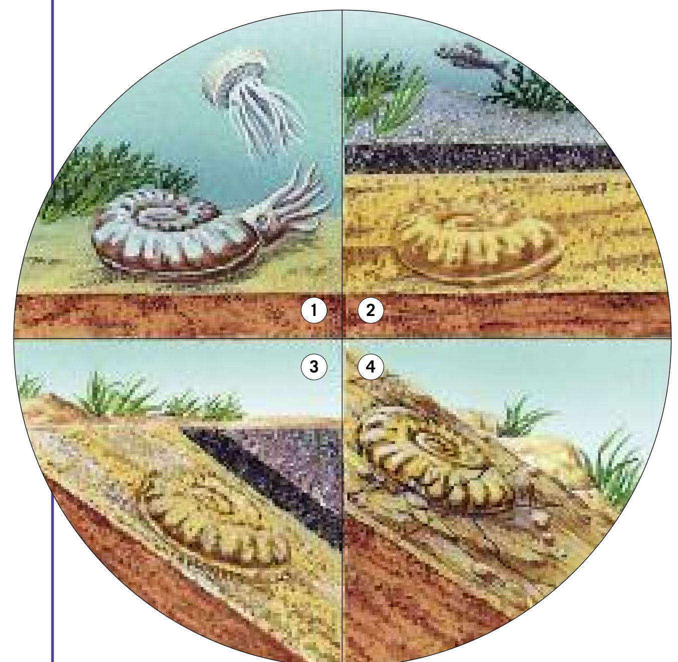


Fossils

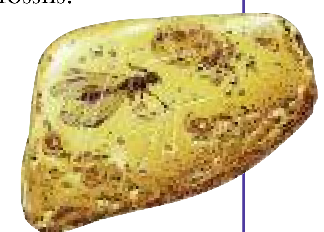
FOSSILS ARE remains of once-living things preserved in rock. Most living things are eaten or die and their soft parts rot away leaving no trace. But sometimes hard body parts remain, like the shells, bones, teeth, horns and claws of animals and the bark, cones and seeds of plants. These are the parts most likely to form fossils. Trace fossils are not actual body parts but signs and traces of living things such as egg shells, footprints and droppings.

Fossils form in sedimentary rocks. They are destroyed if the rock is heated or squashed too much so they do not occur in igneous or metamorphic rocks. Some sediments contain layer upon layer of fossils, like this shelly limestone. It formed after thousands of ammonites died and their shells piled up on the sea bed.

The hard parts like bones and teeth are buried under sediment particles such as sand grains on a beach, silt on a river bank or mud on a sea bed. Slowly the surrounding water dissolves away the remains and replaces them with rock minerals from the water. Meanwhile the particles around them are also turning into rock. If undisturbed, the remains keep their original shape but they are now solid rock—fossils.



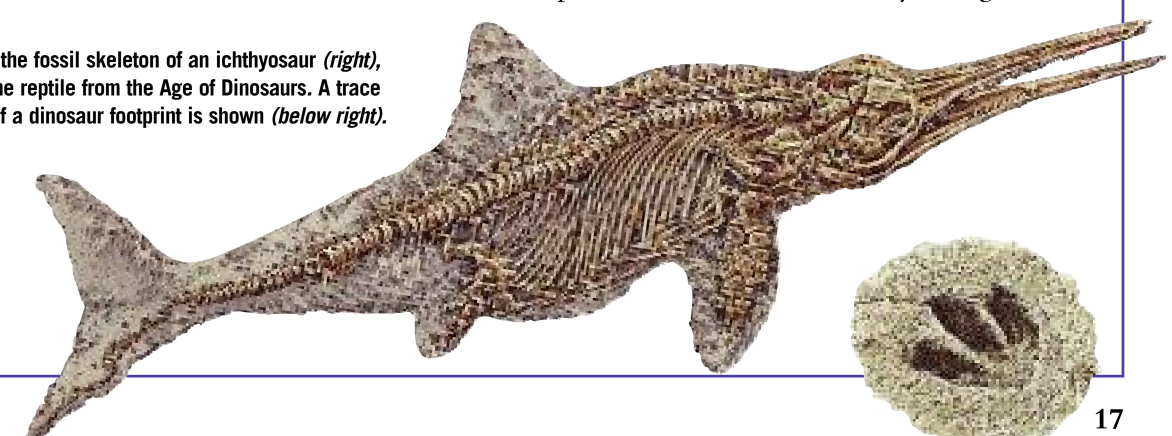
An ammonite, a prehistoric cousin of the octopus and squid, lived in a coiled shell and floated or swam in the sea. When it died its soft, fleshy parts soon rotted away or were eaten (1). Sandy sediments slowly covered the hard shell on the sea bed (2). Both shell and sand gradually turned into rock which was lifted and tilted by massive earth movements (3). Erosion uncovered the fossil shell at the surface (4).



The sticky sap or resin that oozes from trees and other plants may fossilize as a hard yellow substance, amber. This sometimes contains insects and other small animals that were trapped in it, preserved in amazing detail.

Fossils take many thousands or millions of years to form and are found only in sedimentary rocks *(see opposite)*. Then, as part of great earth movements and the wearing-away forces of erosion, the sediments and their fossils may be exposed at or near the surface. Experts called palaeontologists search for fossils, dig them from the ground, study their shapes and structures, and compare them with similar body parts of living things today. This shows the kinds of dinosaurs, mammoths and other animals and plants that lived millions of years ago.

This is the fossil skeleton of an ichthyosaur *(right)*, a marine reptile from the Age of Dinosaurs. A trace fossil of a dinosaur footprint is shown *(below right)*.



EROSION

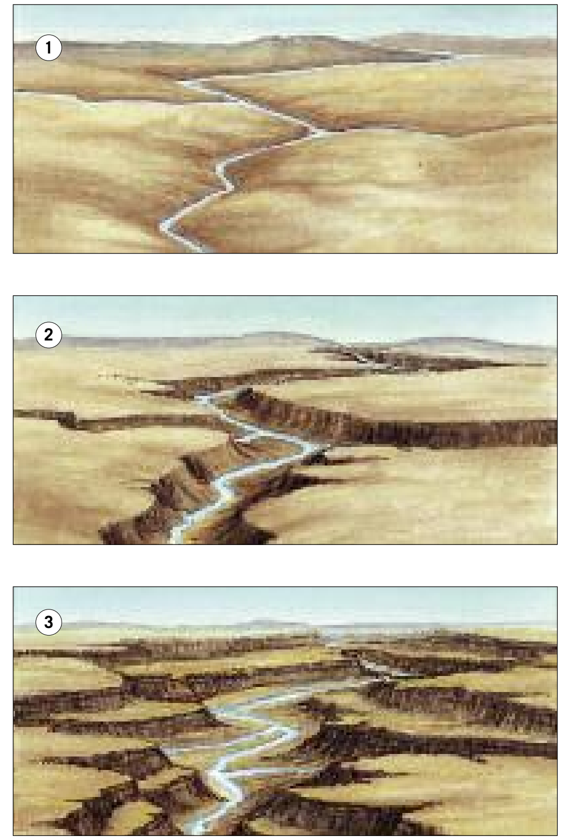
OVER THE MILLIONS of years of geological time, mountain ranges have formed—then disappeared. Continental drift, faulting and other earth movements have created these mountains. What has happened to them? Most have been worn down by the slow processes of weathering and erosion.

Changes in temperature, rain and frost all break down the rocks in a process called **weathering.** Rocks heat up and expand in the hot sun, then cool and contract at night. The temperature changes crack the rock surface and small pieces flake off. Rainwater seeps into crevices in rocks and, as it freezes, it expands with great force and splits off pieces. This is known as frost-wedging.

Erosion is the removal of fragments of rock by the action of running water, glaciers or wind. Rivers, especially if they are fast-flowing or in flood, can carry away pieces of rock. Waves crashing on to cliffs, sometimes hurling pebbles or boulders at the rock, are also powerful forces of erosion.

Weathering wears away higher areas of land fastest *(above).* Ice, wind and water carry the rocky fragments and deposit them in lower regions such as plains, rivers and lakes, where they are known as sediments.

The world's most spectacular example of erosion is the Grand Canyon in Arizona, USA *(below).* The soft rock layers wore away more easily than the hard layers, which today stand out as near-vertical cliff faces.

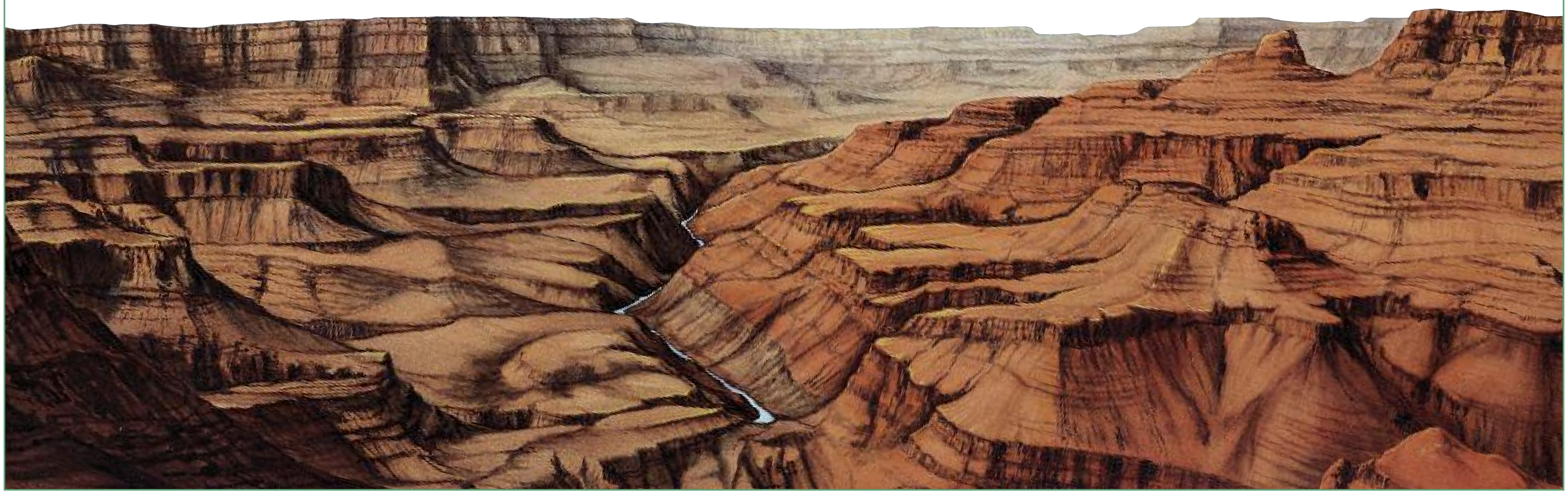


The Colorado River once flowed across desert (*above,* 1), but as the land rose (2) it cut a deeper and deeper valley (3).

THE GRAND CANYON

The Grand Canyon is a great gorge that twists across the dry, rocky region of Arizona, USA for 350 kilometres. It formed over the past six million years as earth movements pushed up the land by more than 1200 metres. The fast-flowing Colorado River has steadily cut into the land to maintain its downward flow to the sea. The result is a step-sided canyon, on average 16 kilometres wide and 1600 metres deep in places. The region's desert climate *(see page 23)* means the softer, upper rock layers have not been washed away.

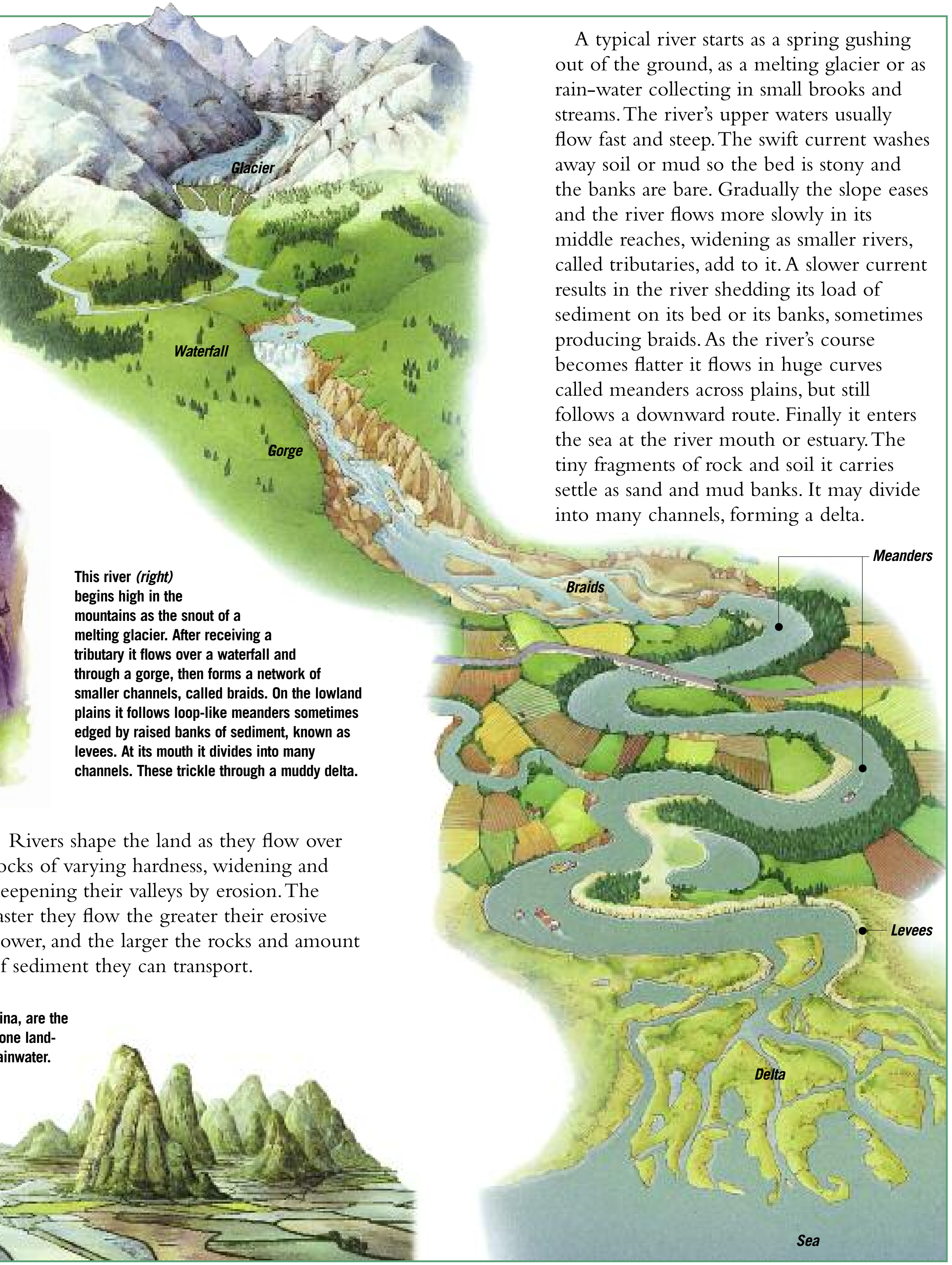
The river is especially powerful in spring when melting snows in the distant Rockies send floodwaters down the canyon. They sweep along boulders that chip away at the river's bed and banks. As the river cuts deeper, it reveals ancient layers of rock and the fossils they contain, almost like chapters in the Earth's prehistory. The lowest layers of rocks are 1700 million years old. They were themselves once mountains towering thousands of metres above sea level.



RIVERS

RIVERS ARE natural channels that carry rain, melted ice and snow downhill from mountains and uplands to lowlands, lakes and seas. They support much wildlife in their waters and along their banks. The world's longest rivers are the Nile in Africa and the Amazon in South America, both about 6600 kilometres long. But the Amazon is so wide and fast-flowing, it carries more water than the Nile plus the next five longest rivers combined together. The Amazon gathers water from seven million square kilometres of land, an area larger than Western Europe.

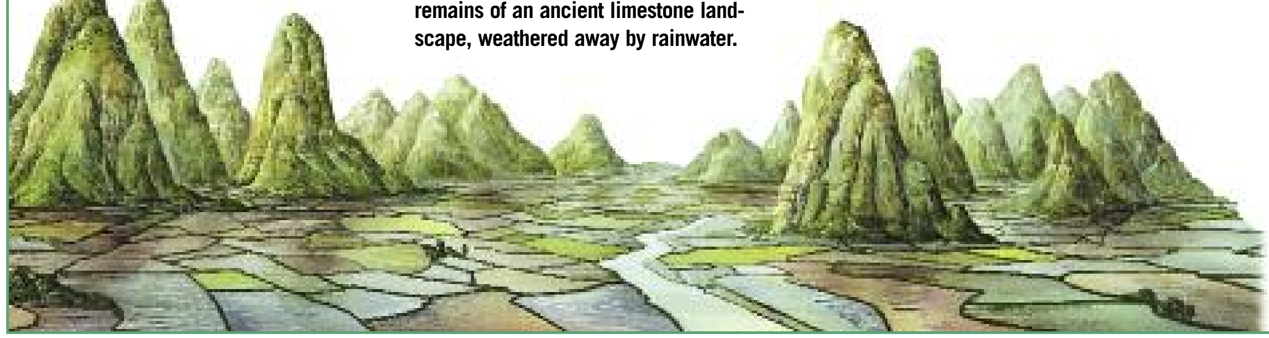
A waterfall forms where a river cascades down a cliff, or where its bed changes from hard to softer rock. The river wears down the softer rock more quickly so a "lip" of hard rock forms above it. The world's highest waterfalls are Salto Angel (Angel Falls, *right*) on the Carraro River in Venezuela, South America. The total height is 979 metres with the tallest single drop at 807 metres. The water becomes a mist before reaching the bottom.



This river *(right)* begins high in the mountains as the snout of a melting glacier. After receiving a tributary it flows over a waterfall and through a gorge, then forms a network of smaller channels, called braids. On the lowland plains it follows loop-like meanders sometimes edged by raised banks of sediment, known as levees. At its mouth it divides into many channels. These trickle through a muddy delta.

Rivers have had great effects on our history. Early towns and cities grew up along them because they provided transport routes by boat, food such as fish, and water supplies for drinking, cooking and raising farm crops and animals.

Rivers shape the land as they flow over rocks of varying hardness, widening and deepening their valleys by erosion. The faster they flow the greater their erosive power, and the larger the rocks and amount of sediment they can transport.



The Guilin Hills, southern China, are the remains of an ancient limestone land-scape, weathered away by rainwater.

A typical river starts as a spring gushing out of the ground, as a melting glacier or as rain-water collecting in small brooks and streams. The river's upper waters usually flow fast and steep. The swift current washes away soil or mud so the bed is stony and the banks are bare. Gradually the slope eases and the river flows more slowly in its middle reaches, widening as smaller rivers, called tributaries, add to it. A slower current results in the river shedding its load of sediment on its bed or its banks, sometimes producing braids. As the river's course becomes flatter it flows in huge curves called meanders across plains, but still follows a downward route. Finally it enters the sea at the river mouth or estuary. The tiny fragments of rock and soil it carries settle as sand and mud banks. It may divide into many channels, forming a delta.

CAVES

CAVES are underground holes in the rock. Some caves open up when the ground splits, as in an earthquake. Some are eroded by waves hurling stones and pebbles at a cliff. But most are made in limestone rocks by a chemical process. Rainwater naturally contains tiny amounts of acid. It trickles into cracks and reacts with the rock's lime substances to dissolve them away. Over thousands of years small cracks are widened into huge caves.

Inside this cave, a stalactite above has merged with a stalagmite below to form a column or pillar of rock. Stalactites and stalagmites can reach 30 metres in length.

In a limestone landscape, a stream disappears into a swallow hole, or when the stream no longer flows, a dry pot hole. Underground is a cave system of many chambers, some with underground lakes, and linked by upright shafts and horizontal galleries. As water drips from the ceiling, dissolved minerals in it gradually harden to form icicle-like shapes of rock called stalactites hanging down. Stalagmites grow up from the floor where water containing dissolved minerals drips from the ceiling.

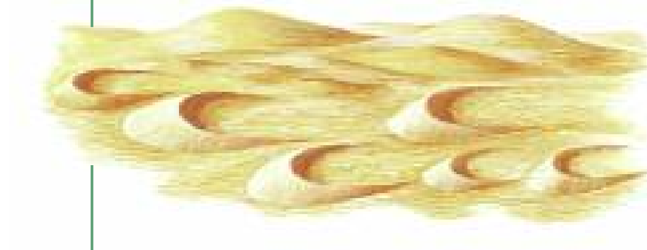
GLACIERS

A GLACIER is a moving mass of ice. Some glaciers snake down mountain valleys, while others such as the ice sheets of Greenland or Antarctica are so huge and thick they almost totally cover the land. Although it is solid, ice can flow down slopes and around bends—although much more slowly than a river, often less than a metre per day. Glaciers occur in very cold regions, high in mountains and in the far north and south polar regions. Ice covers about 15 million square kilometres, nearly one-tenth of the Earth's land surface. The largest glacier in the world is Antarctica's Lambert Glacier which is usually more than 500 kilometres long.

A glacier is fed by snow. Over many years, the snow piles up at the head of a high valley and compacts into ice. It collects in a cirque, a bowl-shaped feature. Being thick and heavy, the ice moves under the pressure of its own weight, flowing downhill as a glacier. The ice carries pieces of rock loosened by frost weathering and scrapes against the valley sides. It carries this loose rock along in long bands called lateral moraines, or underneath the glacier as subglacial moraine. As two glaciers merge their lateral moraines combine into a medial moraine. Where the ice runs over a steeper slope, it develops cracks known as crevasses. Lower down, the glacier melts at its snout, leaving a pile of the rocks it has carried as a terminal moraine, and a meltwater stream.

DESERTS

A DESERT is an area with very low rainfall, usually with less than 25 centimetres of rain (or snow) yearly. It may be hot all year round, as in the Sahara of Africa, or always cold as in Greenland or Antarctica. The Gobi desert of Central Asia is hot in summer and cold in winter. "Hot" deserts may be bitterly cold at night. The Takla Makan Desert, China, may be a scorching 40°C by day yet plunge to minus 40°C at night.



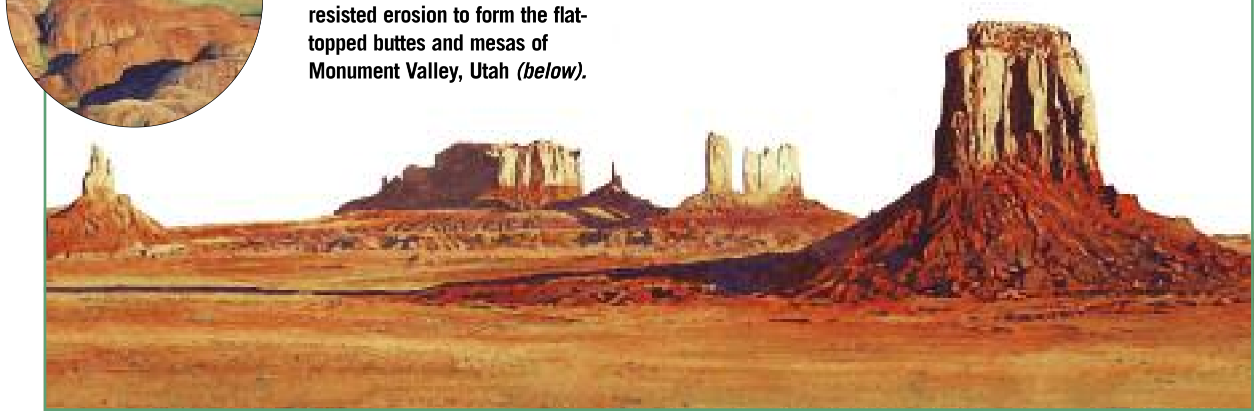
Wind blows sand into crescent dunes, or barchans, with "horns" pointing downwind. They slowly crawl along with the wind.

Deserts and arid regions cover one-eighth of the world's land area. The driest desert is the Atacama in Chile, South America, with an average of less than one millimetre of rain yearly. In some places it has not rained for centuries. The largest desert is the Sahara in Africa, over 5000 kilometres wide and covering 9 million square kilometres. The continent with the largest proportion of desert—about one half its area—is Australia.

The Olgas, Australia *(left)*, are the result of "onion-skin" weathering. Daily heating and cooling flake rock layers away. Hard rock has resisted erosion to form the flat-topped buttes and mesas of Monument Valley, Utah *(below)*.

The Mojave Desert in North America, and the Patagonian Desert of South America have formed because moist winds have dropped their water as rain or snow over nearby mountains. The lands beyond lie in what are known as rain shadows. Deserts like the Gobi form in the middle of huge land-masses far from the main source of moisture, the sea. Most deserts, including the Atacama, Sahara, Kalahari and Namib deserts, lie in a band to the north and south of the Equator. These are the result of global patterns of winds and rainfall.

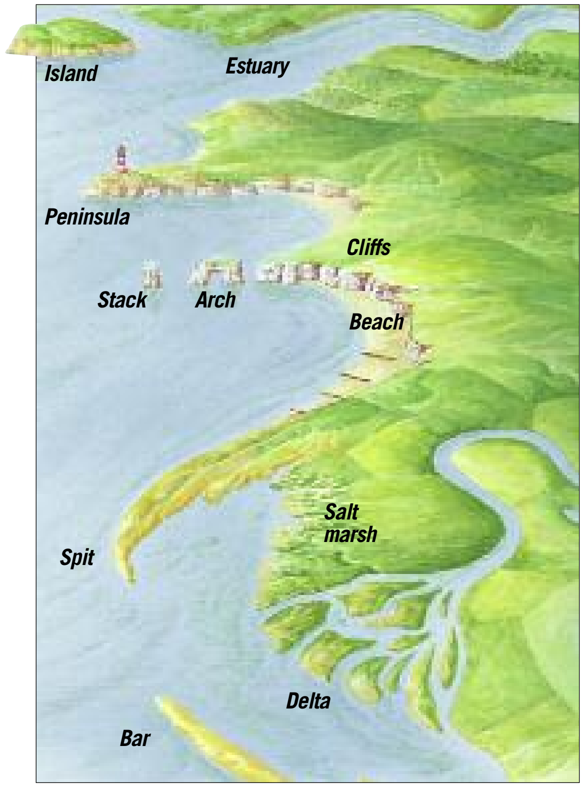
Most people think of deserts as vast sandy regions, but only about 20 per cent of the world's deserts are sandy. The rest are bare rock, or covered with gravel. The erosive power of the wind and rainstorms sculpts the desert landscape. Storms hurls sand at rocks, producing shapes like arches *(above)* or mushrooms and other strange landscapes.



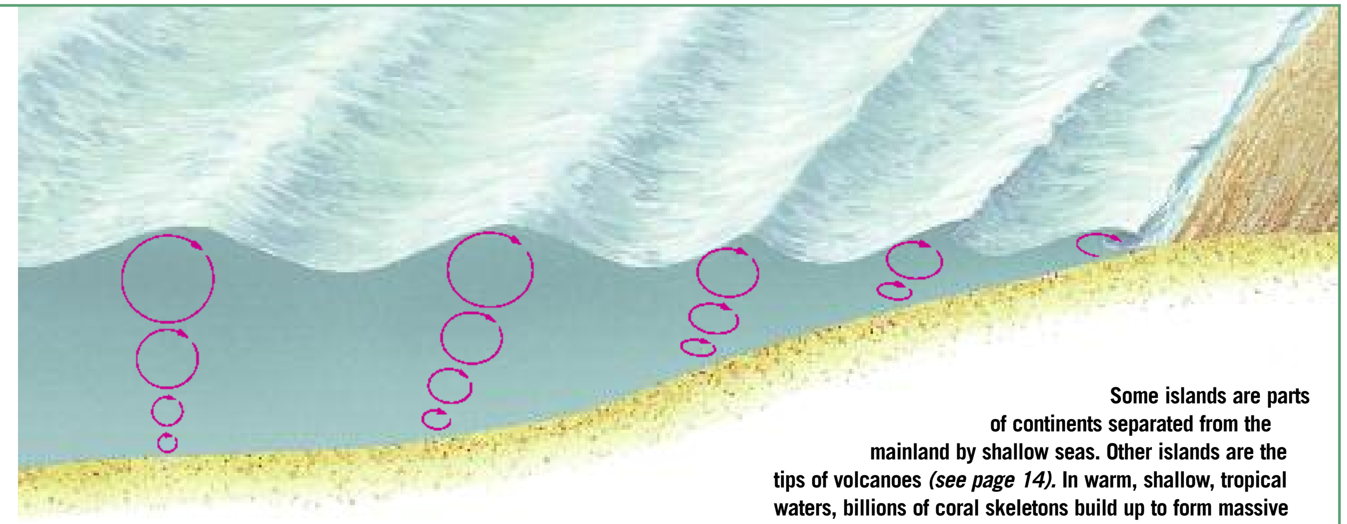
Coastlines

THE COAST is a continuing battle between land and sea. Sometimes the sea "loses" as shingle, sand or mud piles up and the land grows. In other places, the sea "wins" as waves, currents and tides batter and break up the coast. Even hard rocks like granite are gradually worn away, especially during storms when high winds whip up huge waves powerful enough to smash pebbles and boulders against the shore.

The shape and features of a coastline depend on its rocks, winds and currents. Very hard rocks erode slowly and stand out as high headlands. Waves blow at the shore with their greatest force in the direction of the main or prevailing winds in the region. Cliffs are sculpted both by the waves and by rockfalls and landslides. When waves undercut soft rocks, these collapse on to the shore and break up into tiny fragments. Wide beaches may eventually form, protecting the cliffs behind them from the full erosive force of the sea. A fast current may scour away broken rock particles from one part of the shore. As it slows down, it deposits them further along the coast as a mudflat, sand bar or shingle spit.



Along this coast *(above)* a hard rocky outcrop has become an island, cut off from the mainland by a flooded valley. Below the estuary, an arm of land is still linked to the mainland as a peninsula. A third outcrop has been wave-worn into an isolated pillar or stack, an arch and steep cliffs. Currents carry shingle from the bay's beach, slow down and drop it to form a pointed spit and sand bar. Nearby, river mud is deposited to form a marshland and delta.



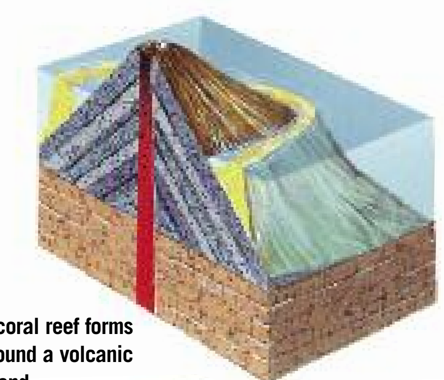
Some islands are parts of continents separated from the mainland by shallow seas. Other islands are the tips of volcanoes *(see page 14)*. In warm, shallow, tropical waters, billions of coral skeletons build up to form massive coral reefs around island coastlines *(below)*. A volcano may eventually sink back into the ocean floor. Coral animals must stay near the light, so they build the reef taller, forming a circular barrier reef enclosing a lagoon containing the disappearing island. The volcano's tip may sink out of sight leaving a ring of coral islands—an atoll.

Waves

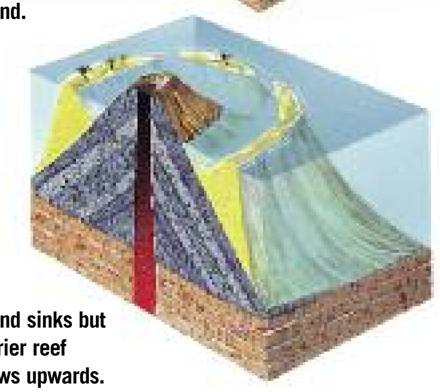
As wind moves across the surface of the ocean, the water turns over and over in circles, forming waves. The wave itself moves along, but the water in a wave does not. It spins around in the same place and makes the water below turn, too. The height and power of a wave depend on the strength of the wind and the expanse of water it has blown across. In mid-ocean, large waves, called swell, can develop.

As a wave approaches the shallower seashore *(see illustration above)*, the lower part drags on the sea bed, while the upper part travels on until, eventually, it topples over, or "breaks", on the shore.

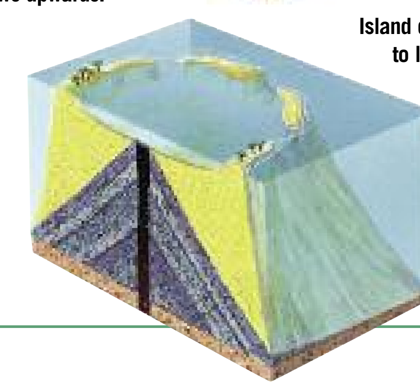
Waves, particularly during a storm, can be powerful forces of erosion *(see page 18)*. They cut away cliffs at the bottom, causing them to collapse. A headland may be attacked on both sides, becoming narrower and narrower. Joints and other weak areas are enlarged into sea caves. If caves form on either side of a headland, they may join up as a tunnel, later becoming a natural arch. If this collapses, a stack will result. This, too, eventually crumbles away over time.



A coral reef forms around a volcanic island.



Island sinks but barrier reef grows upwards.



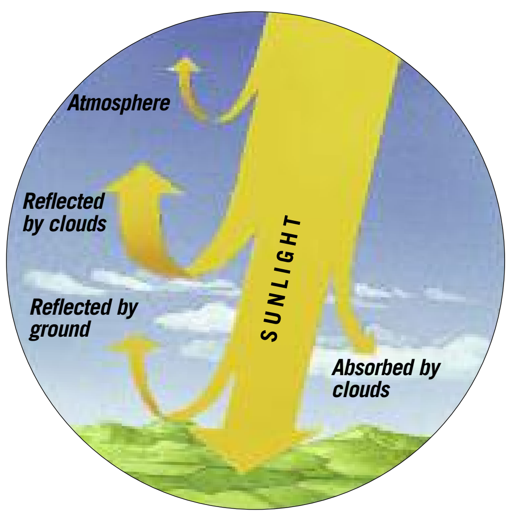
Island disappears to leave coral atoll.

In mountainous regions, valleys have been gouged out by glaciers *(see page 22)*. They have a characteristic U-shape. In some parts of the world, most notably Norway and New Zealand, U-shaped valley near the coast have been "drowned" by rising sea levels. These deep inlets, known as fjords *(left)*, have very steep sides. Some fjords snake inland for many kilometres.

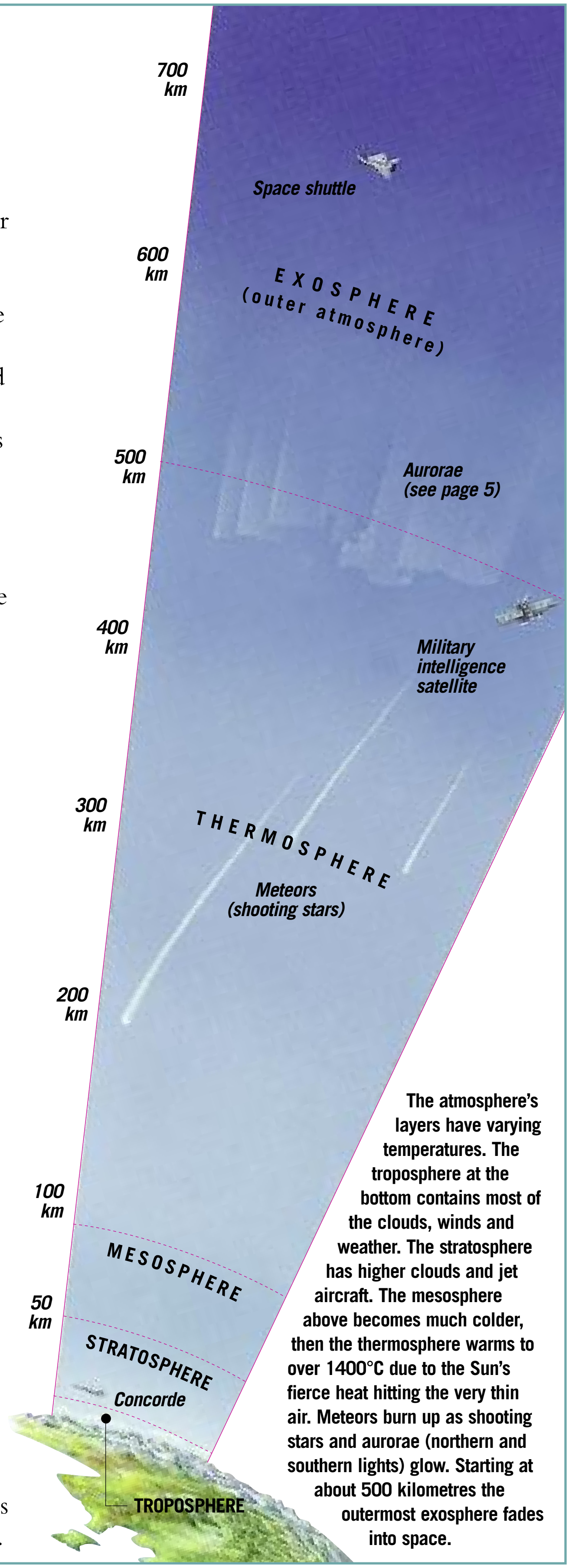
Atmosphere

THE AIR we breathe is part of a thick blanket of air wrapped around the Earth, known as the atmosphere. This air is a mixture of gases, mainly nitrogen (four-fifths) and oxygen (one-fifth). It gets thinner or less dense with height and fades away completely about 800 kilometres above the ground, where the atmosphere ends and the nothingness of space begins.

The atmosphere has layers which rise and fall in temperature as the air gets thinner. The troposphere extends to nine kilometres high over the poles and 16 above the Equator. It is only one-seventieth of the atmosphere's total volume yet it contains four-fifths of all the air. Its temperature falls to minus 55°C, which marks the start of the stratosphere. The temperature rises here to 10°C at about 50 kilometres high, where the mesosphere begins. It then plunges to a low of minus 75°C at 80 kilometres, before rising again in the thermosphere.



The atmosphere not only provides us with oxygen to breathe. It shields us from the Sun's harmful rays. Some of these are reflected by various layers such as the stratosphere and the clouds *(above)*. Other rays have their energy absorbed and spread out through the atmosphere. The gas ozone occurs thinly in the stratosphere and absorbs most of the Sun's dangerous ultraviolet rays.

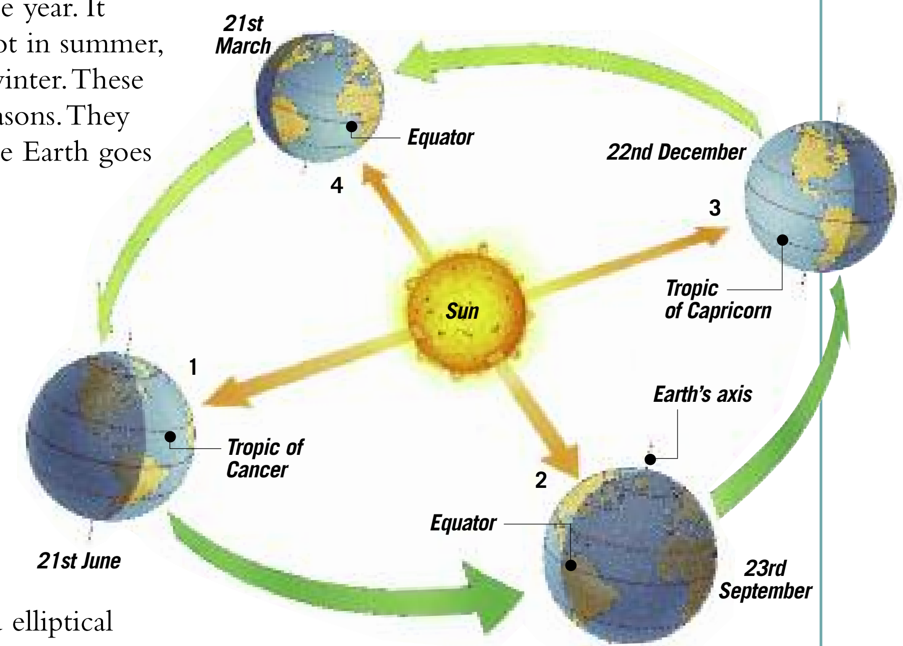


The atmosphere's layers have varying temperatures. The troposphere at the bottom contains most of the clouds, winds and weather. The stratosphere has higher clouds and jet aircraft. The mesosphere above becomes much colder, then the thermosphere warms to over 1400°C due to the Sun's fierce heat hitting the very thin air. Meteors burn up as shooting stars and aurorae (northern and southern lights) glow. Starting at about 500 kilometres the outermost exosphere fades into space.

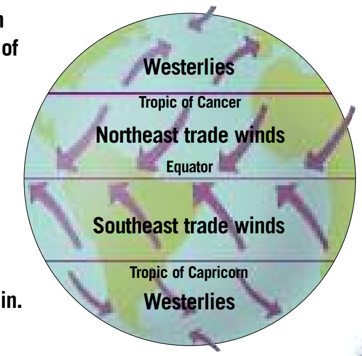
Seasons and Climate

IN TROPICAL REGIONS of the Earth (around the middle or Equator) it is hot all year round. Farther north the temperature varies through the year. It becomes warmer in spring, hot in summer, cool in autumn and cold in winter. These time periods are called the seasons. They happen because of the way the Earth goes around or orbits the Sun. The Earth's orbit is not an exact circle around the Sun, but an oval-like ellipse. Also, the Earth spins each day around an imaginary line or axis going through the North and South Poles, but this axis is not at right angles to the orbit. It is tilted at an angle of 23.5°. The combination of tilted axis and elliptical orbit produce the yearly cycle of seasons in northern and southern regions.

At the middle of the year (1) Earth's top or northern half leans towards the Sun. The Sun is nearer and higher in the sky for longer each day so the north has summer. The southern half leans farther away from the Sun and days are shorter so it is winter. As Earth continues its orbit the tilt becomes sideways to the Sun (2), giving autumn in the north and spring in the south. At the year's end the southern half leans nearer the Sun and has summer while the north has winter (3), followed by southern autumn and spring in the north (4).

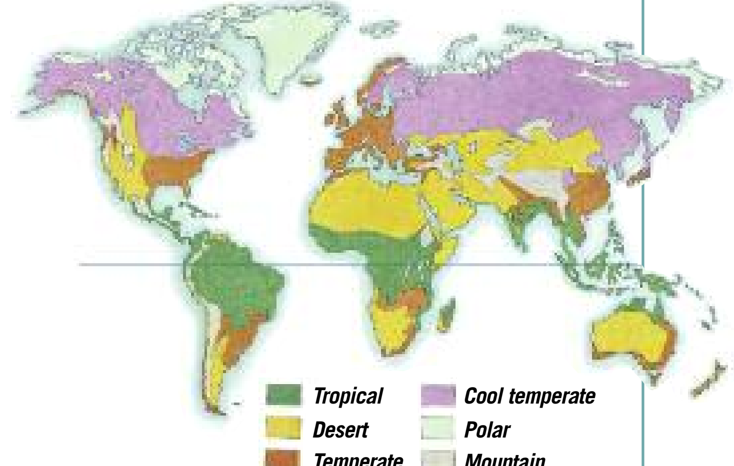


Winds result from uneven heating of different parts of the world. In the tropics, the surface is hot. This heats the air above it, which rises. Cooler air from the north and south blows in to replace it. These are called trade winds. Their direction is affected by the Earth's spin.



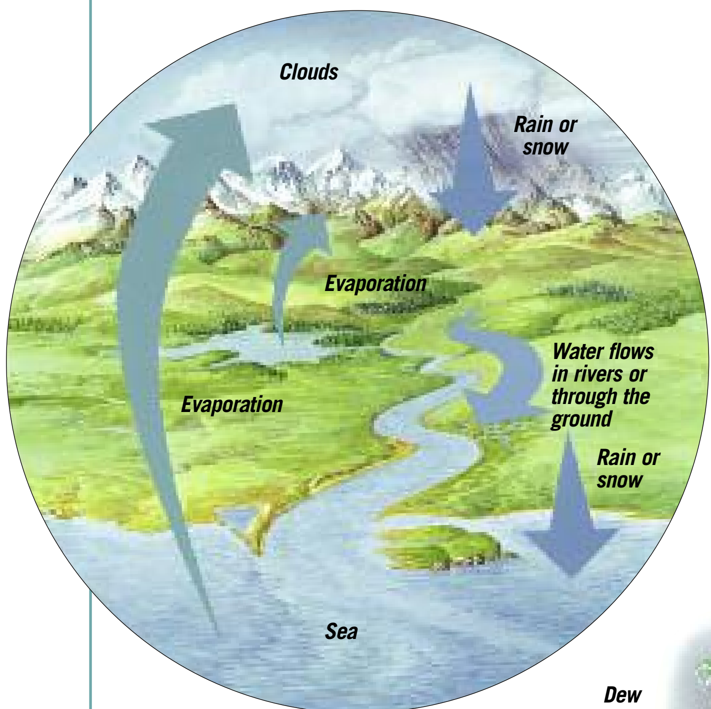
Weather varies from day to day around the world *(see page 28)*. Over a longer period, especially many years, each region has a regular pattern of rain, wind, temperature and other weather features. This long-term pattern of weather is called climate. It is due to the way the Earth orbits the Sun *(top)* and the way that ocean currents and wind patterns *(above)* carry the Sun's warmth and rain-laden clouds around the globe.

The map below shows the world's main climate regions. The Sun is nearest and highest in the sky over the tropical regions on either side of the Equator. Also it shines directly down through the atmosphere here rather than at a low, slanting angle, so the atmosphere absorbs and scatters less of its heat. This is why tropical regions are hot all year. If dry winds blow over a tropical region they cause a tropical desert climate. At the top and bottom of the Earth are polar regions where the Sun is farther away and lower in the sky, so these places are much colder. Between the topics and poles are temperate lands which have warm summer and cool winters.



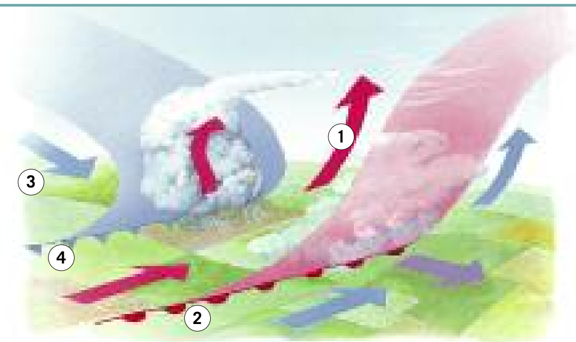
WEATHER

WEATHER is the conditions and changes that take place in the lower atmosphere, up to about 20 kilometres high. It includes temperatures by day and night, wind speed and direction, cloud type and cover, rain, hail, snow, frost, ice, droughts and storms. Weather can change by the minute or from day to day. The study of the weather is called meteorology.



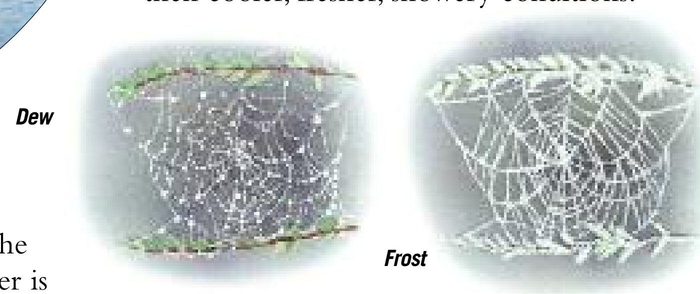
WATER CYCLE

A vital part of weather and climate is the water cycle *(above)*. On our planet, water is not produced or destroyed—the same water goes round and round in an endless cycle. In rivers, lakes and seas it is warmed by the Sun's heat. This evaporates or turns it into an invisible gas, water vapour. The warm water vapour rises high into the atmosphere where it is colder, so the vapour cools and condenses or turns back into liquid water. It forms tiny droplets or ice crystals floating as clouds. These merge, become bigger and fall as rain or snow. The rain and melted snow flow into rivers, lakes and seas—and the endless cycle continues.



FRONTS

The driving force for our weather is the Sun. By day and night, winter and summer, it warms different parts of the Earth's surface by different amounts. It evaporates water into the atmosphere to form clouds and also makes some regions of air warmer than others. Warm air rises and cooler air flows along to take its place, producing winds. When warm air *(above,* 1) flows up and over colder, heavier air, the moisture in it condenses, causing clouds to form and rain to fall. This is a warm front, shown on weather maps as a line with semicircles (2). When cold air (3) pushes against warm air along a cold front (4), it forms a low wedge, bringing a narrow band of heavy rain and then cooler, fresher, showery conditions.



DEW AND FROST

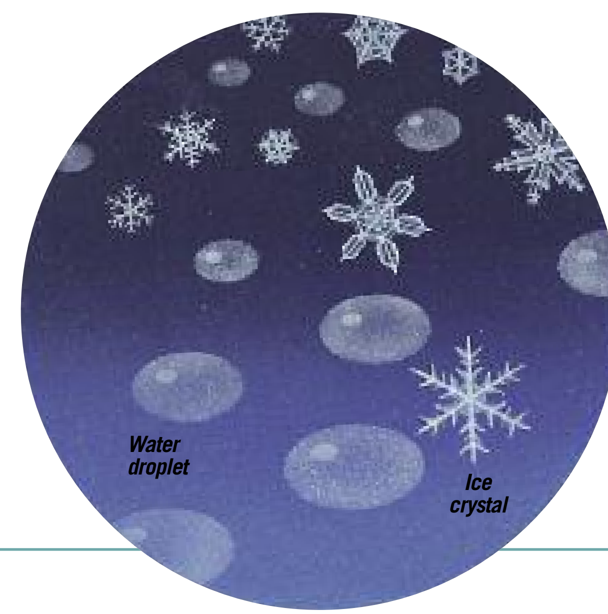
Water vapour is in the air around us, although we cannot see it. Sometimes it turns into liquid water or ice, which of course we can see. When the Sun goes down, the land cools faster than the air. Water vapour in the warmer air that touches the cooler land condenses. This covers everything with drops of water known as dew. If surface temperatures are below freezing, the water vapour turns into a layer of sparkling ice crystals called frost.

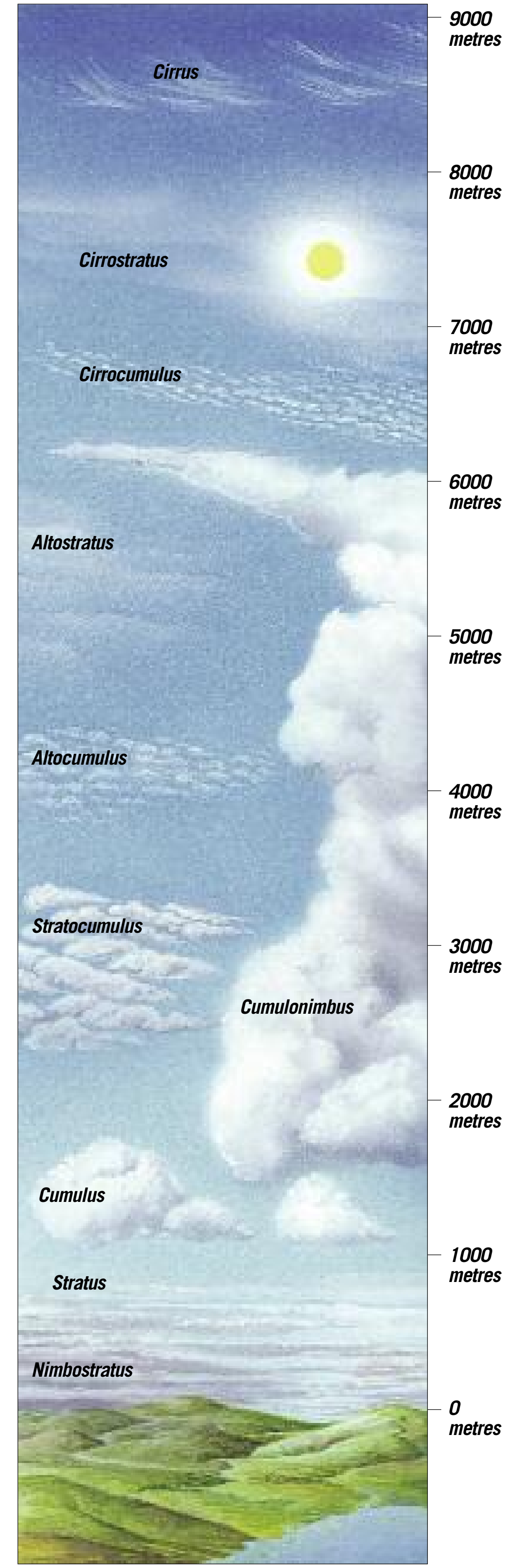
CLOUDS

A cloud is a vast gathering of billions of tiny water droplets, ice crystals or a mixture of both *(below)*. They are so small and light that they float in the air. Clouds form at various heights above the ground and have different shapes *(right)*. The names describe these shapes using a combination of meanings. For example, *cirrus* is wispy or feathery, *stratus* is flat and blanket-like and *cumulus* is puffy and fluffy. Clouds form at ground level, too. We call them mist if they are thin and fog if they are thicker.

It is possible to forecast the weather from observing the different types of clouds. Highest at 10 kilometres and above are cirrus, made of tiny ice crystals. Thin and wispy, they signal fine, dry, settled conditions. Cirrocumulus are small, regular-shaped clouds that look almost like fish scales and make a so-called "mackerel sky". Altostratus and altocumulus form at medium heights and often mean that rain is on the way. Cumulus are the "cotton wool" clouds of a summer's day. Stratus are low clouds that cover the whole sky like a flat, pale grey sheet. Nimbostratus are even lower and usually bring heavy rain or snow.

The biggest and most impressive cloud is the cumulonimbus. It towers 5000 metres or more, with a fluffy white top and flat, grey "anvil" base. It usually brings fierce storms with thunder and lightning.

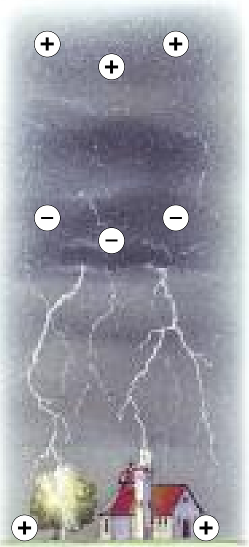




STORMS

THERE ARE many different kinds and sizes of storms. Most involve severe, violent weather with regions of high winds and heavy rain, and perhaps a sudden change in temperature. Some have thunder and lightning. They move across sea and land and may cause great damage and loss of life. Powerful winds blow down buildings and bridges and toss cars and trucks about like toys. Heavy rain or snow causes floods, mudslides or avalanches.

Most storms begin as the Sun heats an area of land or sea and causes warm air to rise rapidly. Storms vary greatly in size and duration. A small tornado or "twister" may have a base just a few metres across and be gone in half an hour. A typical thunder-storm is 5-10 kilometres wide and lasts for a few hours. A large hurricane may be more than 2000 kilometres across and rage on for two or three weeks.

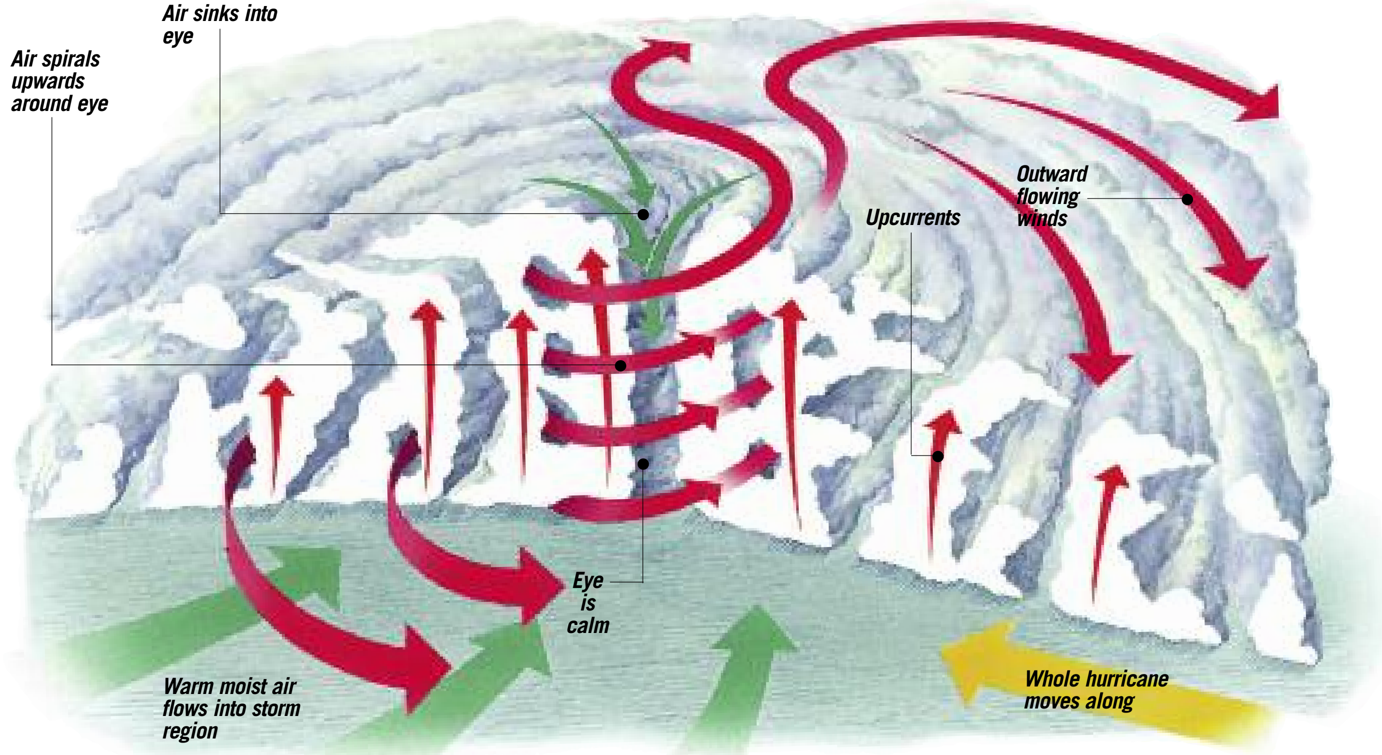


After hot, dry weather some parts of the land become very warm. As cool, moist air blows over them it is heated, rises fast, and cools. Its moisture turns into water droplets or ice crystals which form towering cumulonimbus clouds. The droplets and crystals swirl up and down inside the cloud. As they bump together, they become charged with static electricity. This builds up until it is suddenly released as a great spark of lightning. The heat of the flash makes the air around it expand so fast it makes a boom of thunder.

There are about 50,000 thunderstorms around the world every day. Each second, 100 bolts of lightning flash through clouds or down to the ground. A typical bolt has an electrical force of 100 million volts or more, and lasts one-fifth of a second. Thunderstorms often become more severe over cities because warm, moist air rises from the buildings and adds to their power.

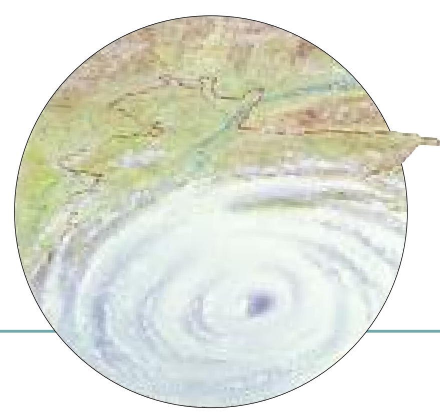
Many storms are parts of cyclones. These are regions or centres of low air pressure around which winds blow. Because of the way the Earth spins around, the winds blow anticlockwise in the northern hemisphere and clockwise in the southern hemisphere. Near the Equator, winds blowing around a tropical cyclone may increase in speed and tighten into a spiral to become a hurricane (known as a typhoon in the Pacific Ocean).

Hurricanes may cause extensive damage. The winds roll cars, tip over planes, blow off roofs and uproot trees. They also whip up great waves that pound the coast.



HURRICANES

Hurricanes begin as warm, moist air is heated by the fierce Sun and rises high into the atmosphere, usually over the western parts of the tropical Atlantic and Pacific Oceans. The rising air sucks in more air, which begins to swirl around in a spiral.



In 1970 a tropical cyclone (hurricane or typhoon) whipped up huge waves that surged over the low-lying mouth of the River Ganges in Bangladesh. Up to half a million people lost their lives.

The moisture in the rising air condenses into clouds and begins to fall as heavy rain. Quickly the hurricane balloons in size and the swirling winds reach 250 kilometres per hour. The spirals of deep cumulonimbus clouds unleash massive downpours, bringing up to half a year's average rainfall in a few hours. The hurricane moves along at 25-50 kilometres per hour as warmed air rises and swirls most powerfully near its centre. Most spills out at the top and is flung to the edges where it sinks. A small portion drifts down at the centre or "eye" of the storm. This is usually 25-50 kilometres across and, amazingly, it is calm with light winds and clear skies.

TORNADOES

The fastest winds occur in the smallest storms—tornadoes. A tornado usually forms at the rear of a thundercloud as the winds swirl at 400 kilometres per hour or more. A twisting column of air grows from the cloud like an upside-down funnel. Its base is only 20-100 metres across. But the winds are so powerful that animals, people, cars and even houses are plucked up into the clouds and then thrown outwards. As the main storm moves at 40-80 kilometres per hour the base may "skip" along the ground, touching down here and there to do most damage. Most tornadoes occur in the Midwest US states, east of the Andes in South America and in eastern India.

A tornado causes a narrow but severe trail of damage 300 kilometres or more in length.

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