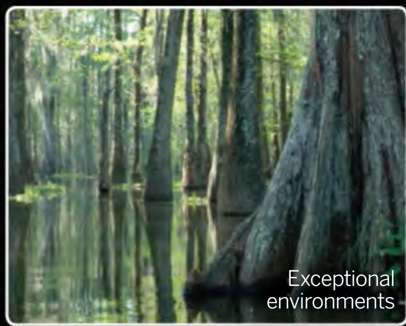
NEW

Climate | Plants | Geography | Geology | Animals


Awesome octopuses


Exceptional environments


Inside a lightning storm


What is coral?

HOW IT WORKS BOOK OF INCREDIBLE EARTH

EVERYTHING YOU NEED TO KNOW ABOUT THE WORLD WE LIVE IN

NEW FACTS & IMAGES INSIDE

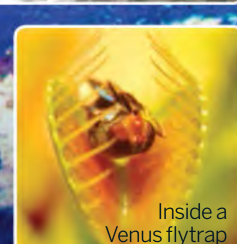

Endangered animals


How coffee grows

Violent volcanoes


Waterfalls explained


Crazy creatures


Inside a Venus flytrap

Welcome to

HOW IT WORKS
BOOK OF

INCREDIBLE EARTH

The planet we live on is a remarkable place, with incredible things happening everywhere, all the time. But have you ever wondered how or why these things occur? How the Earth was created? Why flowers smell? How caves are formed? What causes earthquakes? Why animals hibernate? Or where acid rain comes from? The How It Works Book of Incredible Earth provides answers to all these questions and more as it takes you on a thrilling journey through everything you need to know about the world we live in. Covering the scientific explanations behind weather phenomena, plant life, extreme landscapes and volatile volcanoes, as well as the amazing creatures found throughout the animal kingdom, there is something for everyone to learn about and enjoy. Packed full of fascinating facts, gorgeous photographs and insightful diagrams, the Book of Incredible Earth will show you just how awe-inspiring our planet really is.

HOW IT WORKS
BOOK OF
INCREDIBLE EARTH

Imagine Publishing Ltd
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33 Richmond Hill
Bournemouth
Dorset BH2 6EZ
☎ +44 (0) 1202 586200
Website: www.imagine-publishing.co.uk

Publishing Director
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Printed by
William Gibbons, 26 Planetary Road, Willenhall, West Midlands, WV13 3XT

Cover images courtesy of
DK Images, Thinkstock, Y_Tambe, NASA, A./B./, Larsen, José Braga-Didier Descouens, Scotto Bear, Ballista, Wallace63, JM Luijt

Distributed in the UK, Eire & the Rest of the World by
Marketforce, Blue Fin Building, 110 Southwark Street, London, SE1 0SU
Tel 0203 148 3300
www.marketforce.co.uk

Distributed in Australia by:
Network Services (a division of Bauer Media Group), Level 21 Civic Tower, 66-68 Goulburn Street, Sydney, New South Wales 2000, Australia
Tel +61 2 8667 5288

ISBN 978 1785 460 890

Part of the HOW IT WORKS bookazine series

IMAGINE PUBLISHING

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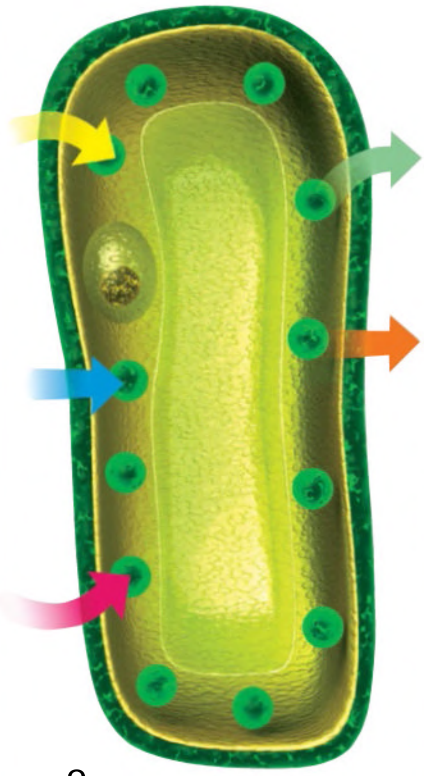

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INCREDIBLE STORY OF EARTH

Ancient and teeming with life, Earth is a truly amazing planet, with a fascinating tale to tell…

Today, science has revealed much about our planet, from how it formed and has evolved over billions of years through to its position in the universe. Indeed, right now we have a clearer picture of Earth than ever before.

And what a terrifying and improbable picture it is. A massive spherical body of metal, rock, liquid and gas suspended perilously within a vast void by an invisible, binding force. It is a body that rotates continuously, is tilted on an axis by 23 degrees and orbits once every 365.256 solar days around a flaming ball of hydrogen 150 million kilometres (93 million miles) away. It is a celestial object that, on face value, is mind-bendingly unlikely.

As a result, the truth about our planet and its history eluded humans for thousands of years. Naturally, as beings that like to know the answers to *how* and *why*, we have come up with many ways to fill in the gaps. The Earth was flat; the Earth was the centre of the universe; and, of course, all manner of complex and fiercely defended beliefs about creation.

But then in retrospect, who could have ever guessed that our planet formed from specks of dust and mineral grains in a cooling gas cloud of a solar nebula? That the spherical Earth consists of a series of fluid elemental layers and plates around an iron-rich molten core? Or that our world is over 4.5 billion years old and counting? Only some of the brightest minds over many millennia could grant an insight into these geological realities.

While Earth may only be the fifth biggest planet in our Solar System, it is by far the most awe-inspiring. Perhaps most impressive of all, it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang. Here, we celebrate our world in all its glory, charting its journey from the origins right up to the present and what lies ahead.

"Earth is awe-inspiring… it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang"

From dust to planet

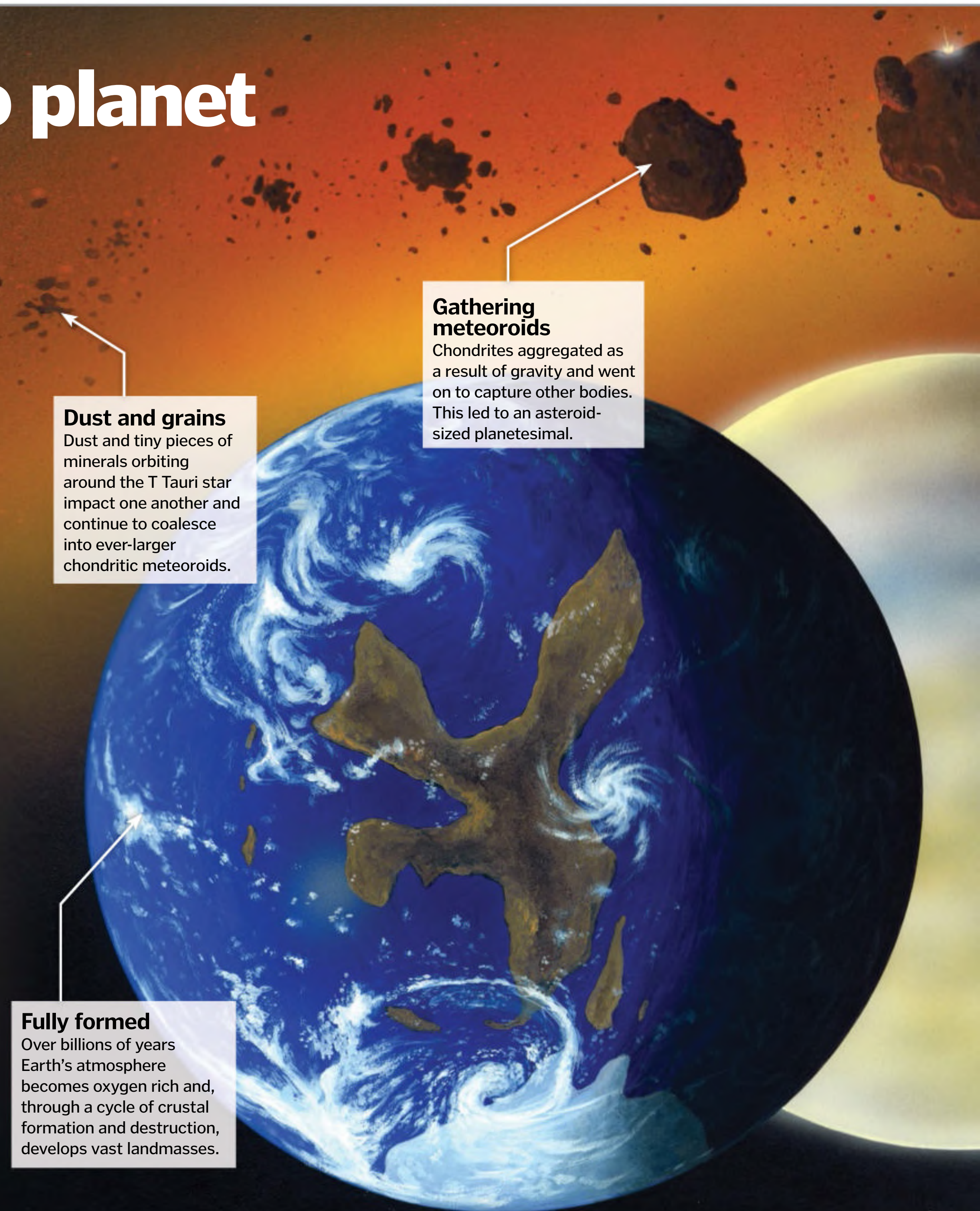
To get to grips with how the Earth formed, first we need to understand how the Solar System as a whole developed – and from what. Current evidence suggests that the beginnings of the Solar System lay some 4.6 billion years ago with the gravitational collapse of a fragment of a giant molecular cloud.

In its entirety this molecular cloud – an interstellar mass with the size and density to form molecules like hydrogen – is estimated to have been 20 parsecs across, with the fragment just five per cent of that. The gravitationally induced collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today and consisting primarily of hydrogen, helium and lithium gases generated by Big Bang nucleosynthesis (BBN).

At the heart of this pre-solar nebula, intense gravity – along with supernova-induced over-density within the core, high gas pressures, nebula rotation (caused by angular momentum) and fluxing magnetic fields – in conjunction caused it to contract and flatten into a protoplanetary disc. A hot, dense protostar formed at its centre, surrounded by a 200-astronomical-unit cloud of gas and dust.

It is from this solar nebula's protoplanetary disc that Earth and the other planets emerged. While the protostar would develop a core temperature and pressure to instigate hydrogen fusion over a period of approximately 50 million years, the cooling gas of the disc would produce mineral grains through condensation, which would amass into tiny meteoroids. The latest evidence indicates that the oldest of the meteoroidal material formed about 4.56 billion years ago.

As the dust and grains were drawn together to form ever-larger bodies of rock (first chondrules, then chondritic meteoroids), through continued accretion and collision-induced compaction, planetesimals and then protoplanets appeared – the latter being the precursor to all planets in the Solar System. In terms of the formation of Earth, the joining of multiple planetesimals meant it developed a gravitational attraction powerful enough to sweep up additional particles, rock fragments and meteoroids as it rotated around the Sun. The composition of these materials would, as we shall see over the page, enable the protoplanet to develop a superhot core.



"The collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today"

The history of Earth

Follow the major milestones in our planet's epic development
***(BYA = billion years ago)**

13.8 BYA*
Big Bang fallout
Nucleosynthesis as a result of the Big Bang leads to the gradual formation of chemical elements on a huge scale.

4.6 BYA
New nebula
A fragment of a giant molecular cloud experiences a gravitational collapse and becomes a pre-solar nebula.

Origins of the Moon

Today most scientists believe Earth's sole satellite formed off the back of a collision event that occurred roughly 4.53 billion years ago. At this time, Earth was in its early development stage and had been impacted numerous times by planetesimals and other rocky bodies – events that had shock-heated the planet and brought about the expansion of its core.

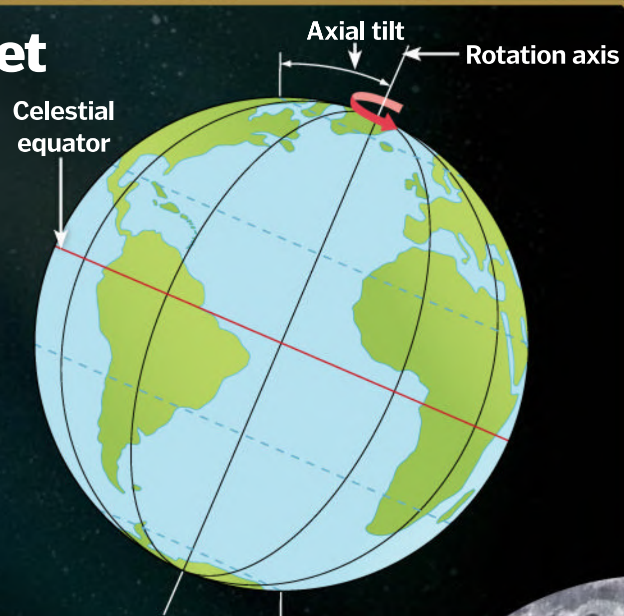
One collision, however, seems to have been a planet-sized body around the size of Mars – dubbed Theia. Basic models of impact data suggest Theia struck Earth at an oblique angle, with its iron core sinking into the planet, while its mantle, as well as that of Earth, was largely hurled into orbit. This ejected material – which is estimated to be roughly 20 per cent of Theia's total mass – went on to form a ring of silicate material around Earth and then coalesce within a relatively short period (ranging from a couple of months up to 100 years) into the Moon.

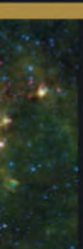
Why does our planet have an axial tilt?

Earth's axial tilt (obliquity), which is at 23.4 degrees in respect to the planet's orbit currently, came about approximately 4.5 billion years ago through a series of large-scale impacts from planetesimals and other large bodies (like Theia). These collisions occurred during the early stages of the planet's development and generated forces great enough to disrupt Earth's alignment, while also producing a vast quantity of debris.

While our world's obliquity might be 23.4 degrees today, this is by no means a fixed figure, with it varying over long periods due to the effects of precession and orbital resonance.

For example, for the past 5 million years, the axial tilt has varied from 22.2-24.3 degrees, with a mean period lasting just over 41,000 years. Interestingly, the obliquity would be far more variable if it were not for the presence of the Moon, which has a stabilising effect.





4.57 BYA
Protostar
Several million years later, the precursor to the Sun (a T Tauri-type star) emerges at the heart of the nebula.

4.56 BYA
Disc develops
Around the T Tauri star a protoplanetary disc of dense gas begins to form and then gradually cools.

4.54 BYA
Planet
As dust and rock gather, Earth becomes a planet, with planetary differentiation leading to the core's formation.

4.53 BYA
Birth of the Moon
Theia, a Mars-sized body, impacts with the Earth. The resultingdebris rises into orbit and will coalesce into the Moon.

Earth's structure

As the mass of the Earth continued to grow, so did its internal pressure. This in partnership with the force of gravity and 'shock heating' – see boxout opposite for an explanation – caused the heavier metallic minerals and elements within the planet to sink to its centre and melt. Over many years, this resulted in the development of an iron-rich core and, consequently, kick-started the interior convection which would transform our world.

Once the centre of Earth was hot enough to convect, planetary differentiation began. This is the process of separating out different elements of a planetary body through both physical and chemical actions. Simply put, the denser materials of the body sink towards the core and the less dense rise towards the surface. In Earth's case, this would eventually lead to the distinct layers of inner core, outer core, mantle and crust – the latter developed largely through outgassing.

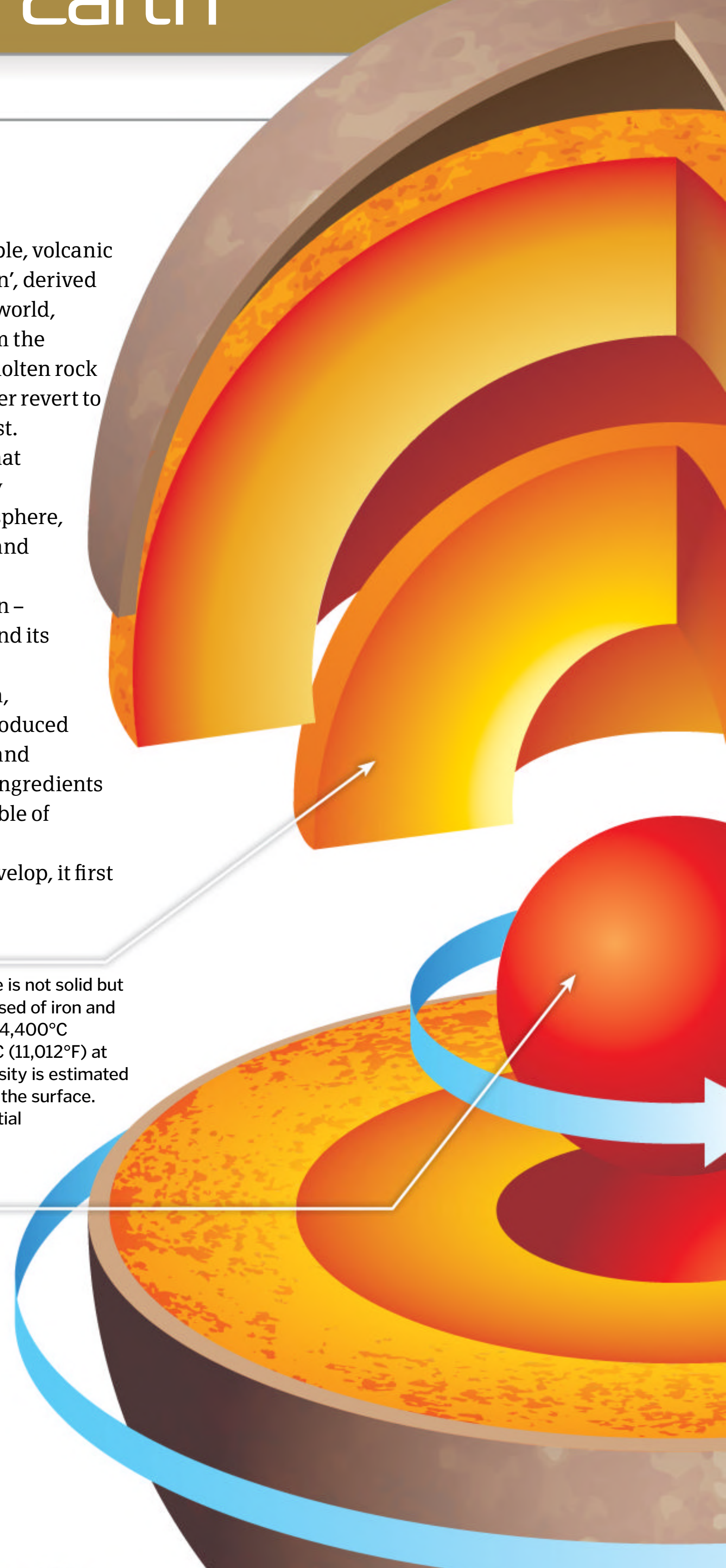
Outgassing in Earth occurred when volatile substances located in the lower mantle began to melt approximately 4.3 billion years ago. This partial melting of the interior caused chemical separation, with resulting gases rising up through the mantle to the surface, condensing and then crystallising to form the first crustal layer. This original crust proceeded to go through a period of recycling back into the mantle through convection currents, with successive outgassing gradually forming thicker and more distinct crustal layers.

The precise date when Earth gained its first complete outer crust is unknown, as due to the recycling process only incredibly small parts of it remain today. Certain evidence, however, indicates that a proper crust was formed relatively early in the Hadean eon (4.6-4 billion years ago). The Hadean eon on Earth was characterised by a highly unstable, volcanic surface (hence the name 'Hadean', derived from the Greek god of the underworld, Hades). Convection currents from the planet's mantle would elevate molten rock to the surface, which would either revert to magma or harden into more crust.

Scientific evidence suggests that outgassing was also the primary contributor to Earth's first atmosphere, with a large region of hydrogen and helium escaping – along with ammonia, methane and nitrogen – considered the main factor behind its initial formation.

By the close of the Hadean eon, planetary differentiation had produced an Earth that, while still young and inhospitable, possessed all the ingredients needed to become a planet capable of supporting life.

But for anything organic to develop, it first needed water…



Outer core
Unlike the inner core, Earth's outer core is not solid but liquid, due to less pressure. It is composed of iron and nickel and ranges in temperature from 4,400°C (7,952°F) at its outer ranges to 6,100°C (11,012°F) at its inner boundary. As a liquid, its viscosity is estimated to be ten times that of liquid metals on the surface. The outer core was formed by only partial melting of accreted metallic elements.

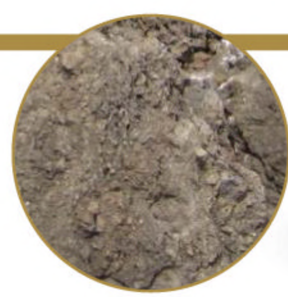
Inner core
The heaviest minerals and elements are located at the centre of the planet in a solid, iron-rich heart. The inner core has a radius of 1,220km (760mi) and has the same surface temperature as the Sun (around 5,430°C/9,800°F). The solid core was created due to the effects of gravity and high pressure during planetary accretion.

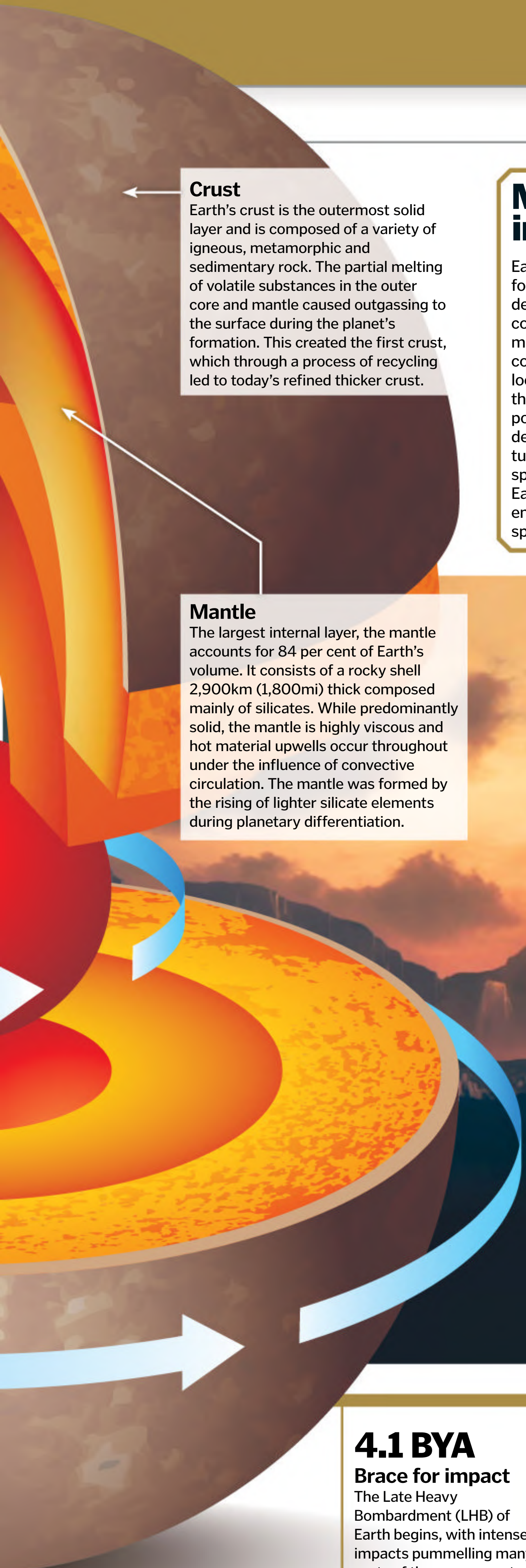
"Outgassing occurred when volatile substances in the lower mantle began to melt 4.3 billion years ago"

4.4 BYA
Surface hardens
Earth begins developing its progenitor crust. This is constantly recycled and built up through the Hadean eon.

4.3 BYA
Early atmosphere
Outgassing and escaping gases from surface volcanism form the first atmosphere around the planet. It is nitrogen heavy.

4.28 BYA
Ancient rocks
A number of rocks have been found in northern Québec, Canada, that date from this period. They are volcanic deposits.





Crust

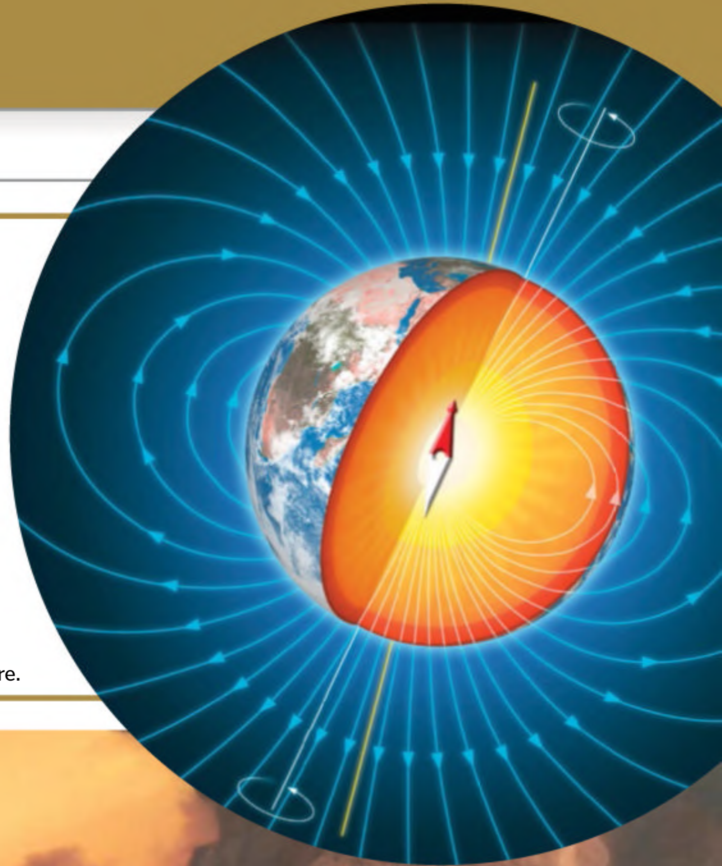
Earth's crust is the outermost solid layer and is composed of a variety of igneous, metamorphic and sedimentary rock. The partial melting of volatile substances in the outer core and mantle caused outgassing to the surface during the planet's formation. This created the first crust, which through a process of recycling led to today's refined thicker crust.

Mantle

The largest internal layer, the mantle accounts for 84 per cent of Earth's volume. It consists of a rocky shell 2,900km (1,800mi) thick composed mainly of silicates. While predominantly solid, the mantle is highly viscous and hot material upwells occur throughout under the influence of convective circulation. The mantle was formed by the rising of lighter silicate elements during planetary differentiation.

Magnetic field in the making

Earth's geomagnetic field began to form as soon as the young planet developed an outer core. The outer core of Earth generates helical fluid motions within its electrically conducting molten iron due to current loops driven by convection. As a result, the moment that convection became possible in Earth's core it began to develop a geomagnetic field – which in turn was amplified by the planet's rapid spin rate. Combined, these enabled Earth's magnetic field to permeate its entire body as well as a small region of space surrounding it – the magnetosphere.



Shock heating explained

During the accretion to its present size, Earth was subjected to a high level of stellar impacts by space rocks and other planetesimals too. Each of these collisions generated the effect of shock heating, a process in which the impactor and resultant shock wave transferred a great deal of energy into the forming planet. For meteorite-sized bodies, the vast majority of this energy was transferred across the planet's surface or radiated back off into space, however in the case of much larger planetesimals, their size and mass allowed for deeper penetration into the Earth. In these events the energy was distributed directly into the planet's inner body, heating it well beneath the surface. This heat influx contributed to heavy metallic fragments deep underground melting and sinking towards the core.

4.1 BYA
Brace for impact
The Late Heavy Bombardment (LHB) of Earth begins, with intense impacts pummelling many parts of the young crust.

4 BYA
Archean
The Hadean eon finally comes to an end and the new Archean period begins.

3.9 BYA
Ocean origins
Earth is now covered with liquid oceans due to the release of trapped water from the mantle and from asteroid/comet deposition.

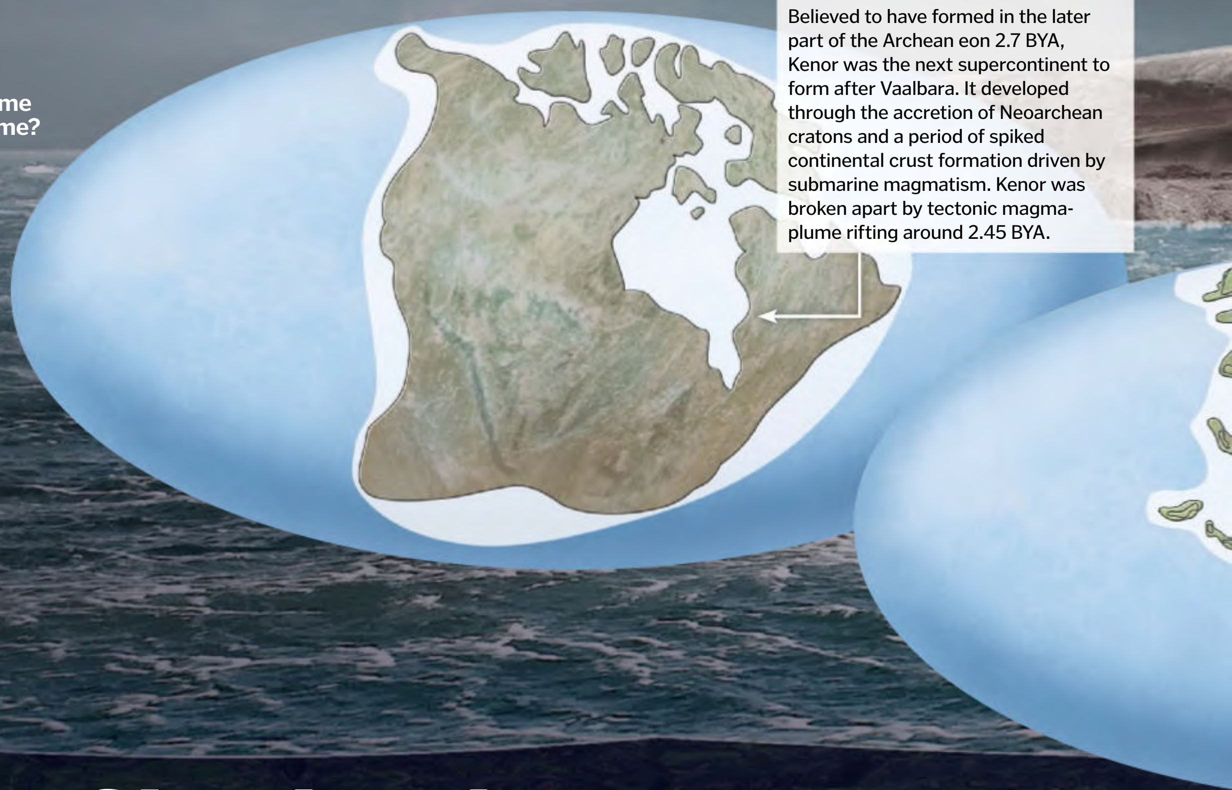
3.6 BYA
Supercontinent
Our world's very first supercontinent, Vaalbara, begins to emerge from a series of combining cratons.

Supercontinent development

Where did the earliest landmasses come from and how did they change over time?

It started with Vaalbara…

Approximately 3.6 billion years ago, Earth's first supercontinent – Vaalbara – formed through the joining of several large continental plates. Data derived from parts of surviving cratons from these plates – eg the South African Kaapvaal and Australian Pilbara; hence 'Vaal-bara' – show similar rock records through the Archean eon, indicating that, while now separated by many miles of ocean, they once were one. Plate tectonics, which were much fiercer at this time, drove these plates together and also were responsible for separating them 2.8 billion years ago.



Kenor

Believed to have formed in the later part of the Archean eon 2.7 BYA, Kenor was the next supercontinent to form after Vaalbara. It developed through the accretion of Neoarchean cratons and a period of spiked continental crust formation driven by submarine magmatism. Kenor was broken apart by tectonic magma-plume rifting around 2.45 BYA.

Formation of land and sea

Current scientific evidence suggests that the formation of liquid on Earth was, not surprisingly, a complex process. Indeed, when you consider the epic volcanic conditions of the young Earth through the Hadean eon, it's difficult to imagine exactly how the planet developed to the extent where today 70 per cent of its surface is covered with water. The answer lies in a variety of contributory processes, though three can be highlighted as pivotal.

The first of these was a drop in temperature throughout the late-Hadean and Archean eons. This cooling caused outgassed volatile substances to form an atmosphere around the planet – see the opposite boxout for more details – with sufficient pressure for retaining liquids. This outgassing also transferred a large quantity of water that was trapped in the planet's internal accreted material to the surface. Unlike previously, now pressurised and trapped by the developing atmosphere, it began to condense and settle on the surface rather than evaporate into space.

The second key liquid-generating process was the large-scale introduction of comets and water-rich meteorites to the Earth during its formation and the Late Heavy Bombardment period. These frequent impact events would cause the superheating and vaporisation of many trapped minerals, elements and ices, which then would have been adopted by the atmosphere, cooled over time, condensed and re-deposited as liquid on the surface.

The third major contributor was photodissociation – which is the separation of substances through the energy of light. This process caused water vapour in the developing upper atmosphere to separate into molecular hydrogen and molecular oxygen, with the former escaping the planet's influence. In turn, this led to an increase in the partial pressure of oxygen on the planet's surface, which through its interactions with surface materials gradually elevated vapour pressure to a level where yet more water could form.

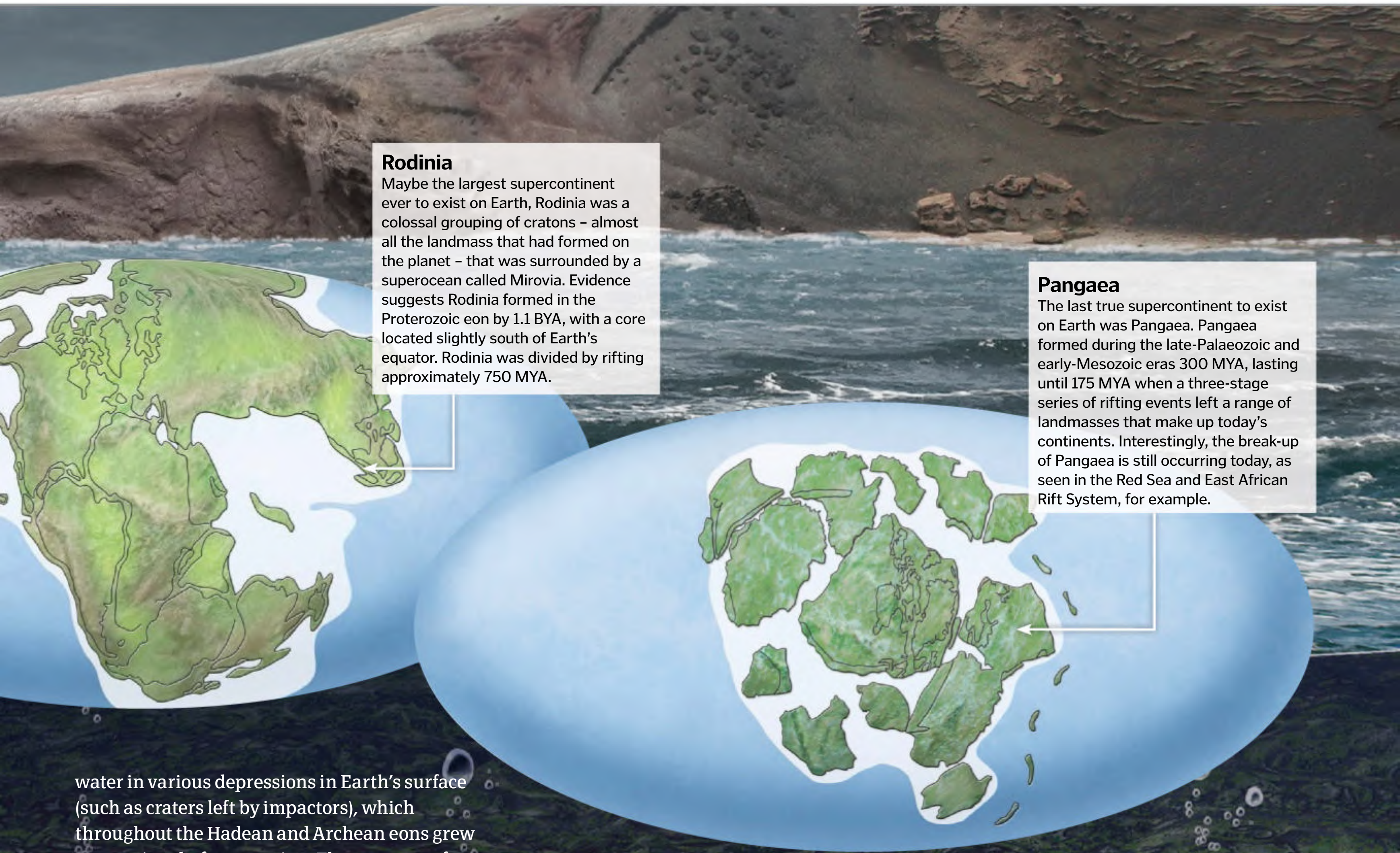
The combined result of these processes – as well as others – was a slow buildup of liquid

> *"This erosion of Earth's crustal layer aided the distinction of cratons – the base for some of the first continental landmasses"*

3.5 BYA
Early bacteria
Evidence suggests that the earliest primitive life forms – bacteria and blue-green algae – begin to emerge in Earth's growing oceans at this time.

3.3 BYA
Hadean discovery
Sedimentary rocks have been found in Australia that date from this time. They contain zircon grains with isotopic ages between 4.4 and 4.2 BYA.

2.9 BYA
Island boom
The formation of island arcs and oceanic plateaux undergoes a dramatic increase that will last for about another 200 million years.



Rodinia
Maybe the largest supercontinent ever to exist on Earth, Rodinia was a colossal grouping of cratons – almost all the landmass that had formed on the planet – that was surrounded by a superocean called Mirovia. Evidence suggests Rodinia formed in the Proterozoic eon by 1.1 BYA, with a core located slightly south of Earth's equator. Rodinia was divided by rifting approximately 750 MYA.

Pangaea
The last true supercontinent to exist on Earth was Pangaea. Pangaea formed during the late-Palaeozoic and early-Mesozoic eras 300 MYA, lasting until 175 MYA when a three-stage series of rifting events left a range of landmasses that make up today's continents. Interestingly, the break-up of Pangaea is still occurring today, as seen in the Red Sea and East African Rift System, for example.

water in various depressions in Earth's surface (such as craters left by impactors), which throughout the Hadean and Archean eons grew to vast sizes before merging. The presence of extensive carbon dioxide in the atmosphere also caused the acidulation of these early oceans, with their acidity allowing them to erode parts of the surface crust and so increase their overall salt content. This erosion of Earth's crustal layer also aided the distinction of cratons – stable parts of the planet's continental lithosphere – which were the base for some of the first continental landmasses.

With liquid on the surface, a developing atmosphere, warm but cooling crust and continents starting to materialise, by the mid-Archean (approximately 3.5 billion years ago) conditions were ripe for life, which we look at in depth over the next couple of pages.

A closer look at Earth's evolving atmosphere

Earth has technically had three atmospheres throughout its existence. The first formed during the planet's accretion period and consisted of atmophile elements, such as hydrogen and helium, acquired from the solar nebula. This atmosphere was incredibly light and unstable and deteriorated quickly – in geological terms – by solar winds and heat emanating from Earth. The second atmosphere, which developed through the late-Hadean and early-Archean eons due to impact events and outgassing of volatile gases through volcanism, was anoxic – with high levels of greenhouse gases like carbon dioxide and very little oxygen. This second atmosphere later evolved during the mid-to-late-Archean into the third oxygen-rich atmosphere that is still present today. This oxygenation of the atmosphere was driven by rapidly emerging oxygen-producing algae and bacteria on the surface – Earth's earliest forms of life.

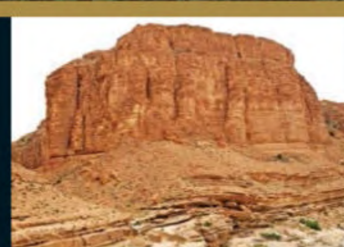
2.8 BYA
Breakup
After fully forming circa 3.1 BYA, Vaalbara begins to fragment due to the asthenosphere overheating.

2.5 BYA
Proterozoic
The Archean eon finally draws to a close after roughly 1.5 billion years, leading to the beginning of the Proterozoic era.

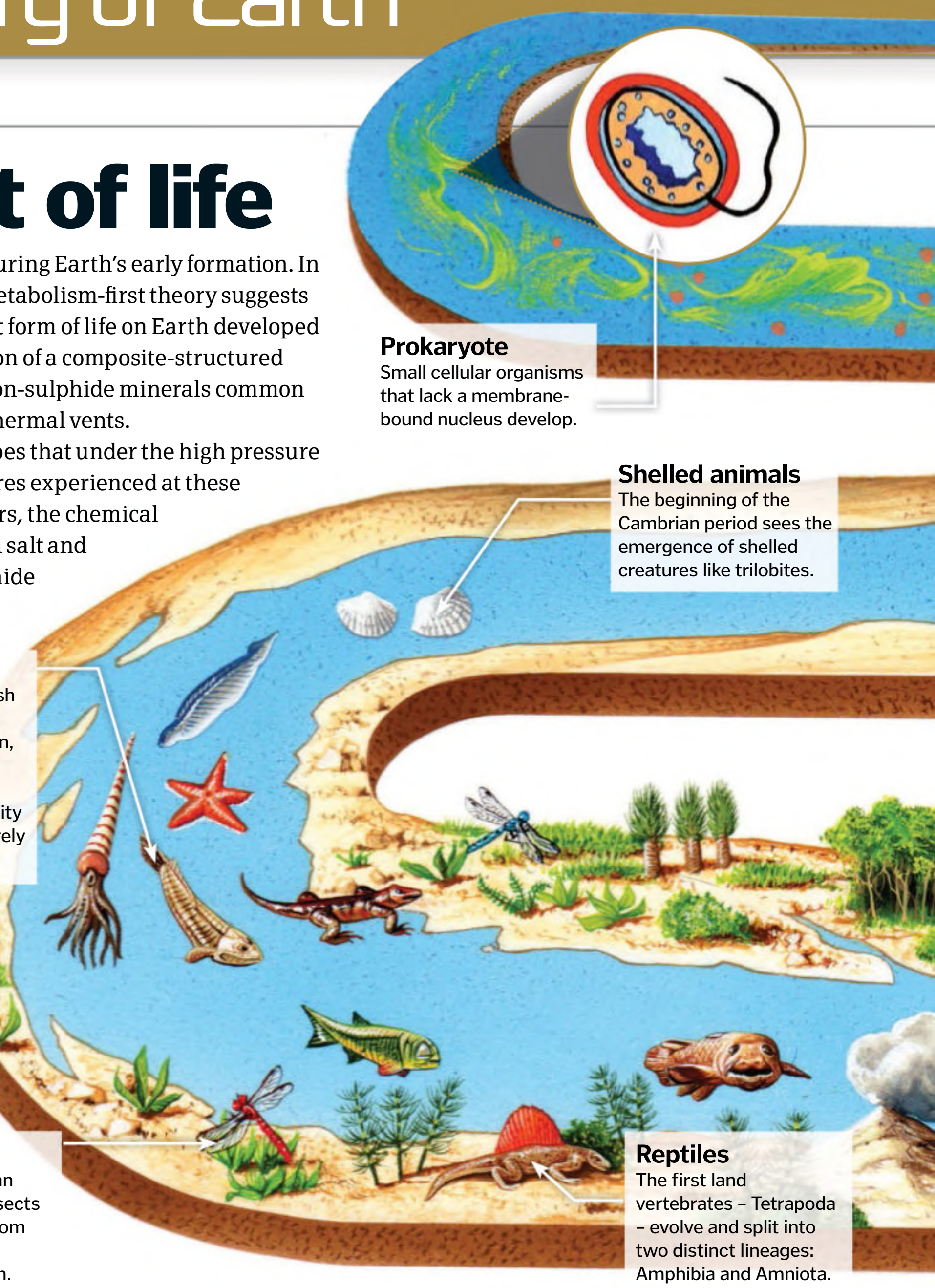
2.4 BYA
More oxygen
The Earth's atmosphere evolves into one that is rich in oxygen due to cyanobacterial photosynthesis.

2.1 BYA
Eukaryotes
Eukaryotic cells appear. These most likely developed by prokaryotes consuming each other via phagocytosis.

1.8 BYA
Red beds
Many of Earth's red beds – ferric oxide-containing sedimentary rocks – date from this period, indicating that an oxidising atmosphere was present.



The development of life



Of all the aspects of Earth's development, the origins of life are perhaps the most complex and controversial. That said, there's one thing upon which the scientific community as a whole agrees: that according to today's evidence, the first life on Earth would have been almost inconceivably small-scale.

There are two main schools of thought for the trigger of life: an RNA-first approach and a metabolism-first approach. The RNA-first hypothesis states that life began with self-replicating ribonucleic acid (RNA) molecules, while the metabolism-first approach believes it all began with an ordered sequence of chemical reactions, ie a chemical network.

Ribozymes are RNA molecules that are capable of both triggering their own replication and also the construction of proteins – the main building blocks and working molecules in cells. As such, ribozymes seem good candidates for the starting point of all life. RNA is made up of nucleotides, which are biological molecules composed of a nucleobase (a nitrogen compound), five-carbon sugar and phosphate groups (salts). The presence of these chemicals and their fusion is the base for the RNA-world theory, with RNA capable of acting as a less stable version of DNA.

This theory begs two questions: one, were these chemicals present in early Earth and, two, how were they first fused? Until recently, while some success has been achieved in-vitro showing that activated ribonucleotides can polymerise (join) to form RNA, the key issue in replicating this formation was showing how ribonucleotides could form from their constituent parts (ie ribose and nucleobases).

Interestingly in a recent experiment reported in *Nature*, a team showed that pyrimidine ribonucleobases can be formed in a process that bypasses the fusion of ribose and nucleobases, passing instead through a series of other processes that rely on the presence of other compounds, such as cyanoacetylene and glycolaldehyde – which are believed to have been present during Earth's early formation. In contrast, the metabolism-first theory suggests that the earliest form of life on Earth developed from the creation of a composite-structured organism on iron-sulphide minerals common around hydrothermal vents.

The theory goes that under the high pressure and temperatures experienced at these deep-sea geysers, the chemical coupling of iron salt and hydrogen sulphide produced a composite structure with a mineral base and a metallic centre (such as iron or zinc).

The presence of this metal, it is theorised, triggered the conversion of inorganic carbon into organic compounds and kick-started constructive metabolism (forming new molecules from a series of simpler units). This process became self-sustaining by the generation of a sulphur-dependent metabolic cycle. Over time the cycle expanded and became more efficient, while simultaneously producing ever-more complex compounds, pathways and reaction triggers.

As such, the metabolism-first approach describes a system in which no cellular components are necessary to form life; instead, it started with a compound such as pyrite – a mineral which was abundant in early Earth's oceans. When considering that the oceans during the Hadean and early-Archean eons were extremely acidic – and that the planet's overall temperature was still very high –

1.4 BYA
Fungi
The earliest signs of fungi according to current fossil evidence suggest they developed here in the Proterozoic.

1.2 BYA
Reproduction
With the dawn of sexual reproduction, the rate of evolution increases rapidly and exponentially.

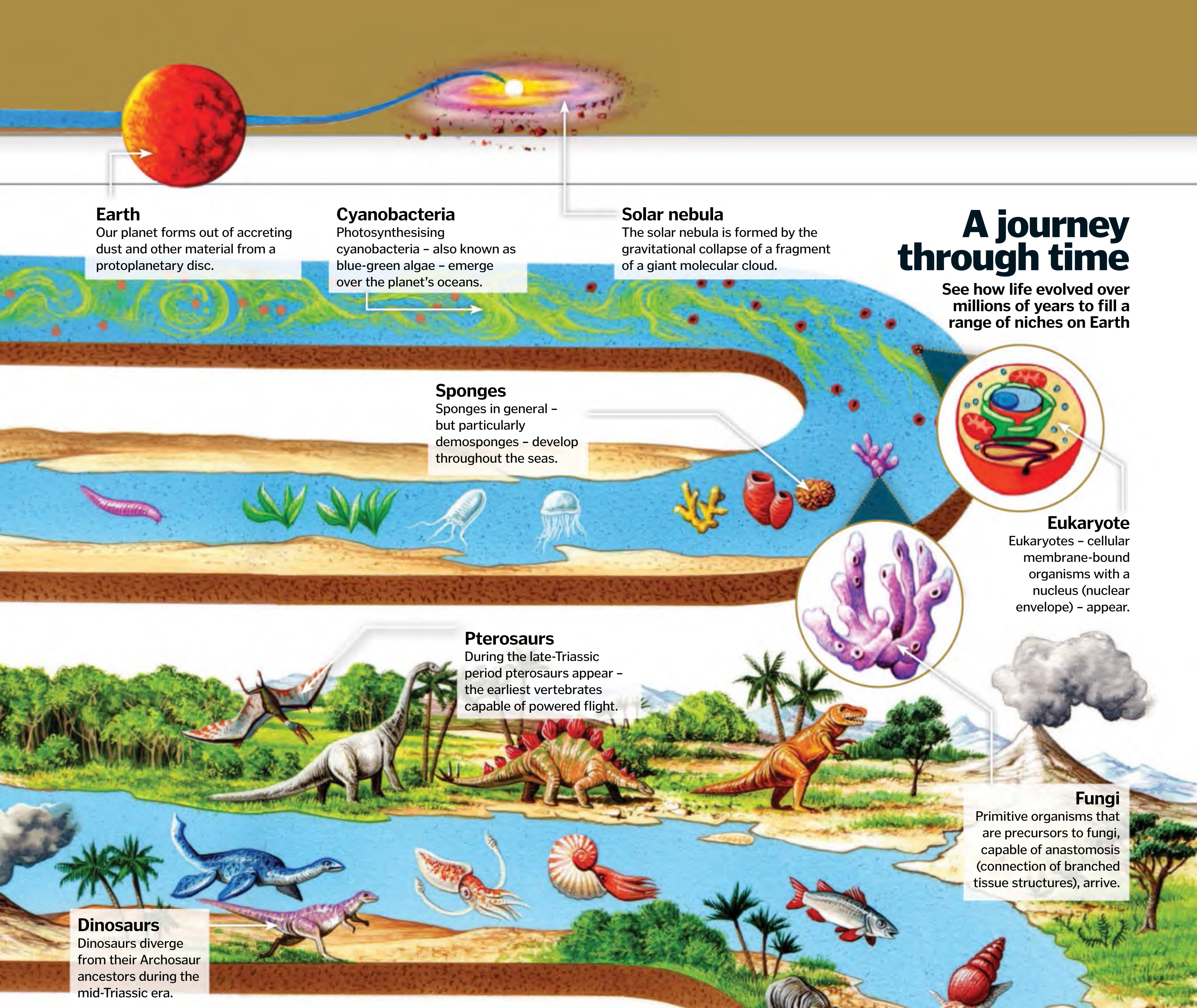
542 MYA
Explosion
The Cambrian explosion occurs – a rapid diversification of organisms that leads to the development of most modern phyla (groups).

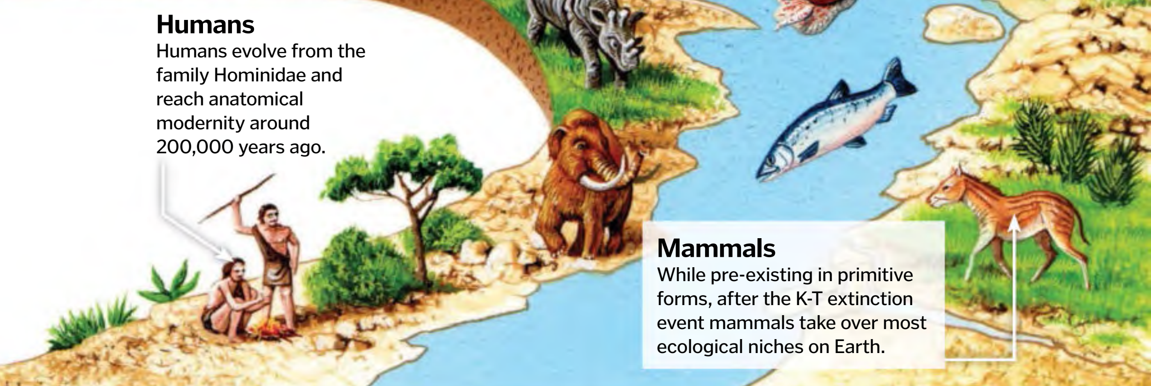
541 MYA
Phanerozoic
The Proterozoic eon finally draws to a close and the current geologic eon – the Phanerozoic – commences.

106 MYA
Spinosaurus
The largest theropod dinosaur ever to live on Earth, weighing up to an astonishing 20 tons, emerges at this time.

A journey through time

See how life evolved over millions of years to fill a range of niches on Earth





a model similar to the iron-sulphur world type is plausible, if not as popular as the RNA theory.

There are other scientific theories explaining the origins of life – for example, some think organic molecules were deposited on Earth via a comet or asteroid – but all return to the notion that early life was tiny. It's also accepted that life undertook a period of fierce evolution in order to adapt to the ever-changing Earth. But without the right initial conditions, we might never have evolved to call this planet home.

65.5 MYA
K-T event
The Cretaceous-Palaeogene extinction event occurs, wiping out half of all animal species on Earth, including the dinosaurs.

55 MYA
Birds take off
Bird groups begin to diversify dramatically, with many species still around today – such as parrots.

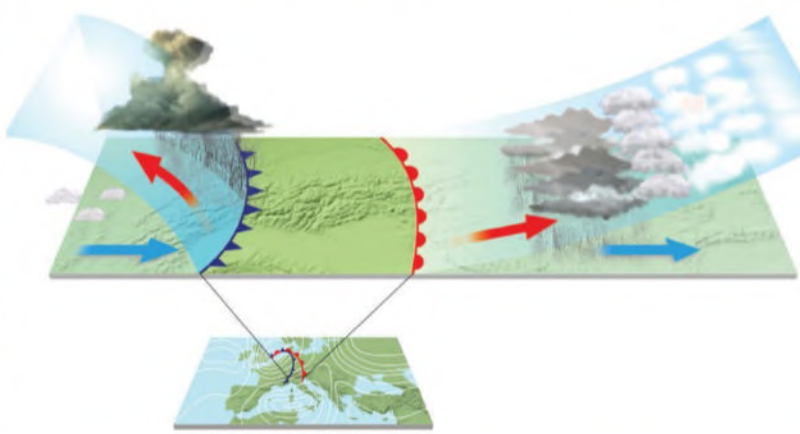
2 MYA
Homo genus
The first members of the genus Homo, of which humans are members appear in the fossil record.

350,000 years ago
Neanderthal
Neanderthals evolve and spread across Eurasia. They become extinct 220,000 years later.

200,000 years ago
First human
Anatomically modern humans evolve in Africa; 150,000 years later they start to move farther afield.

WEATHER WONDERS

How do we predict the weather?
036



Firestorms explained
042

026
Why does rain smell?

© Thinkstock; SPL

50 AMAZING FACTS ABOUT WEATHER

How many lightning strikes are there each second globally? 100

How high is a typical cloud? 2,000m (6,550ft)

How many thunderstorms break out worldwide at any given moment? 2,000

How hot is the Sun? The core is around 15,000,000°C (27,000,000°F)

We answer your burning questions about the incredible variety and awesome power of the planet's most intriguing climatic phenomena

We like to be able to control everything, but weather – those changes in the Earth's atmosphere that spell out rain, snow, wind, heat, cold and more – is one of those things that is just beyond our power. Maybe that's why a cloudless sunny day or a spectacular display of lightning both have the ability to delight us. Meteorologists have come a long way in their capability to predict weather patterns, track changes and forecast what we can expect to see when we leave our homes each day. But they're not always right. It's not their fault; we still don't completely understand all of the processes that contribute to changes in the weather.

Here's what we do know: all weather starts with contrasts in air temperature and moisture in the atmosphere. Seems simple, right? Not exactly. Temperature and moisture vary greatly depending on a huge number of factors, like the Earth's rotation, where you're located, the angle at which the Sun is hitting it at any given time, your elevation, and your proximity to the ocean. These all lead to changes in atmospheric pressure. The atmosphere is chaotic, meaning that a very small, local change can have a far-reaching effect on much larger weather systems. That's why it's especially tough to make accurate forecasts more than a few days in advance.

Is there a way to tell how close a storm is?

Lightning and thunder always go together, because thunder is the sound that results from lightning. Lightning bolts are close to 30,000 degrees Celsius (54,000 degrees Fahrenheit), so the air in the atmosphere that they zip through becomes superheated and quickly expands. That sound of expansion is called thunder, and on average it's about 120 decibels (a chainsaw is 125, for reference). Sometimes you can see lightning but not hear the thunder, but that's only because the lightning is too far away for you to hear it. Because light travels faster than sound, you always see lightning before hearing it.

1. Start the count
When you see a flash of lightning, start counting. A stopwatch would be the most accurate way.

2. Five seconds
The rule is that for every five seconds, the storm is roughly 1.6 kilometres (one mile) away.

3. Do the maths
Stop counting after the thunder and do the maths. If the storm's close, take the necessary precautions.

Lightning occurs most often in hot, summer-like climates

Where are you most likely to get hit by lightning?

Generally lightning strikes occur most often during the summer. So the place where lightning strikes occur the most is a place where summer-like weather prevails year-round: Africa. Specifically, it's the village of Kifuka in the Democratic Republic of Congo. Each year, it gets more than 150 lightning strikes within one square kilometre. Roy Sullivan didn't live in Kifuka but he still managed to get struck by lightning seven separate times while working as a park ranger in the Shenandoah National Park in the USA. The state in which he lived – Virginia – does have a high incidence of lightning strikes per year, but since Sullivan spent his job outdoors in the mountains, his risk was greater due to his exposure.

What is the fastest wind ever recorded, not in a tornado?

407km/h (253mph)

Gusts recorded during Cyclone Olivia in 1996

Is it possible to stop a hurricane?

We can't control the weather… or can we? Some scientists are trying to influence the weather through cloud seeding, or altering the clouds' processes by introducing chemicals like solid carbon dioxide (aka dry ice), calcium chloride and silver iodide. It has been used to induce rainfall during times of drought as well as to prevent storms.

CAN IT REALLY RAIN ANIMALS?

Animals have fallen from the sky before, but it's not actually 'raining' them. More likely strong winds have picked up large numbers of critters from ponds or other concentrations – perhaps from tornadoes or downspouts – then moved and deposited them. Usually the animals in question are small and live in or around water for a reason.

DOES FREAK WEATHER CONFUSE WILDLIFE?

A short period of unseasonable weather isn't confusing, but a longer one can be. For example, warm weather in winter may make plants bloom too early or animals begin mating long before spring actually rolls around.

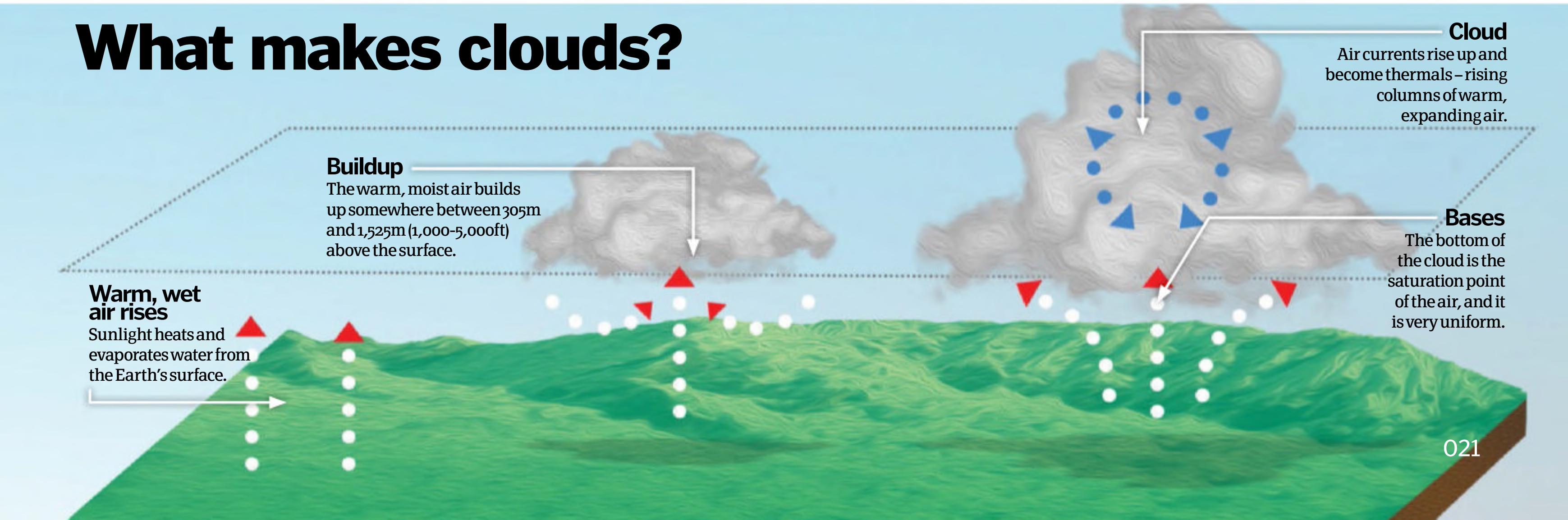
IS THE 'RED SKY AT NIGHT, SHEPHERD'S DELIGHT' SAYING TRUE?

The rest of the proverb is, 'Red sky at morning, shepherd's warning'. A red sky means you could see the red wavelength of sunlight reflecting off clouds. At sunrise, it was supposed to mean the clouds were coming towards you so rain might be on the way. If you saw these clouds at sunset, the risk had already passed. Which is 'good' or 'bad' is a matter of opinion.

WHAT ARE SNOW DOUGHNUTS?

Snow doughnuts, or rollers, are a rare natural phenomenon. If snow falls in a clump, gravity can pull it down over itself as it rolls. Normally it would collapse, but sometimes a hole forms. Wind and temperature also play key roles.

What makes clouds?



WHAT ARE KATABATIC WINDS?

From the Greek for 'going downhill', a katabatic wind is also known as a drainage wind. It carries dense air down from high elevations, such as mountain tops, down a slope thanks to gravity. This is a common occurrence in places like Antarctica's Polar Plateau, where incredibly cold air on top of the plateau sinks and flows down through the rugged landscape, picking up speed as it goes. The opposite of katabatic winds are called anabatic, which are winds that blow *up* a steep slope.

DOES IT EVER SNOW IN AFRICA?

Several countries in Africa see snow – indeed, there are ski resorts in Morocco and regular snowfall in Tunisia. Algeria and South Africa also experience snowfall on occasion. It once snowed in the Sahara, but it was gone within 30 minutes. There's even snowfall around the equator if you count the snow-topped peaks of mountains.

WHAT COLOUR IS LIGHTNING?

Usually lightning is white, but it can be every colour of the rainbow. There are a lot of factors that go into what shade the lightning will appear, including the amount of water vapour in the atmosphere, whether it's raining and the amount of pollution in the air. A high concentration of ozone, for example, can make lightning look blue.

WHY DO SOME CITIES HAVE THEIR OWN MICROCLIMATE?

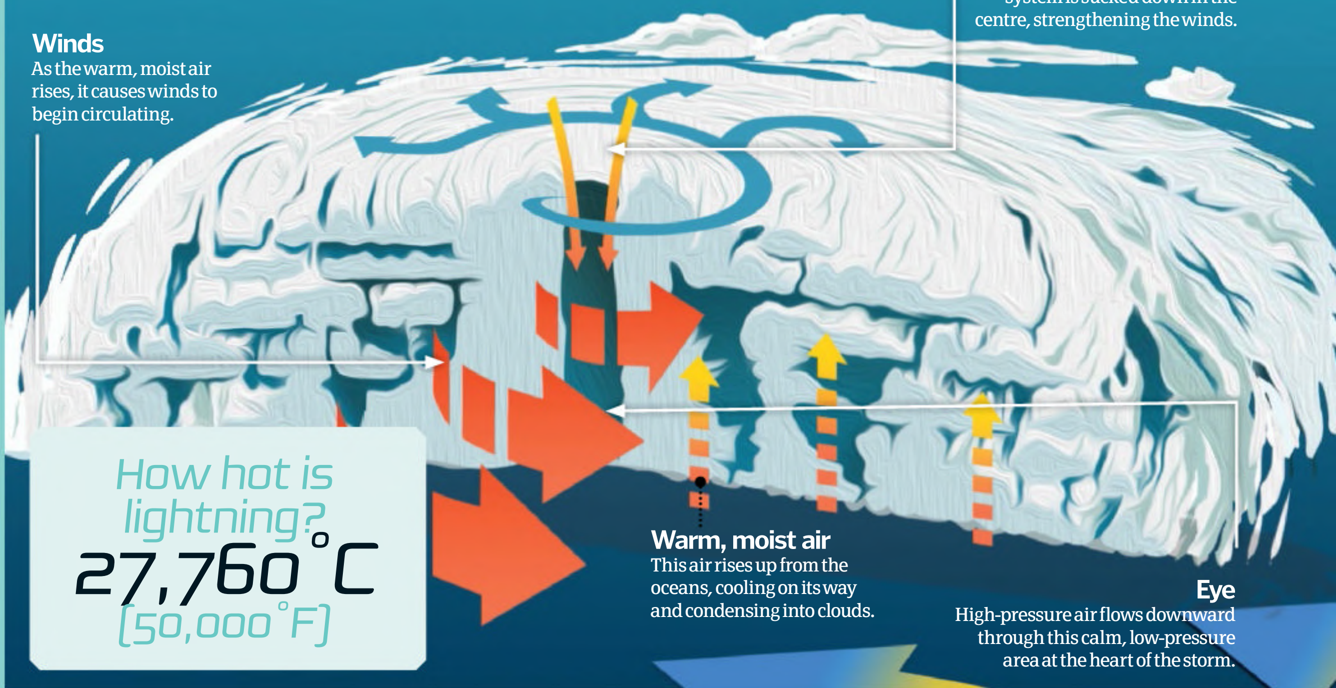
Some large metropolises have microclimates – that is, their own small climates that differ from the local environment. Often these are due to the massive amounts of concrete, asphalt and steel; these materials retain and reflect heat and do not absorb water, which keeps a city warmer at night. This phenomenon specifically is often known as an urban heat island. The extreme energy usage in large cities may also contribute to this.

What causes hurricanes?

Depending on where they start, hurricanes may also be known as tropical cyclones or typhoons. They always form over oceans around the equator, fuelled by the warm, moist air. As that air rises and forms clouds, more warm, moist air moves into the area of lower pressure below. As the cycle continues, winds begin rotating and pick up speed. Once it hits 119 kilometres (74 miles) per hour, the storm is officially a hurricane. When hurricanes reach land, they weaken and die without the warm ocean air. Unfortunately they can move far inland, bringing a vast amount of rain and destructive winds. People sometimes cite 'the butterfly effect' in relation to hurricanes. This simply means something as small as the beat of a butterfly's wing can cause big changes in the long term.

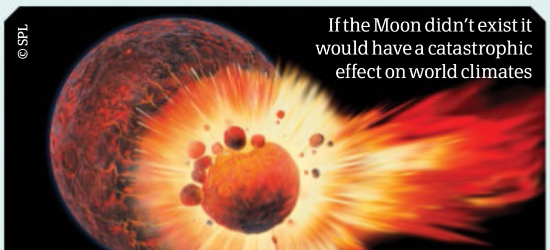
What are the odds of getting hit by lightning in a lifetime?

1 in 300,000



How hot is lightning?

27,760°C [50,000°F]

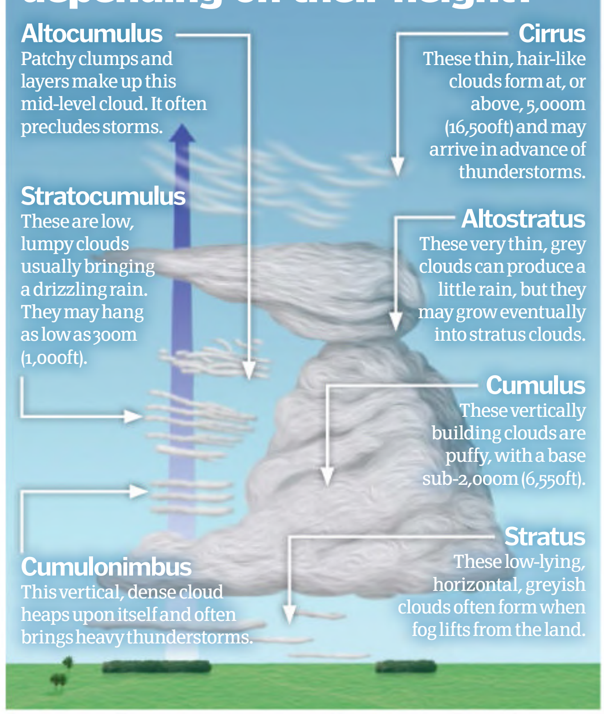


If the Moon didn't exist it would have a catastrophic effect on world climates

What would happen to our weather without the Moon?

It's difficult to know exactly what would happen to our weather if the Moon were destroyed, but it wouldn't be good. The Moon powers Earth's tides, which in turn influence our weather systems. In addition, the loss of the Moon would affect the Earth's rotation – how it spins on its axis. The presence of the Moon creates a sort of drag, so its loss would probably speed up the rotation, changing the length of day and night. In addition it would alter the tilt of the Earth too, which causes the changes in our seasons. Some places would be much colder while others would become much hotter. Let's not neglect the impact of the actual destruction, either; that much debris would block out the Sun and rain down on Earth, causing massive loss of life. Huge chunks that hit the ocean could cause great tidal waves, for instance.

Why do clouds look different depending on their height?



RECORD BREAKERS
KILLER FLOOD

3.7-4MN

DEADLIEST NATURAL DISASTER

The Huang He flood of 1931 covered over 100,000 square kilometres (62,000 square miles) around the Yellow River basin in China, claiming up to a staggering 4 million lives.

DID YOU KNOW? *Sir Francis Beaufort devised his wind scale by using the flags and sails of his ship as measuring devices*

How many volts are in a lightning flash?

1 billion

Why are you safer inside a car during an electrical storm?

People used to think the rubber tyres on a car grounded any lightning that may strike it and that's what kept you safe. However, you're safer in your car during an electrical storm because of the metal frame. It serves as a conductor of electricity, and channels the lightning away into the ground without impacting anything – or anyone – inside; this is known as a Faraday cage. While it is potentially dangerous to use a corded phone or other appliances during a storm because lightning can travel along cables, mobile or cordless phones are fine. It's also best to avoid metallic objects, including golf clubs.

© SPL

What is ball lightning?

This mysterious phenomenon looks like a glowing ball of lightning, and floats near the ground before disappearing, often leaving a sulphur smell. Despite many sightings, we're still not sure what causes it.

© SPL

What causes giant hailstones?

Put simply, giant hailstones come from giant storms – specifically a thunderstorm called a supercell. It has a strong updraft that forces wind upwards into the clouds, which keeps ice particles suspended for a long period. Within the storm are areas called growth regions; raindrops spending a long time in these are able to grow into much bigger hailstones than normal.

WHAT IS CLOUD IRIDESCENCE?

This happens when small droplets of water or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not a common phenomenon because the cloud has to be very thin, and even then the colours are often overshadowed by the Sun.

WHAT DO WEATHER SATELLITES DO?

The GOES (Geostationary Operational Environmental Satellite) system is run by the US National Environmental Satellite, Data, and Information Service (NESDIS). The major element of GOES comprises four different geosynchronous satellites (although there are other geo-satellites either with other uses now or decommissioned).

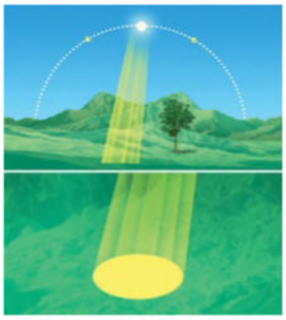
The whole system is used by NOAA's National Weather Service for forecasting, meteorological research and storm tracking. The satellites provide continuous views of Earth, giving data on air moisture, temperature and cloud cover. They also monitor solar and near-space activities like solar flares and geomagnetic storms.

How does the Sun cause the seasons?

Seasons are caused by the Earth's revolution around the Sun, as well as the tilt of the Earth on its axis. The hemisphere receiving the most direct sunlight experiences spring and summer, while the other experiences autumn and winter. During the warmer months, the Sun is higher in the sky, stays above the horizon for longer, and its rays are more direct. During the cooler half, the Sun's rays aren't as strong and it's lower in the sky. The tilt causes these dramatic differences, so while those in the northern hemisphere are wrapping up for snow, those in the southern hemisphere may be sunbathing on the beach.

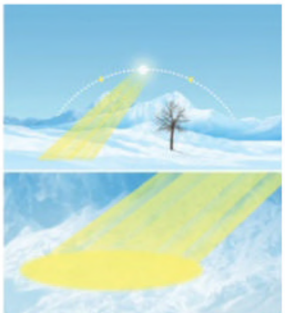
SUMMER

The Sun is at its highest point in the sky and takes up more of the horizon. Its rays are more direct.



WINTER

The Sun is at its lowest point in the sky and there is less daylight. The rays are also more diffuse.

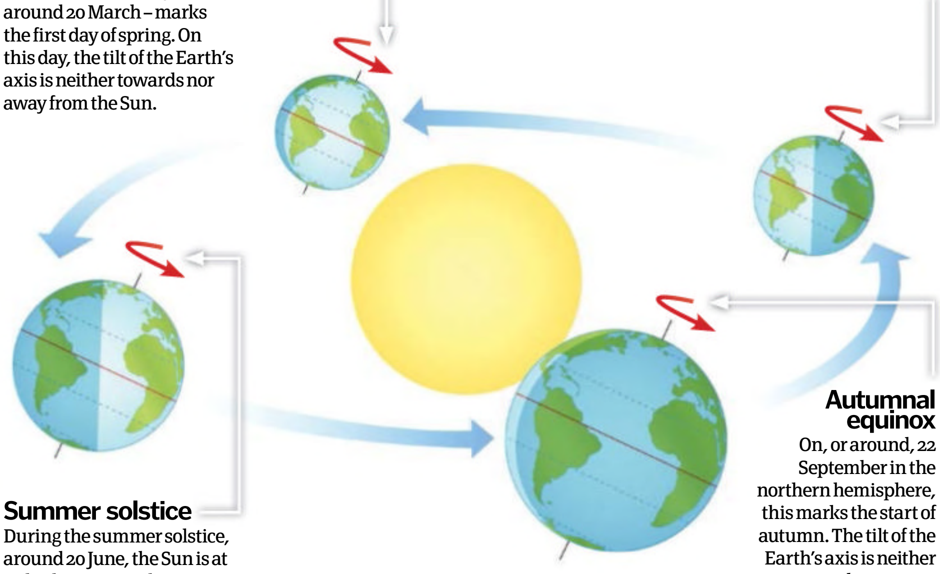


Vernal equinox

For the northern hemisphere, this day – around 20 March – marks the first day of spring. On this day, the tilt of the Earth's axis is neither towards nor away from the Sun.

Winter solstice

The winter solstice marks the beginning of winter, with the Sun at its lowest point in the sky; it takes place around 20 December each year.



Summer solstice

During the summer solstice, around 20 June, the Sun is at its highest, or northernmost, point in the sky.

Autumnal equinox

On, or around, 22 September in the northern hemisphere, this marks the start of autumn. The tilt of the Earth's axis is neither towards nor away from the Sun.

Weather wonders

HOW LONG DOES A RAINBOW LAST?

There is no set rule for the duration a rainbow will last. It all depends on how long the light is refracted by water droplets in the air (eg rain, or the spray from a waterfall).

WHY DOES THE AIR SMELL FUNNY AFTER RAIN HAS FALLEN?

This scent comes from bacteria in the soil. Once the earth dries, the bacteria (called actinomycetes) release spores. Rainfall kicks these spores up into the air, and then the moist air disperses them. They tend to have a sweet, earthy odour.

HOW MUCH RAIN CAN A HURRICANE BRING?

The average hurricane, with a radius of about 1,330 kilometres (825 miles), can dump as much as 21.3×10^{15} cubic centimetres (1.3×10^{15} cubic inches) of water a day. That's enough rain to fill up 22 million Olympic-size swimming pools!

WHAT ARE DROUGHTS AND HEAT WAVES?

Droughts are about an extreme lack of water, usually due to lower than average rainfall, and last for months or even years. There's no set definition of a heat wave, but it typically means higher than average temperatures for several consecutive days. Both can lead to crop failures and fatalities.

WHY ARE RAINBOWS ARCH-SHAPED?

Rainbows are arched due to the way sunlight hits raindrops. It bends as it passes through because it slows during this process. Then, as the light passes out of the drop, it bends again as it returns to its normal speed.

How hot was the hottest day in history?

58°C (136°F)

Recorded on 13 September 1922 in Al Aziziyah, Libya

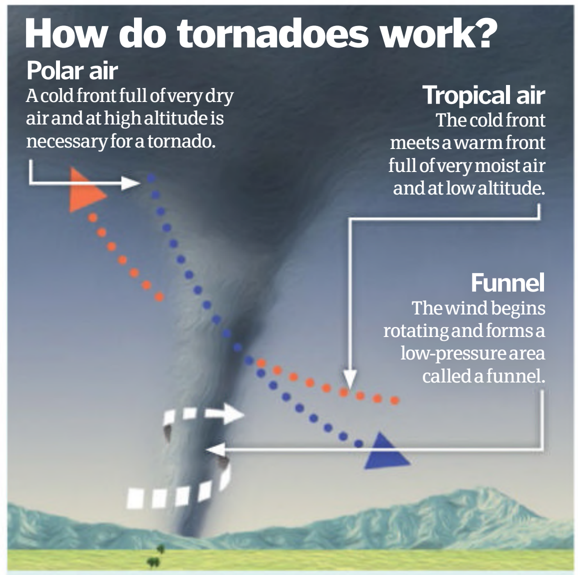
What's the difference between rain, sleet and snow?

When it comes to precipitation, it's all about temperature. When the air is sufficiently saturated, water vapour begins to form clouds around ice, salt or other cloud seeds. If saturation continues, water droplets grow and merge until they become heavy enough to fall as rain. Snow forms when the air is cold enough to freeze supercooled water droplets – lower than -31 degrees Celsius (-34 degrees Fahrenheit) – then falls. Sleet is somewhere in between: it starts as snow but passes through a layer of warmer air before hitting the ground, resulting in some snow melting.

What are gravity wave clouds?

Gravity waves are waves of air moving through a stable area of the atmosphere. The air might be displaced by an updraft or something like mountains as the air passes over. The upward thrust of air creates bands of clouds with empty space between them. Cool air wants to sink, but if it is buoyed again by the updraft, it will create additional gravity wave clouds.

How do tornadoes work?



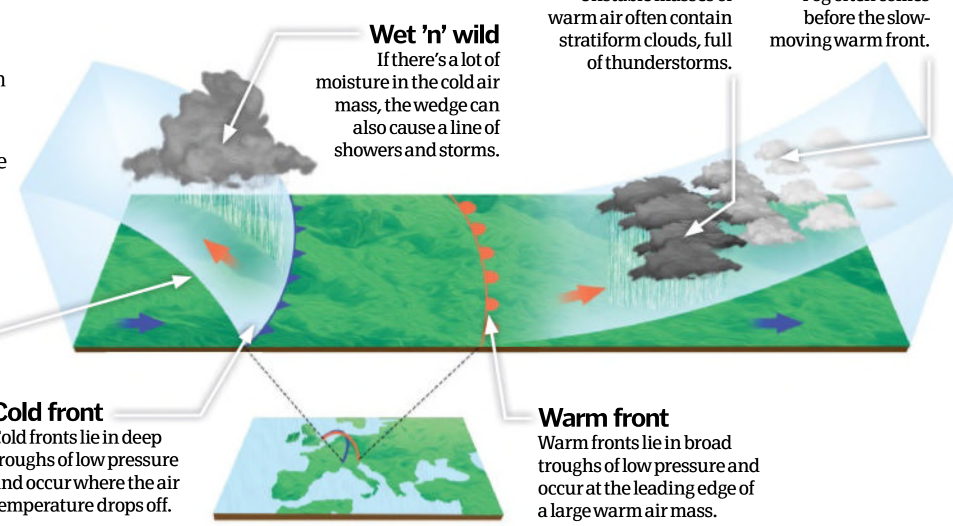
Tornadoes start out with severe thunderstorms called supercells. They form when polar air comes in contact with tropical air in a very unstable atmosphere. Supercells contain a rotating updraft of air that is known as a mesocyclone, which keeps them going for a long time. High winds add to the rotation, which keeps getting faster and faster until eventually it forms a funnel. The funnel cloud creates a sucking area of low pressure at the bottom. As soon as this funnel comes in to contact with the Earth, you have a tornado.

Why is it so quiet after it snows?

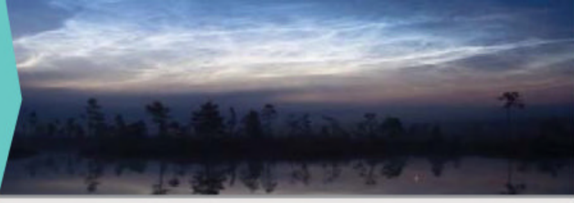
It's peaceful after snowfall as the snow has a dampening effect; pockets of air between the flakes absorb noise. However, if it's compacted snow and windy, the snow might actually reflect sound.

What is a weather front?

A weather front is the separation between two different masses of air, which have differing densities, temperature and humidity. On weather maps, they're delineated by lines and symbols. The meeting of different frontal systems causes the vast majority of weather phenomena.



DID YOU KNOW?
CLOUD LIGHTING



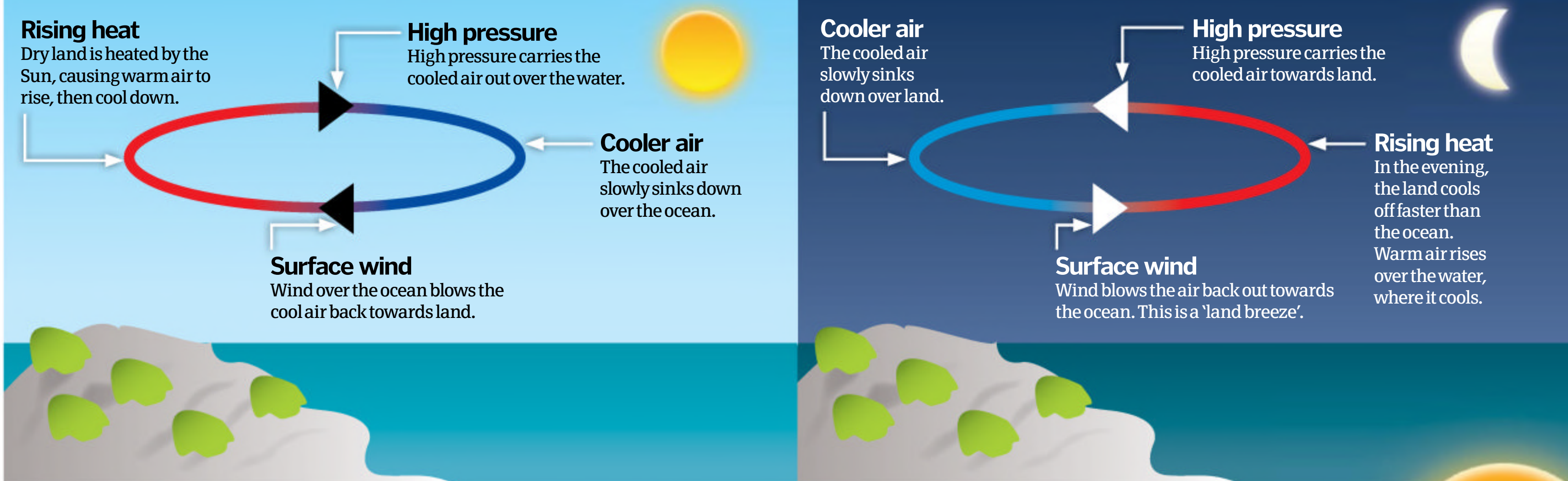
© Martin Koitmäe

Day at night

Noctilucent clouds occur when icy polar mesospheric clouds – the highest clouds in the Earth's atmosphere at 76-85 kilometres (47-53 miles) – refract the fading twilight after the Sun has set, temporarily illuminating the sky.

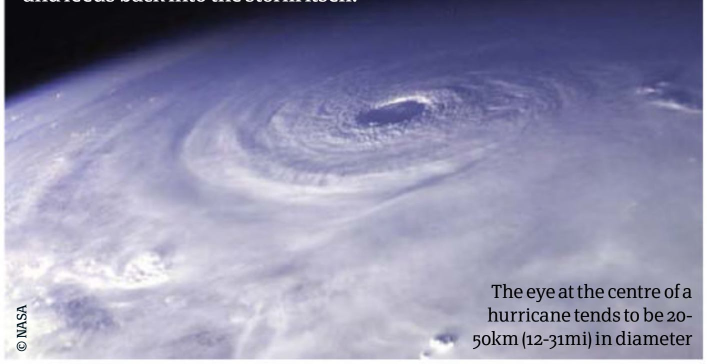
DID YOU KNOW? Fog is made up of millions of droplets of water floating in the air

What is a sea breeze?



What is the eye of a storm?

The eye is the calm centre of a storm like a hurricane or tornado, without any weather phenomena. Because these systems consist of circular, rotating winds, air is funnelled downward through the eye and feeds back into the storm itself.



© NASA

The eye at the centre of a hurricane tends to be 20-50km (12-31mi) in diameter

© SPL

What are red sprites and blue jets?

These are both atmospheric and electrical phenomena that take place in the upper atmosphere, and are also known as upper-atmosphere discharge. They take place above normal lightning; blue jets occur around 40-50 kilometres (25-30 miles) above the Earth, while red sprites are higher at 50-100 kilometres (32-64 miles). Blue jets happen in cone shapes above thunderstorm clouds, and are not related to lightning. They're blue due to ionised emissions from nitrogen. Red sprites can appear as different shapes and have hanging tendrils. They occur when positive lightning goes from the cloud to the ground.

Does lightning ever strike in the same place twice?

Yes, lightning often strikes twice in the same location. If there's a thunderstorm and lightning strikes, it's just as likely to happen again. Many tall structures get struck repeatedly during thunderstorms, such as New York City's famed Empire State Building or NASA's shuttle launch pad in Cape Canaveral, Florida.

How cold was the coldest day in history?

-89°C (-129°F)

Recorded on 21 July 1983 at Vostok II Station, Antarctica

Why does the Sun shine?

The Sun is a super-dense ball of gas, where hydrogen is continually burned into helium (nuclear fusion). This generates a huge deal of energy, and the core reaches 15 million degrees Celsius (27 million degrees Fahrenheit). This extreme heat produces lots of light.

WHY ARE CLOUDS FLUFFY?

Fluffy-looking clouds – the big cotton-ball ones – are a type called cumulus. They form when warm air rises from the ground, meets a layer of cool air and moisture condenses. If the cloud grows enough to meet an upper layer of freezing air, rain or snow may fall from the cloud.

WHAT'S IN ACID RAIN?

Acid rain is full of chemicals like nitrogen oxide, carbon dioxide and sulphur dioxide, which react with water in the rain. Much of it comes from coal powerplants, cars and factories. It can harm wildlife and also damage buildings.

WHY CAN I SEE MY BREATH IF IT'S COLD?

Your breath is full of warm water vapour because your lungs are moist. When it's cold outside and you breathe out, that warm vapour cools rapidly as it hits the cold air. The water molecules slow down, begin to change form, and bunch up together, becoming visible.

WHAT IS THE GREEN FLASH YOU SEE AS THE SUN SETS SOMETIMES?

At sunsets (or indeed sunrises), the Sun can occasionally change colour due to refraction. This can cause a phenomenon called green flash. It only lasts for a second or two so can be very tricky to spot.

Where does acid rain come from?

We've all seen the effects of acid rain on limestone statues, but how does this damaging substance form?

All rainwater is a little bit acidic, because the carbon dioxide present in the atmosphere dissolves in water and forms carbonic acid. Stronger acid rain, however, can damage stone structures and can also be harmful to crops, as well as polluting waterways. It forms in the atmosphere when poisonous gases emitted by human activities combine with the moisture within rain clouds.

Fossil-fuelled power stations and petrol/diesel vehicles give off chemical pollutants – mainly sulphur dioxide (SO_2) and nitrogen oxides (NOx) – which when mixed with the water in the air react and turn acidic.

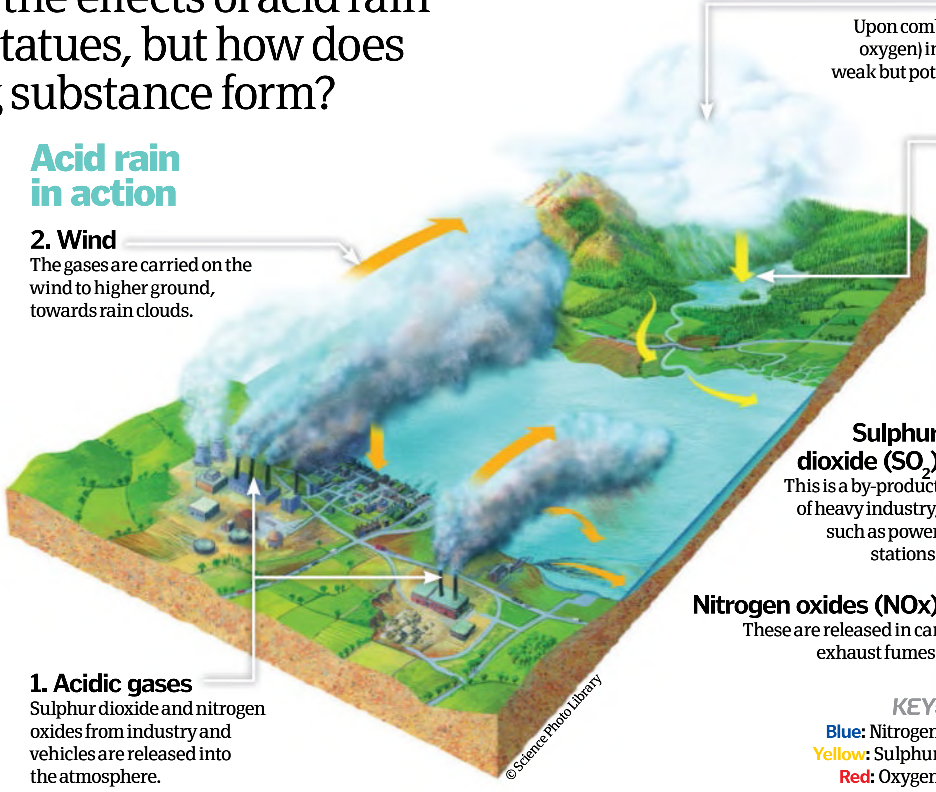
Acid rain in action

1. Acidic gases
Sulphur dioxide and nitrogen oxides from industry and vehicles are released into the atmosphere.

2. Wind
The gases are carried on the wind to higher ground, towards rain clouds.

3. Gasses dissolve
Upon combining with the water vapour (water and oxygen) in the rain clouds, the gasses react to form weak but potentially damaging acid. Sulphur dioxide from industry becomes sulphuric acid.

4. Acid rainfall
When acid rain falls it can damage plant life, infiltrate waterways and erode buildings and statues.



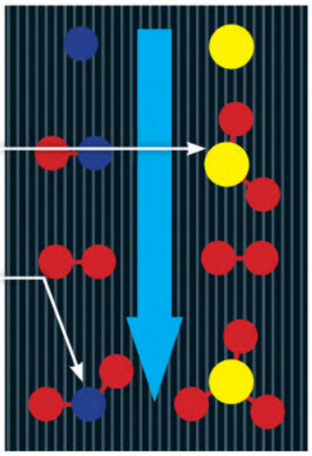
© Science Photo Library

Oxidation of sulphur and nitrogen

Sulphur dioxide (SO_2)
This is a by-product of heavy industry, such as power stations.

Nitrogen oxides (NOx)
These are released in car exhaust fumes.

KEY:
Blue: Nitrogen
Yellow: Sulphur
Red: Oxygen



The smell of rain

Find out why precipitation creates a distinctive aroma that's the same all over the world

It's possible to smell rain before it has even fallen. Lightning has the power to split atmospheric nitrogen and oxygen molecules into individual atoms. These atoms react to form nitric oxide, which in turn can interact with other chemicals to form ozone – the aroma of which is a bit like chlorine and a specific smell we associate with rain. When the scent carries on the wind, we can predict the rain before it falls.

Another smell associated with rain is petrichor – a term coined by a couple of Australian scientists in the mid-Sixties. After a dry spell of weather, the first rain that falls brings with it a very particular aroma that is the same no matter where you are. Two chemicals are responsible for the production of this indescribable odour called petrichor. One of the two chemicals is released by a specific bacteria found in the earth; the other is an oil secreted by thirsty plants. These compounds combine on the ground and, when it rains, the smell of petrichor will fill your nostrils.

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5 TOP FACTS
CLOUD FORMATION

Rising heat
1 When the Sun heats the ground, hot air will rise off of it in columns called thermals. These thermals can produce puffy cumulus clouds.

Airflow obstructions
2 Clouds often form around hills and mountains, as the warm air has to rise around the obstruction, which means it then cools quickly, creating clouds.

Converging streams
3 When two streams of air, flowing in different directions, meet they will be forced to converge upward together. This process can create cumulus clouds.

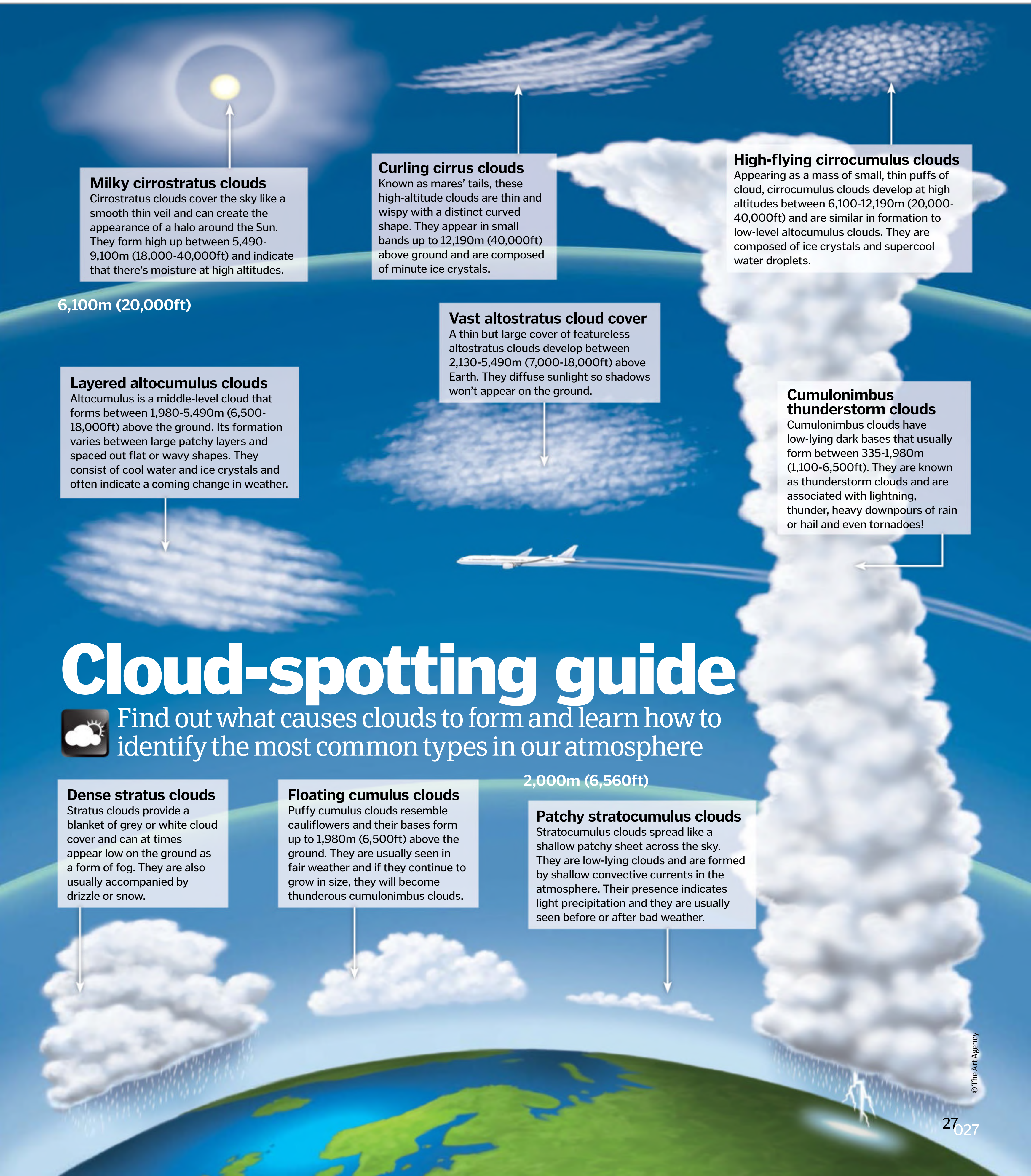
Wind turbulences
4 Changes in wind speed and height creates turbulences, which in turn will cause warm and cool air to meet, enabling clouds to form.

Fronts
5 Fronts separate warm and cold air. When a considerable amount of warm air rises above large amounts of cold air in a front, clouds can form.

DID YOU KNOW? *Clouds on Venus are actually composed of sulphur dioxide and drops of sulphuric acid*

Cloud-spotting guide

Find out what causes clouds to form and learn how to identify the most common types in our atmosphere



Milky cirrostratus clouds
Cirrostratus clouds cover the sky like a smooth thin veil and can create the appearance of a halo around the Sun. They form high up between 5,490-9,100m (18,000-40,000ft) and indicate that there's moisture at high altitudes.

Curling cirrus clouds
Known as mares' tails, these high-altitude clouds are thin and wispy with a distinct curved shape. They appear in small bands up to 12,190m (40,000ft) above ground and are composed of minute ice crystals.

High-flying cirrocumulus clouds
Appearing as a mass of small, thin puffs of cloud, cirrocumulus clouds develop at high altitudes between 6,100-12,190m (20,000-40,000ft) and are similar in formation to low-level altocumulus clouds. They are composed of ice crystals and supercool water droplets.

Vast altostratus cloud cover
A thin but large cover of featureless altostratus clouds develop between 2,130-5,490m (7,000-18,000ft) above Earth. They diffuse sunlight so shadows won't appear on the ground.

Layered altocumulus clouds
Altocumulus is a middle-level cloud that forms between 1,980-5,490m (6,500-18,000ft) above the ground. Its formation varies between large patchy layers and spaced out flat or wavy shapes. They consist of cool water and ice crystals and often indicate a coming change in weather.

Cumulonimbus thunderstorm clouds
Cumulonimbus clouds have low-lying dark bases that usually form between 335-1,980m (1,100-6,500ft). They are known as thunderstorm clouds and are associated with lightning, thunder, heavy downpours of rain or hail and even tornadoes!

Dense stratus clouds
Stratus clouds provide a blanket of grey or white cloud cover and can at times appear low on the ground as a form of fog. They are also usually accompanied by drizzle or snow.

Floating cumulus clouds
Puffy cumulus clouds resemble cauliflowers and their bases form up to 1,980m (6,500ft) above the ground. They are usually seen in fair weather and if they continue to grow in size, they will become thunderous cumulonimbus clouds.

Patchy stratocumulus clouds
Stratocumulus clouds spread like a shallow patchy sheet across the sky. They are low-lying clouds and are formed by shallow convective currents in the atmosphere. Their presence indicates light precipitation and they are usually seen before or after bad weather.

How deserts grow

Discover why farmland across the planet is being swallowed at a terrifying rate by creeping sands…

Each year 0.2 per cent of usable farmland is lost from arid regions worldwide. That may not sound like a lot, but pressure on food and water resources is growing exponentially. Indeed, Earth's population is predicted to increase by a staggering 4 billion people by the year 2100.

Desertification occurs when farmland is overused in dry climates with fragile ecosystems already vulnerable to drought. Many affected areas are home to the poorest people in the world.

Livestock overgraze grass and wear away earth with their hooves, while intensive arable farming depletes nutrients in the soil. Toxic salts build up and farmland becomes waterlogged when fields are overwatered by irrigation. Water and wind make the problem even worse by removing nutrient-rich soil, gradually leaving nothing but a bare desert behind.

No continent is immune from desertification. Around a third of our planet is directly affected and population pressure is typically the root cause of it.

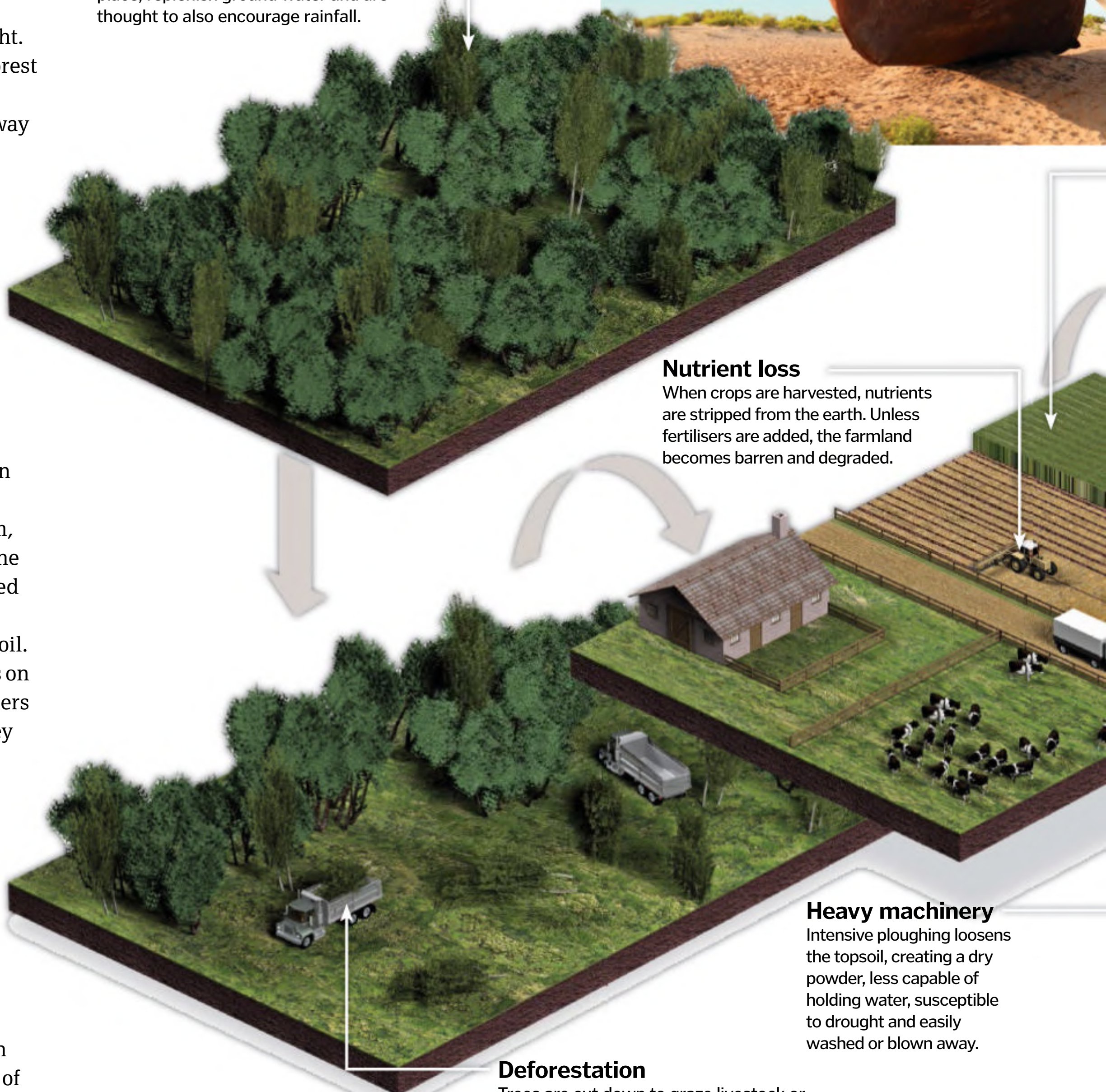
Land degradation is not a new problem, though. Studies suggest the collapse of the Mayan civilisation in 900 CE was triggered by population growth followed by crop cultivation on steep slopes with fragile soil.

Desertification has devastating effects on people and the environment alike. Farmers face famine or the threat of disease if they migrate away from depleted farmland. Dust from the affected land can also cause lung diseases. In China, sandstorms and dunes from the advancing Gobi Desert swallow up entire villages and affect air quality in Beijing some 80 kilometres (50 miles) away.

In Africa's Sahel, desertification increases drought risk too; vegetation dying back exposes the pale sand, which reflects more heat, reducing updraughts of damp air that generate clouds and rain, so once it begins, desertification is self-propagating.

Farmland to wasteland

See how intensive agriculture can transform a fertile landscape into a barren terrain



5 TOP FACTS
DESERTED LANDS

Easter Island
1 The ancient Rapa Nui who built 900 giant hollow-eyed Moai statues – some weighing 75 tons – may have collapsed after stripping the island of palm forest.

Greenland
2 Cutting trees for fuel and livestock overgrazing may have contributed to the disappearance of Vikings from Greenland – a cold desert – in mid-15th century.

Carthage
3 The Ancient Romans are said to have polluted the croplands around Carthage in modern Tunisia with salt after winning the Third Punic War, hoping to render the city uninhabitable.

Mesopotamia
4 By the second millennium BCE, farmers in southern Mesopotamia had swapped wheat for salt-tolerant barley, forced by desertification caused by irrigation.

Sardis
5 An ancient city in Turkey, destroyed by landslides, soil loss and overgrazing. Forests were stripped from the slopes for construction and firewood for Roman baths.

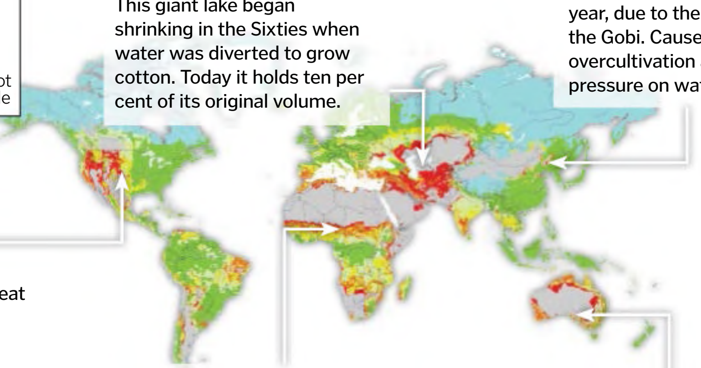
DID YOU KNOW? *A single millimetre (0.04in) of soil can take hundreds of years to form in dry climates*

The Aral Sea is an extreme example of desertification, where the water has receded so much that many ships now sit rusting miles away from the once-huge lake

Desert expansion around the globe

What places on Earth have been most affected by desertification?

Vulnerability	Other regions
Very high	Dry
High	Cold
Moderate	Humid not vulnerable
Low	



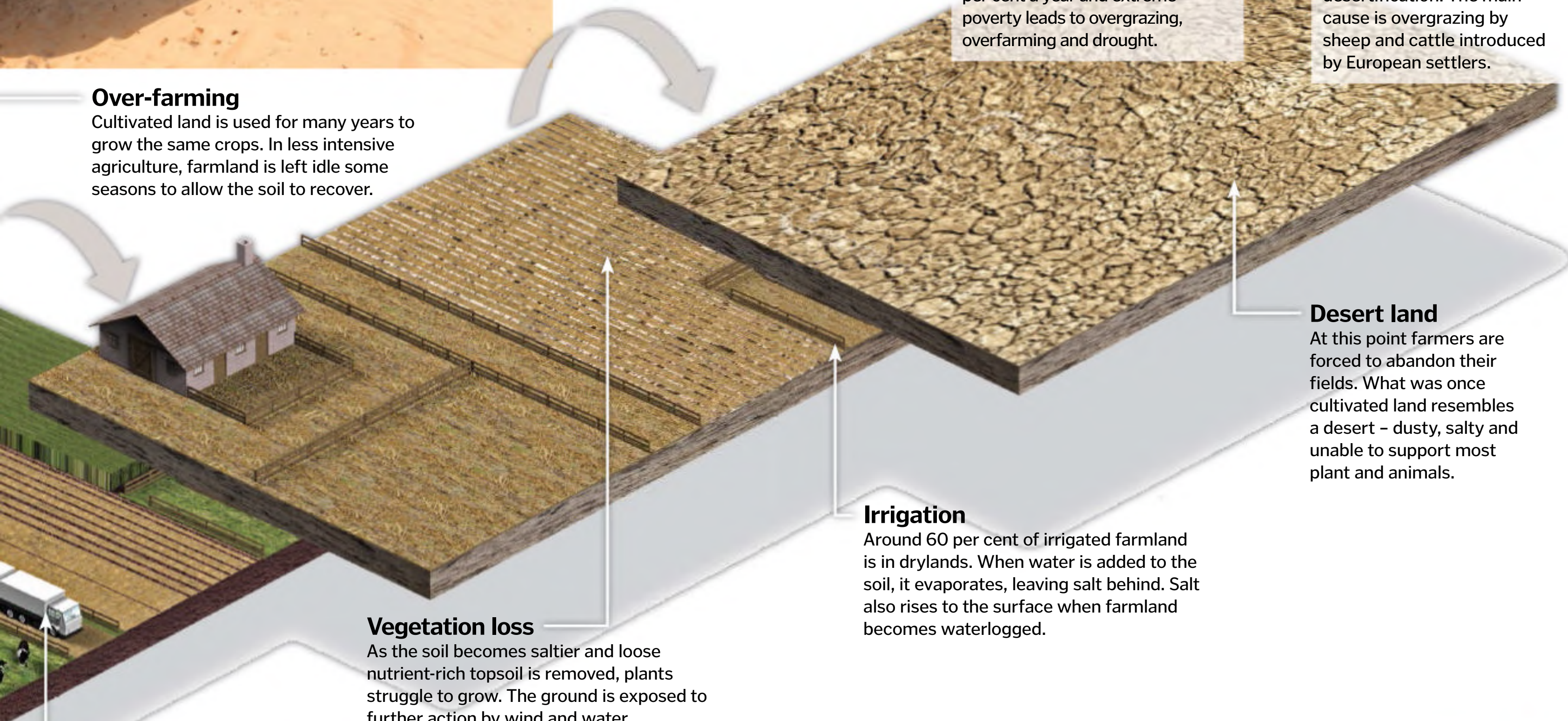
Aral Sea
This giant lake began shrinking in the Sixties when water was diverted to grow cotton. Today it holds ten per cent of its original volume.

Gobi Desert
Around 3,600km^2 (1,400mi^2) of China becomes desert each year, due to the expansion of the Gobi. Causes include overcultivation and population pressure on water and soil.

Great Plains
The US Great Plains turned into a 'dust bowl' when wheat production expanded after WWI. Improved farming methods helped the Plains recover, but they remain vulnerable to desertification.

Sahel region
Approximately 40 per cent of Africa is affected by desertification. Population growth of three to four per cent a year and extreme poverty leads to overgrazing, overfarming and drought.

Australia
An estimated 42 per cent of Australia is affected by desertification. The main cause is overgrazing by sheep and cattle introduced by European settlers.

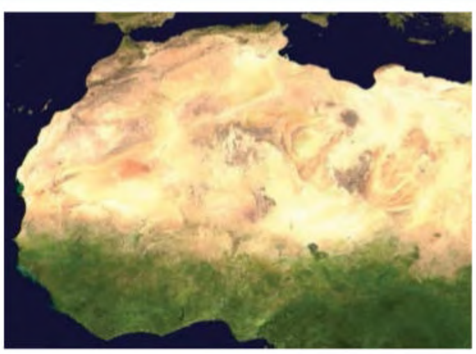


Over-farming
Cultivated land is used for many years to grow the same crops. In less intensive agriculture, farmland is left idle some seasons to allow the soil to recover.

Desert land
At this point farmers are forced to abandon their fields. What was once cultivated land resembles a desert – dusty, salty and unable to support most plant and animals.

Irrigation
Around 60 per cent of irrigated farmland is in drylands. When water is added to the soil, it evaporates, leaving salt behind. Salt also rises to the surface when farmland becomes waterlogged.

Vegetation loss
As the soil becomes saltier and loose nutrient-rich topsoil is removed, plants struggle to grow. The ground is exposed to further action by wind and water.



How can we fight desertification?

Reversing desertification depends on tackling human exploitation of land by providing sources of income. Imagine a wall of trees and shrubs – 8,000 kilometres (5,000 miles) long and 15 kilometres (nine miles) wide – snaking west to east across Africa. The Great Green Wall project began in 2011 to counter desertification on the Sahara Desert fringe. Since then, 12 million drought-resistant acacia trees have been planted in Senegal alone.

Large-scale planting schemes were used to tackle desertification in 1935 during the US Dust Bowl too. China initiated its own green-wall project in 1978, which afforested 9 million hectares (22.2 million acres) in the first ten years.

Large forested areas replenish the water table, act as wind breaks to stop sand dunes in their tracks, and may increase rainfall; for example, an estimated 60 per cent of Amazon rainfall is created by the rainforest itself. Advocates of the African green wall believe it can even counter terrorism, providing jobs by producing gum arabic from acacia.

Other techniques to fight desertification include improving irrigation techniques, applying bacteria to dunes and introducing sand fences and pools.

How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

Jet streams are currents of fast-moving air found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas.

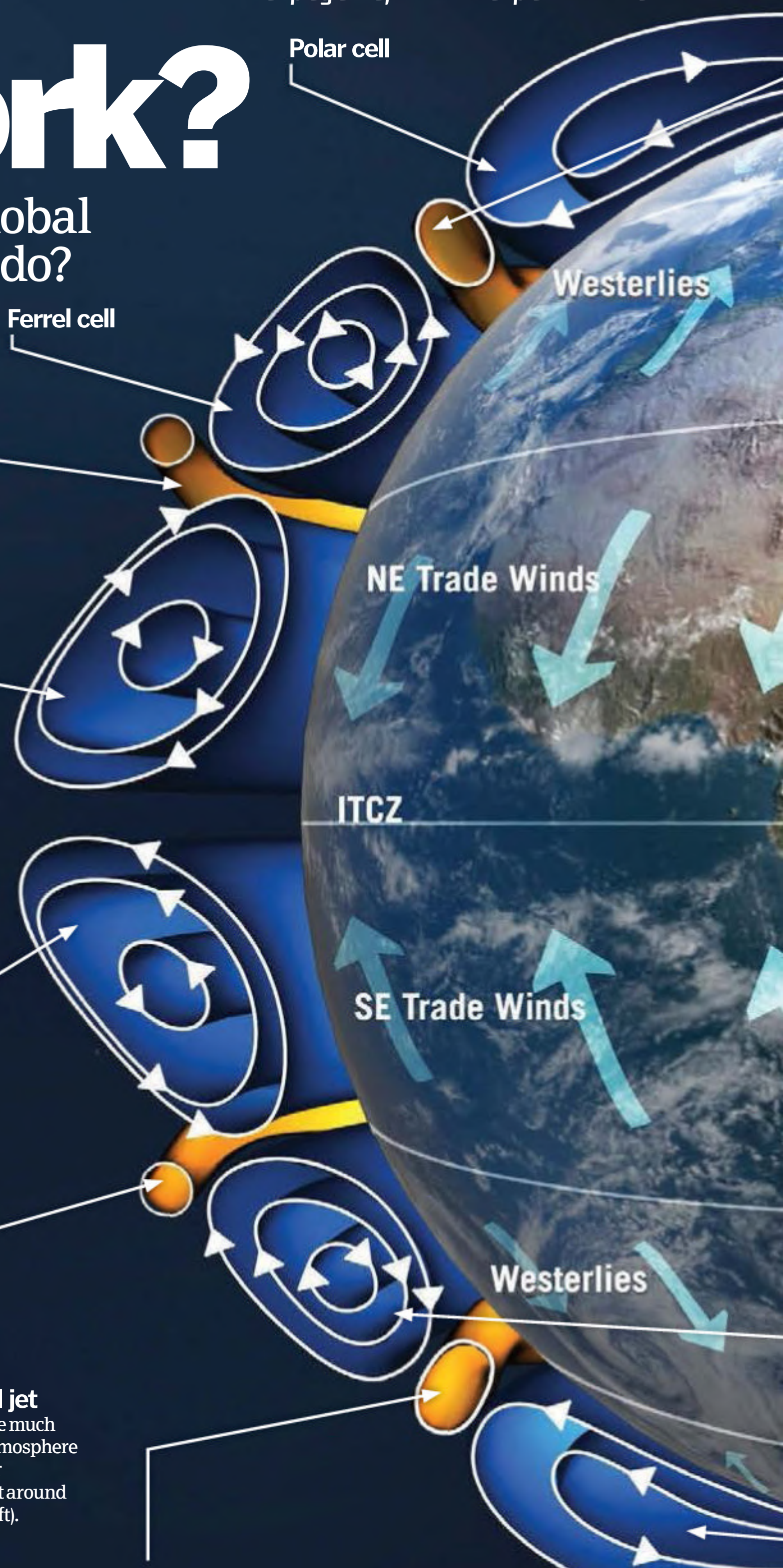
The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere known as the tropopause (the border between the troposphere and the stratosphere). It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, thus, pressure gradients along which air rushes.

In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south.

In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface, although it can impact the weather in exactly the same way as the northern jet stream does.

Earth's jet streams

A closer look at some of the invisible phenomena that play a major role in our planet's climate



Hadley cell
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

Subtropical jet
These winds are much higher in the atmosphere than their polar counterparts, at around 17,000m (55,000ft).

Southern polar jet
The southern hemisphere's jet stream runs around the circumference of the Antarctic landmass.

Winds of change

Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

RECORD BREAKERS
BLOW ME DOWN!

372km/h

FASTEST WIND IN THE (NORTH)-WEST

The highest terrestrial wind speed ever recorded was in April 1934 on Mount Washington, USA, where a very strong jet stream descended onto the 1,917m (6,288ft) summit.

DID YOU KNOW? *Mount Everest is so high that its 8,848m [29,029ft] summit actually sits in a jet stream*

Northern polar jet
Travelling west to east around the northern hemisphere, it helps keep northern Europe temperate.

Ferrel cell
These cells are balanced by the Hadley and Polar cells, and create westerly winds. They are sometimes referred to as the 'zone of mixing'.

Polar cell
These north-south circulating winds bring in cold air from the freezing poles and produce polar easterlies.

Where is the jet stream?

A layer-by-layer breakdown of the Earth's atmosphere and whereabouts the jet stream sits

The sulphur cycle

Always mixing and mingling, sulphur is an element that really likes to get around

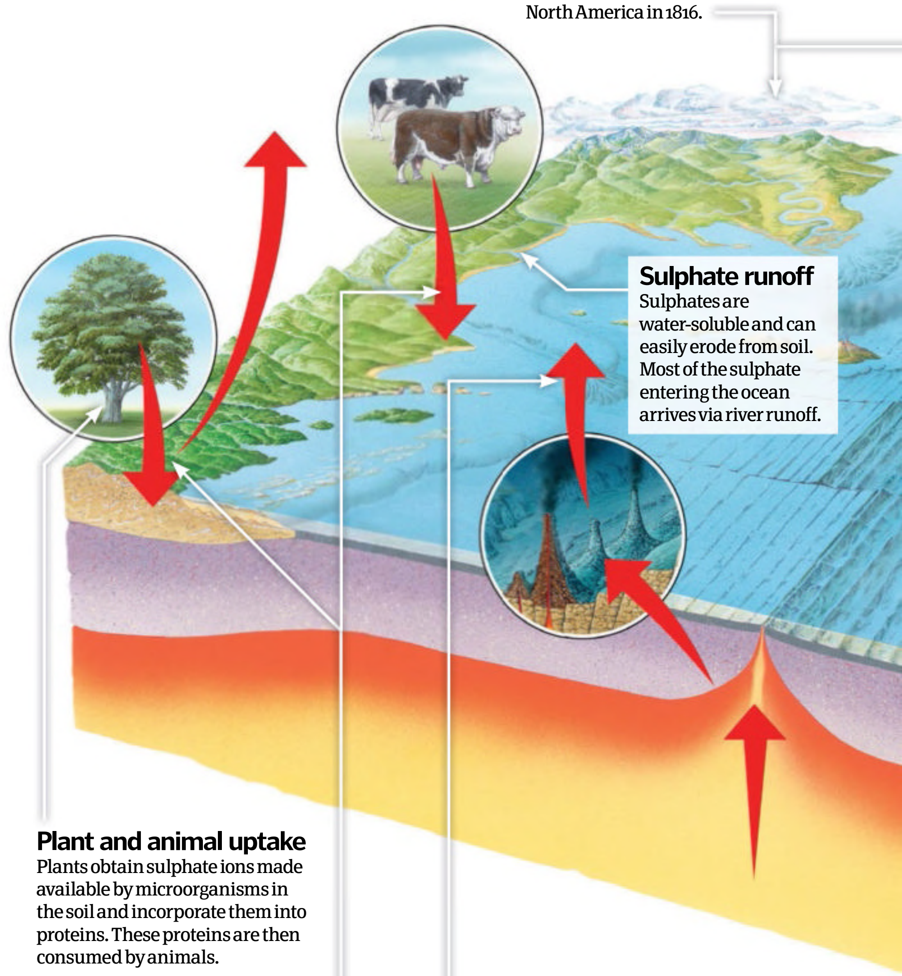
The sulphur cycle is one of many biochemical processes where a chemical element or compound moves through the biotic and abiotic compartments of the Earth, changing its chemical form along the way. As with both the carbon and nitrogen cycles, sulphur moves between the biosphere, atmosphere, hydrosphere and lithosphere (the rigid outer layer of the Earth). In biology, the water, oxygen, nitrogen, carbon, phosphorus and sulphur cycles are of particular interest because they are integral to the cycle of life.

Sulphur, which is present in the amino acids cysteine and methionine as well as the vitamin thiamine, is a vital part of all organic material. Plants acquire their supply from microorganisms in the soil and water, which convert it into usable organic forms. Animals acquire sulphur by consuming plants and one another. Both plants and animals release sulphur back into the ground and water as they die and are themselves broken down by microorganisms. This part of the cycle can form its own loop in both terrestrial and aquatic environments, as sulphur is consumed by plants and animals and then released again through decomposition.

But this isn't the only iron that sulphur has in the fire. Elemental sulphur is found around volcanoes and geothermal vents, and when volcanoes erupt, massive quantities of sulphur, mostly in the form of sulphur dioxide, can be propelled into the atmosphere. Weathering of rocks and the production of volatile sulphur compounds in the ocean can also both lead to the release of sulphur. Increasingly, atmospheric sulphur is a result of human activity, such as the burning of fossil fuels.

Once in the air, sulphur dioxide reacts with oxygen and water to form sulphate salts and sulphuric acid. These compounds dissolve well in water and may return to Earth's surface via both wet and dry deposition. Of course, not all the sulphur is getting busy; there are also vast reservoirs in the planet's crust as well as in oceanic sediments.

Atmospheric sulphur
Once in the atmosphere some sulphur aerosols can remain for years, reflecting the Sun's energy back into space and lowering surface temperatures many miles away. The eruption of Mount Tambora in Indonesia is thought to have caused the 'year without summer' reported in Europe and North America in 1816.



Sulphate runoff
Sulphates are water-soluble and can easily erode from soil. Most of the sulphate entering the ocean arrives via river runoff.

Plant and animal uptake
Plants obtain sulphate ions made available by microorganisms in the soil and incorporate them into proteins. These proteins are then consumed by animals.

Organic deposition
When biological material breaks down, sulphur is released by microbes in the form of hydrogen sulphide and sulphate salts, as well as organic sulphate esters and sulphonates.

Wet and dry deposition
The airborne deposition of sulphur compounds, whether sulphate salts or sulphuric acid, is the dominant cause of acidification in both terrestrial and coastal ecosystems.

Sulphur and the climate

Human activities like burning fossil fuels and processing metals generate around 90 per cent of the sulphur dioxide in the atmosphere. This sulphur reacts with water to produce sulphuric acid and with other emission products to create sulphur salts. These new compounds fall back to Earth, often in the form of acid rain. This type of acid deposition can have catastrophic effects on natural communities, upsetting the chemical balance of waterways, killing fish and plant life. If particularly concentrated, acid rain can even damage buildings and cause chemical weathering.

However, the environmental impact of sulphur pollution isn't entirely negative; atmospheric sulphur contributes to cloud formation and absorbs ultraviolet light, somewhat offsetting the temperature increases caused by the greenhouse effect. In addition, when acid rain deposits sulphur in bodies of wetlands, the sulphur-consuming bacteria quickly out-compete methane-producing microbes, greatly reducing the methane emissions which comprise about 22 per cent of the human-induced greenhouse effect.

Burning fossil fuels accounts for a large proportion of the sulphur dioxide in the atmosphere

DID YOU KNOW?

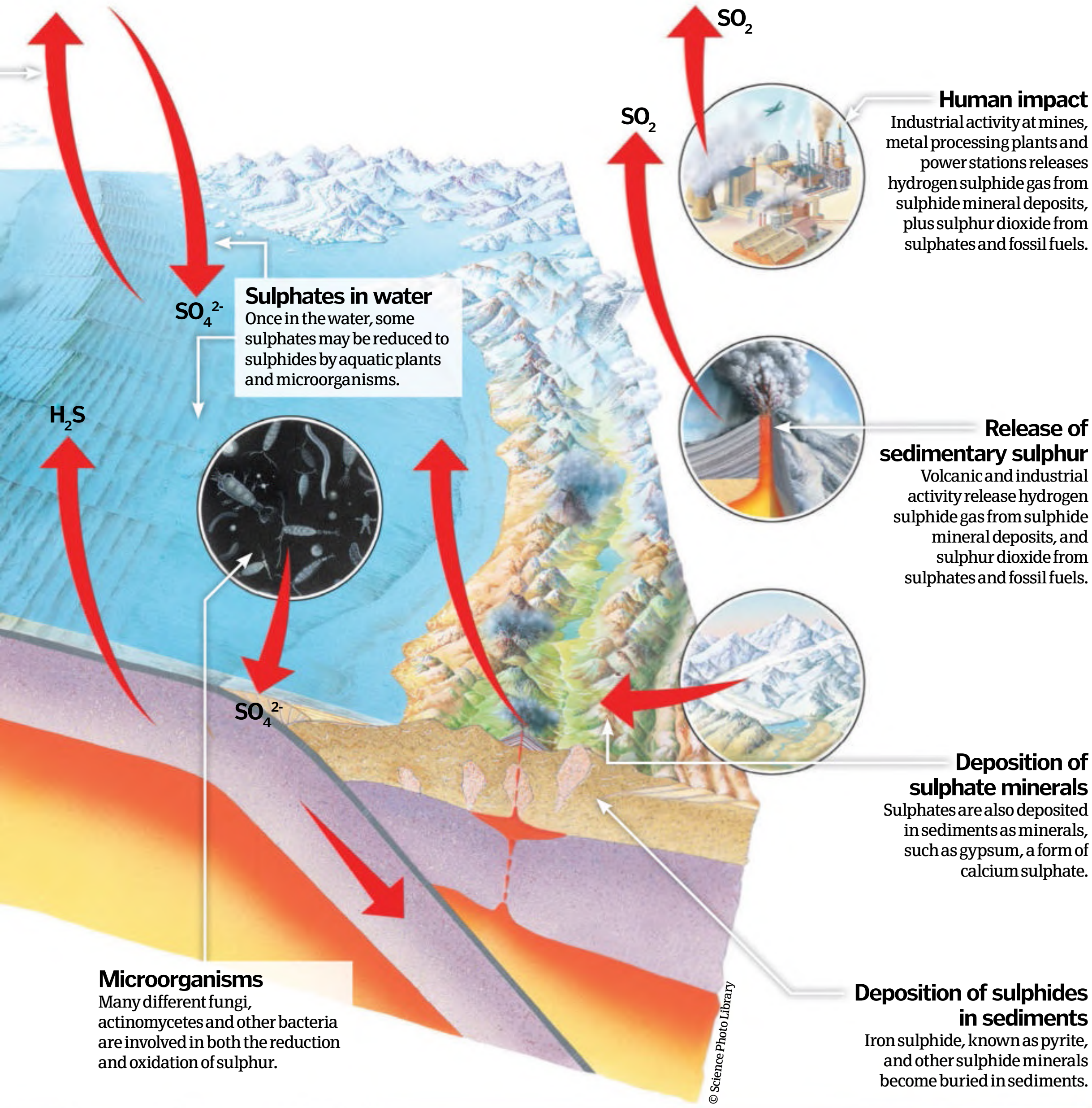
Do you smell something?

Most famous for its stench of rotten eggs, sulphur can really make its presence known. Decomposing organic matter results in the formation of hydrogen sulphide. Not only does it smell terrible but hydrogen sulphide can also be dangerous to aerobic (oxygen-using) organisms as it interferes with respiration.

DID YOU KNOW? *Sulphur is actually the 'brimstone' of biblical fame, where it is said to fuel the fires of hell*

The cycle in action

Sulphur is ubiquitous on Earth but much like your average teenager, the behaviour of sulphur depends heavily on its companions. The element is both necessary for all life and potentially highly toxic, depending on the chemical compound. It moves through different compartments of the planet, taking a range of forms, with many and varied impacts.




Large quantities of sulphur in its mineral form are found around volcanoes


Its yellow colour led some alchemists to try and re-create gold with sulphur
© Science Photo Library

What is sulphur?

Sulphur is one of the most important and common elements on Earth. It exists in its pure form as a non-metallic solid and is also found in many organic and inorganic compounds. It can be found throughout the environment, from the soil, air and rocks through to plants and animals.

Because of its bright yellow colour, sulphur was used by early alchemists in their attempts to synthesise gold. That didn't pan out, but people still found many useful applications for it, including making black gunpowder. Today sulphur and sulphur compounds are used in many consumer products such as matches and insecticides. Sulphur is also a common garden additive, bleaching agent and fruit preservative, and is an important industrial chemical in the form of sulphuric acid.

Early users mined elemental sulphur from volcanic deposits, but when the demand for sulphur outstripped supply towards the end of the 19th century, other sources had to be found. Advances in mining techniques enabled the extraction of sulphur from the large salt domes found along the Gulf Coast of the United States. Both volcanic and underground sulphur deposits still contribute to the global supply, but increasingly, industrial sulphur is obtained as a byproduct of natural gas and petroleum refinery processes.

Cave weather

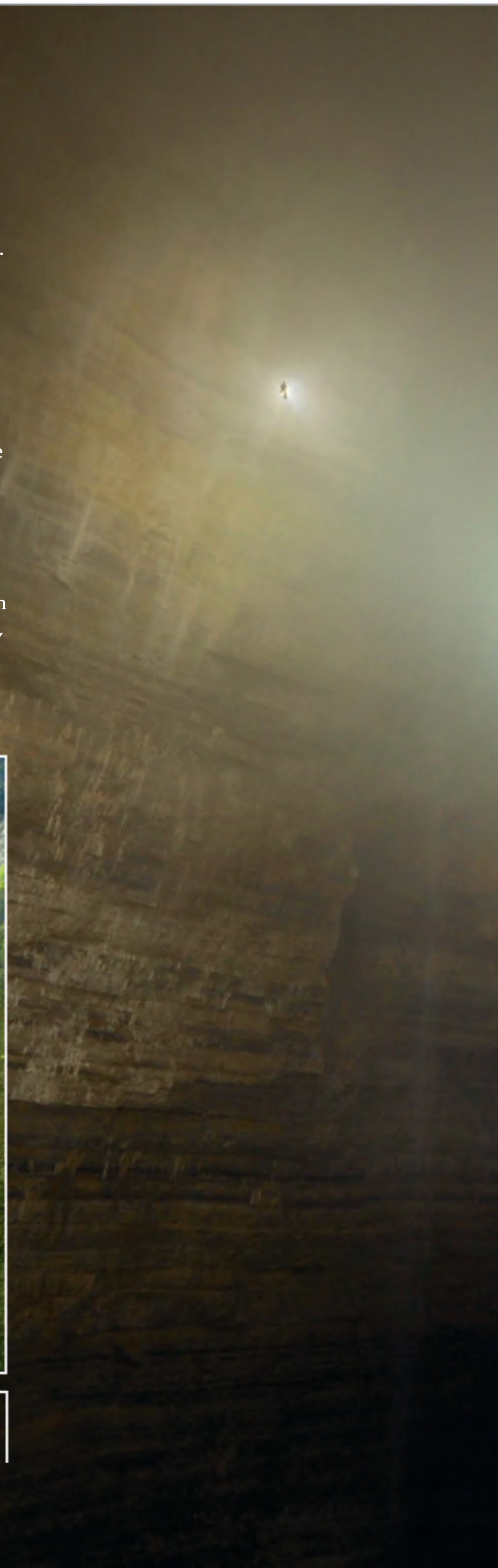
Explore one of China's most stunning cave systems to learn why it has developed its own microclimate

Cut off from the Sun, rain and wind that we experience on the surface, you might assume meteorological conditions in caves never change. However, the reality is that their climates do vary significantly – not only from location to location, but within individual caves over time. Indeed, some examples, like the Er Wang Dong cave system in Chongqing Province, China (main picture), even host their own weather. Ultimately this is because very few caves are 100 per cent cut off from their surroundings.

In the case of Er Wang Dong, it all comes down to an imbalance in the local topology. There are several tunnels around the cave system's perimeter where wind can blow in. Once trapped underground air from outside gains moisture, pooling into huge chambers like Cloud Ladder Hall – the second-biggest natural cavern in the world with a volume of 6 million cubic metres (211.9 million cubic feet). Once in an open chamber this humid air rises.

While there are numerous entrances into this subterranean complex, exits are few and far between. In Cloud Ladder Hall's case, it's a hole in the roof some 250 metres (820 feet) above the floor, leading to a bottleneck effect. As the damp air hits a cooler band near the exit, tiny water droplets condense out to create wispy mist and fog. In other chambers plants and underground waterways can also contribute to underground weather.

Even caves without any direct contact with the outside world can still experience climatic variations, as they are subject to fluctuations in atmospheric pressure and geothermal activity, where the heat from Earth's core emanates through the rocky floor. However, in such caves, changes are more evenly distributed so take place over longer time frames.



Here, fog clouds can be seen in the deep sinkhole at the entrance of the caves while the Sun shines above it

Sizing up Cloud Ladder Hall

RECORD BREAKERS
HUGE CAVERN

10mn m³

BIGGEST UNDERGROUND CHAMBER

The Cloud Ladder Hall is only beaten by the Sarawak Chamber in Borneo in scale. Sarawak is estimated to have almost double the volume of the Chinese cavern, in the range of 10mn m^3 (353.1mn ft^3).

DID YOU KNOW? *Although previously mined, the Er Wang Dong cave system was properly explored for the first time in 2013*

© Robbie Shone

Looks like high pressure has moved in…

Cold front conditions
As the warm air is forced upwards so quickly, when it cools and condenses it forms cumulonimbus clouds and therefore heavy rain or thunderstorms. Cumulus clouds follow on from this, with showery conditions and eventually clear skies.

Cold front
Heavy, cool air comes from the east behind a body of warm air, which is forced sharply upwards. The quick movement of air causes cool, windy conditions.

Predicting the weather

To take an umbrella or not? How we get those all-important forecasts…

The simple fact of the matter is that weather is unpredictable. So how is it that we can gather information and make predictions about what conditions on Earth will be like?

Most weather phenomena occur as a result of the movement of warm and cold air masses. The border between these bodies of air are known as 'fronts', and it's here that the most exciting weather, including precipitation and wind, occurs.

As a body of air passes across different types of terrain – such as over the oceans, low-lying areas or even mountainous regions – air temperature and moisture levels can change dramatically. When two air masses at different temperatures meet, the less dense, warmer of the two masses rises up and over the colder. Rising warm air creates an area of low pressure (a depression), which is associated with unsettled conditions like wind and rain.

We know how a frontal weather system will behave and which conditions it will produce down on the ground. The man who first brought the idea of frontal weather systems to the fore in the early 20th century was a Norwegian meteorologist called Vilhelm Bjerknes. Through his constant observation of the weather conditions at frontal boundaries, he discovered that numerical calculations could be used to predict the weather. This model of weather prediction is still used today.

Since the introduction of frontal system weather forecasting, the technology to crunch the numbers involved has advanced immeasurably, enabling far more detailed analysis and prediction. In order to forecast the weather with the greatest accuracy, meteorologists require vast quantities of weather data – including temperature, precipitation, cloud coverage, wind speed and wind direction – collected from weather stations located all over the world. Readings are taken constantly and fed via computer to a central location.

Technology is essential to both gathering and processing the statistical data about the conditions down on Earth and in the upper atmosphere. The massive computational power inside a supercomputer, for example, is capable of predicting the path and actions of hurricanes and issuing life-saving warnings. After taking the information collected by various monitors and sensors, a supercomputer can complete billions of calculations per second to produce imagery that can reveal how the hurricane is expected to develop.

FREAKY

1. Moonbows
These are rainbows caused by moonlight. They often appear white to the naked eye, and appear best with a full moon.

FREAKIER

2. Sundogs
A phenomenon whereby there appears to be more than one sun in the sky. Sundogs are faint rings of light created when horizontal ice crystals in the atmosphere align to refract light.

FREAKIEST

3. Raining animals
It has been known to 'rain' frogs and fish. It is thought that the animals are picked up by strong winds over water.

DID YOU KNOW? *The MET office has more than 200 automatic weather stations in the UK; they are usually 40km (25mi) apart*

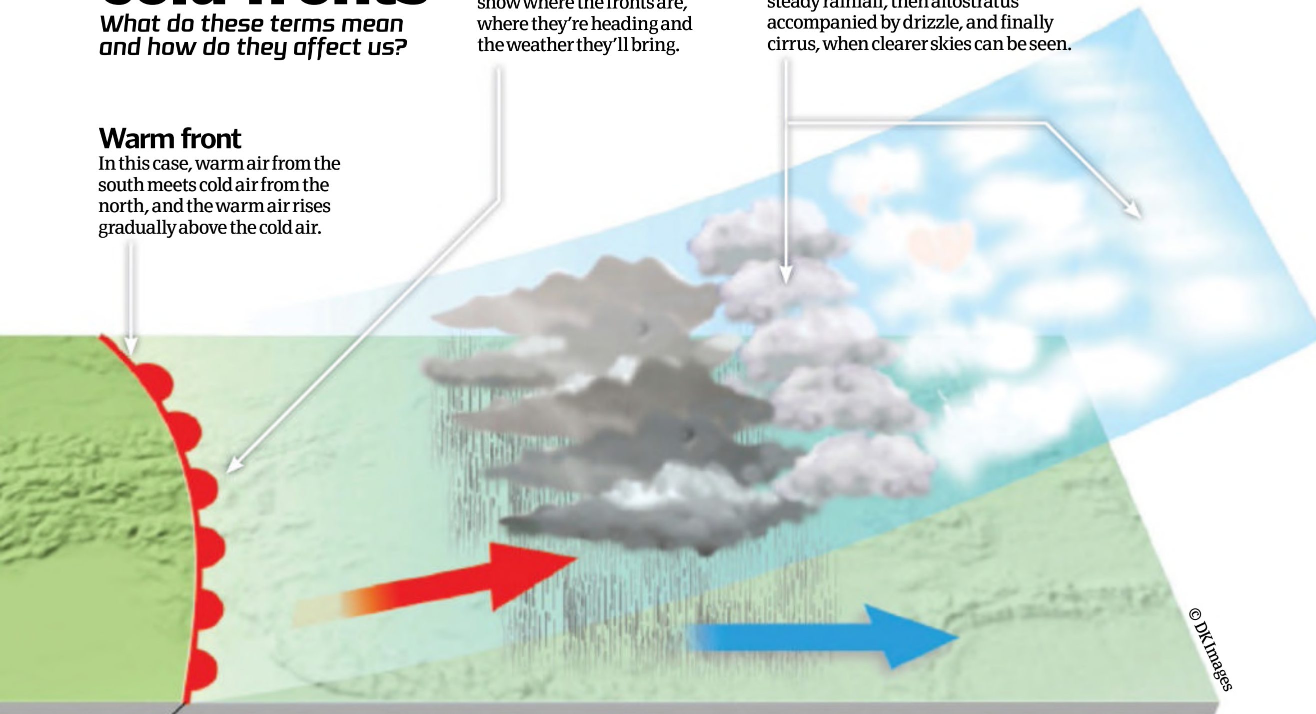
Warm and cold fronts

What do these terms mean and how do they affect us?

In practice
The red curves of a warm front and blue triangles of a cold front are shown on a map to show where the fronts are, where they're heading and the weather they'll bring.

Warm front conditions
As the warm air slowly rises, it cools and condenses and clouds are formed. These are nimbostratus, causing steady rainfall, then altostratus accompanied by drizzle, and finally cirrus, when clearer skies can be seen.

Warm front
In this case, warm air from the south meets cold air from the north, and the warm air rises gradually above the cold air.



© DK Images

WEATHER FORECAST MAP

Learn what these weather-related signs and symbols mean

High pressure
Weather here will be clear and dry, due to the high pressure. If this high pressure occurs in summer weather will be warm, whereas in winter it will be cold and crisp.

Wind
The conditions at this point will be windy. This is indicated by the position of the isobars; the closer together they are the windier the conditions.

Low pressure
At the centre of these circular patterns of isobars is where systems of high or low pressure lie. Where there is low pressure conditions will be rainy and windy.

Isobars
These indicate atmospheric pressure. Areas of equal atmospheric pressure are joined together with the lines shown and the numbers indicate pressure measured in millibars. Lower numbers indicate low pressure, while higher numbers indicate high pressure.

© DK Images

Occluded front
This is where one front 'catches up' with another. In this example, the cold has caught up with the warm. Occluded fronts cause the weather to change quite quickly and, in this case, become similar to that of a cold front.

Cold front
As with any cold front, the weather here will be expected to be cool with heavy rainfall and possibly even thunderstorms. This will be followed by showers.

In between
After the passing of the warm front and before the arrival of the cold front conditions should be clear and dry, but normally only for a short period.

Warm front
The warm front will cause steady rainfall, followed by drizzle, accompanied by cloudy skies. These are typical conditions caused by any warm front.

© Thinkstock

Stormy weather

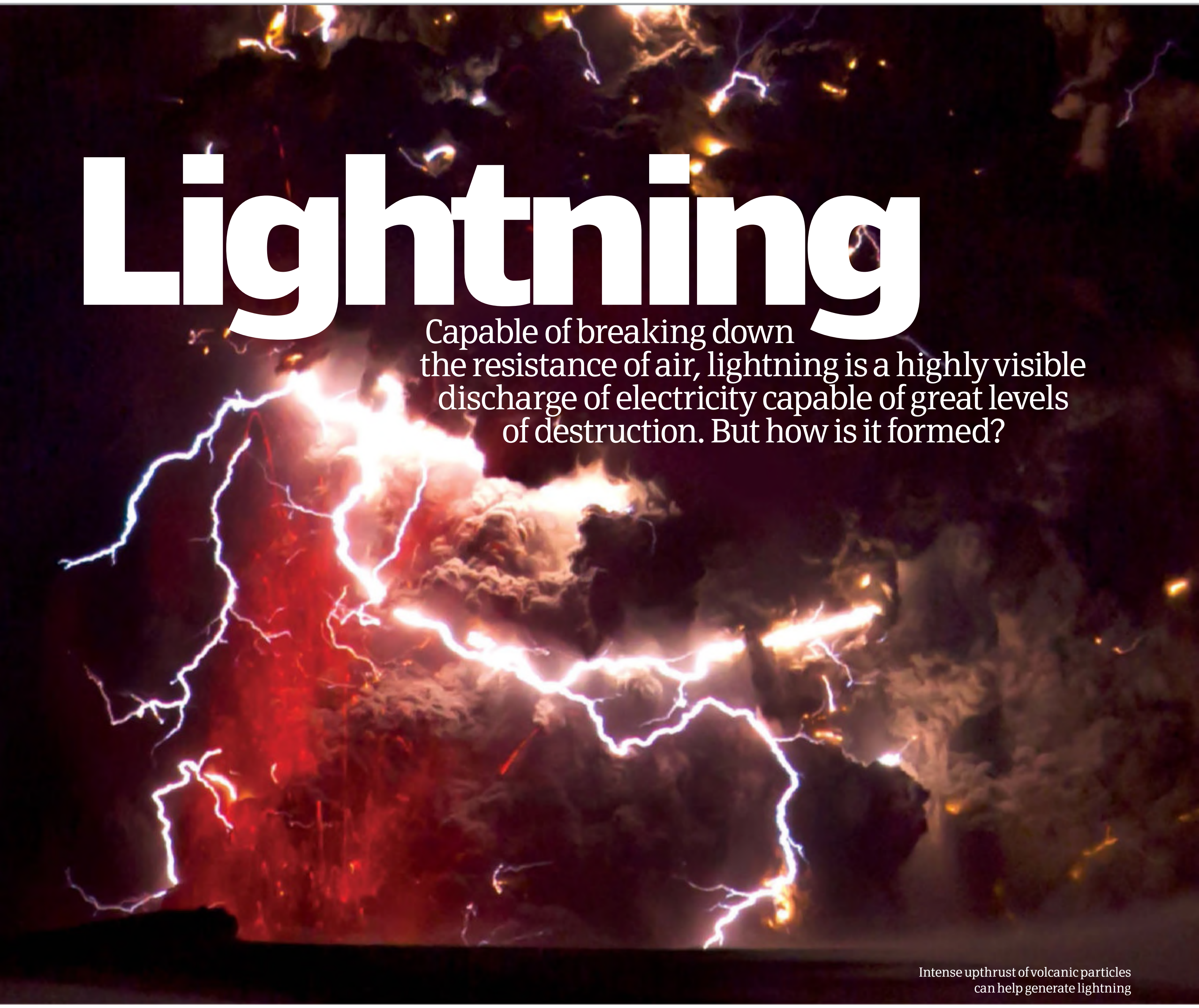
Hail
The tops of storm clouds are full of tiny ice crystals that grow heavier until they fall through the cloud. The biggest hail stone on record was 17.8cm (7in).

Lightning
A flash of lightning is a giant spark caused when the molecules in a thunder cloud collide and build up static electricity. The flash occurs when a spark jumps through a cloud, or from the cloud to the ground, or from one cloud to another.

Thunder
This is the noise produced by lightning. An increase in pressure and temperature cause the air nearby to rapidly expand, which produces the characteristic sound of a sonic boom.

Storm cloud
Your typical run-of-the-mill cloud can be hundreds of metres high. A storm cloud, however, can reach heights of over ten kilometres (that's six miles).

How many...?
16 million thunderstorms occur each year globally.



Lightning

Capable of breaking down the resistance of air, lightning is a highly visible discharge of electricity capable of great levels of destruction. But how is it formed?

Intense upthrust of volcanic particles can help generate lightning

Lightning occurs when a region of cloud attains an excess electrical charge, either positive or negative, that is powerful enough to break down the resistance of the surrounding air. This process is typically initiated by a preliminary breakdown within the cloud between its high top region of positive charge, large central region of negative charge and its smaller lower region of positive charge.

The different charges in the cloud are created when water droplets are supercooled within it to freezing temperatures and then collide with ice crystals. This process causes a slight positive charge to be transferred to the smaller ice crystal particles and a negative one to the larger ice-water mixture, with the former rising to the top on updrafts and the latter falling to the bottom under the effect of gravity. The consequence of this is gradual separation of charge between the upper and lower parts of the cloud.

This polarisation of charges forms a channel of partially ionised air – ionised air is that in which neutral atoms and molecules are converted to electrically charged ones – through which an initial lightning stroke (referred to as a 'stepped leader') propagates down through towards the ground. As the stepped leader reaches the Earth, an upwards connecting discharge of the opposing polarity meets it and completes the connection, generating a return stroke that due to the channel now being the path of least resistance, returns up through it to the cloud at one-third the speed of light and creating a large flash in the sky.

This leader-return stroke sequence down and up the ionised channel through the air commonly occurs three or four times per strike, faster than the human eye is capable of perceiving. Further, due to the massive potential difference between charge areas – often extending from ten to 100 million volts – the return stroke can hold currents up to 30,000 amperes and reach 30,000°C (54,000°F). Typically the leader stroke reaches the ground in ten milliseconds

5 TOP FACTS LIGHTNING

Technicolour
1 The super-rare ball lightning can materialise in different colours, ranging from blue through yellow and on to red. It is also typically accompanied by a loud hissing sound.

Zeus
2 The ancient Greeks believed that lightning was the product of the all-powerful deity, weather controller and sky god Zeus. His weapon for smiting was the lightning bolt.

Harvest
3 Since 1980 lightning has been looked at by energy companies as a possible source of energy, with numerous research projects launched to investigate its potential.

Fawksio
4 In 1769 in Brescia, Italy, lightning struck the Church of St Nazaire, igniting 100 tons of gunpowder in its vaults. The explosion killed 3,000 and destroyed a sixth of the city.

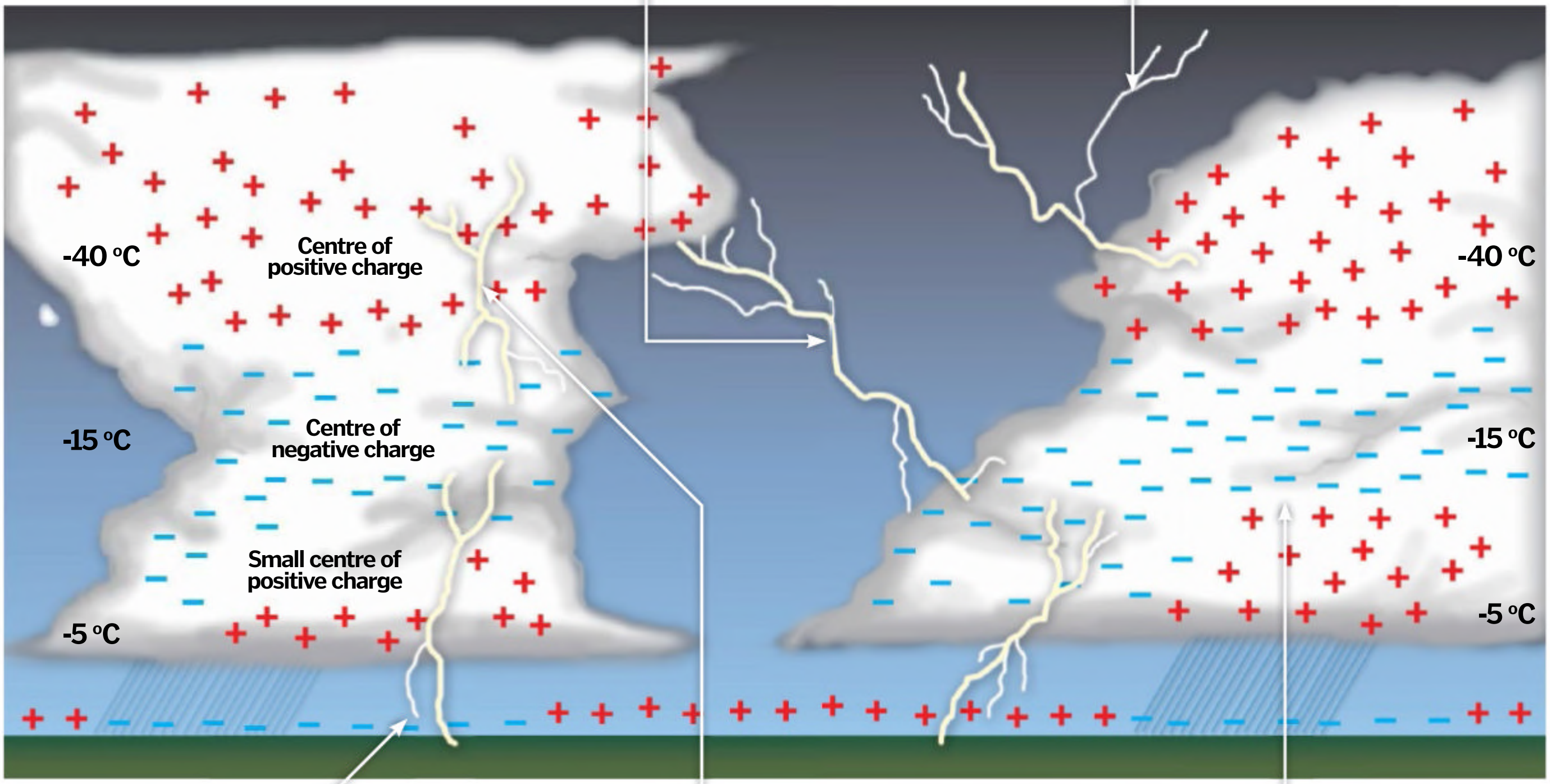
Flashmaster
5 From satellite data, scientists postulate that there are roughly 1.4 billion lightning flashes a year. 75 per cent of these flashes are either cloud-to-cloud or intra-cloud.

DID YOU KNOW? *The peak temperature of a lightning bolt's return-stroke channel is 30,000°C (54,000°F)*

Explaining the formation of lightning

Cloud-to-cloud
As with cloud-to-ground, cloud-to-cloud lightning discharges occur between polarised areas of differing charge, however here the ionised channel runs between clouds instead of a cloud to the ground.

Cloud-to-air
Similar to cloud-to-cloud, cloud-to-air strikes tend to emanate from the top-most area of a cloud that is positively charged, discharging through an ionised channel directly into the air.



Cloud-to-ground
Cloud-to-ground lightning occurs when a channel of partially ionised air is created between areas of positive and negative charges, causing a lightning stroke to propagate downward to the ground.

Intra-cloud
Intra-cloud lightning is the most frequent type worldwide and occurs between areas of differing electrical potential within a single cloud. It is responsible for most aeroplane-related lightning disasters.

Charge differential
Clouds with lightning-generating potential tend to consist of three layers of charge, with the top-most part a centre of positive charge, the middle a centre of negative charge, and the bottom a secondary small centre of positive charge.

and the return stroke reaches the instigating cloud in 100 microseconds.

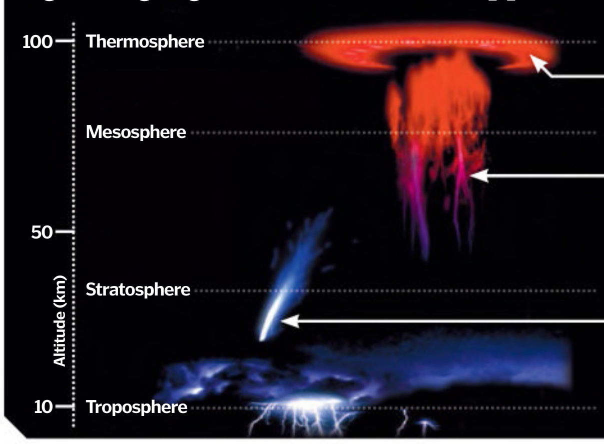
Lightning, however, does not just occur between clouds (typically cumulonimbus or stratiform) and the ground, but also between separate clouds and even intra-cloud. In fact, 75 per cent of all lightning strikes worldwide are cloud-to-cloud or intra-cloud, with discharge channels forming between areas of positive and negative charges between and within them. In addition, much lightning occurs many miles above the Earth in its upper atmosphere (see 'Atmospheric lightning' boxout), ranging from types that emanate from the top of clouds, to those that span hundreds of miles in width.

Interestingly, despite the high frequency of lightning strikes and their large amount of contained energy, current efforts by the scientific community to harvest its power have been fruitless. This is mainly caused by the inability of modern technology to receive and store such a large quantity of energy in such a short period of time, as each strike discharges in mere milliseconds. Other issues preventing lightning's use as an energy source include its sporadic nature – which while perfectly capable of striking the same place twice, rarely does – and the difficulties involved in converting high-voltage electrical power delivered by a strike into low-voltage power that can be stored and used commercially.

> *"Due to the massive potential difference between charge areas the return stroke can hold currents up to 30,000 amperes and reach 30,000°C (54,000°F)"*

Atmospheric lightning

Unseen apart from by satellites, a major part of the world's annual lightning is generated in Earth's upper atmosphere.



Elves
Vast 250-mile wide flattened discs of light, elves occur above low-lying thunderstorms. They are caused by the excitation of nitrogen molecules due to electron collisions in the atmosphere.

Sprites
Sprites are caused by the discharges of positive lightning from thunderclouds to the ground. They vary in colour from red to blue and appear akin to large jellyfish.

Blue jets
Emanating from the top of cumulonimbus clouds and stretching in a cone shape up into the stratosphere and mesosphere, blue jets are caused by intense hail activity within a storm.

Lightning types

Far from uniform, lightning is an unpredictable phenomenon

Bead lightning

A type of cloud-to-ground lightning where the strike seems to break up into smaller, super-bright sections (the beads), lasting longer than a standard discharge channel.

Frequency: **Rare**

Ribbon lightning

Only occurring in storms with high cross winds and multiple return strokes, ribbon lightning occurs when each subsequent stroke is blown to the side of the last, causing a visual ribbon effect.

Frequency: **Quite rare**

Staccato lightning

A heavily branched cloud-to-ground lightning strike with short duration stroke and incredibly bright flash.


© Scotto Bear

Frequency: **Common**

Sheet lightning

A generic term used to describe types of cloud-to-cloud lightning where the discharge path of the strike is hidden from view, causing a diffuse brightening of the surrounding clouds in a sheet of light.


© Christian Artntzen

Frequency: **Common**

Megalightning

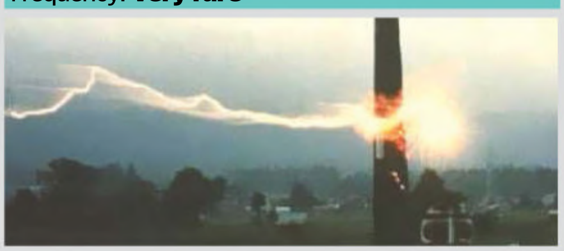
A term commonly used when referring to upper-atmospheric types of lightning. These include sprites, blue jets and elves (see 'Atmospheric lightning' boxout) and occur in the stratosphere, mesosphere and thermosphere.

Frequency: **Frequent**

Ball lightning

Considered as purely hypothetical by meteorologists, ball lightning is a highly luminous, spherical discharge that according to few eyewitnesses last multiple seconds and can move on the wind.

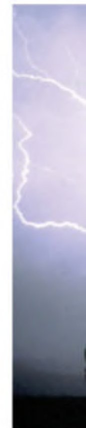
Frequency: **Very rare**



Lightning hotspots

A look at some of the most dangerous places to be when lightning strikes

Multiple strikes
The Empire State Building is struck 24 times per year on average. It was once struck eight times in 24 minutes.



Danger zone
Ten per cent of all people struck by lightning were in Florida at the time.

70% OF GLOBAL LIGHTNING OCCURS IN THE TROPICS


© Cgoodwin

'Damn! And to think that tree was just two months from retirement'


© Thechemicalengineer

Flashes
Above the Catatumbo River in Venezuela lightning flashes several times per minute 160 nights of the year.

Global hotspot
The small village of Kifuka is the most struck place on Earth, with 158 strikes per square kilometre per year.

What are the chances?

The odds of being hit by lightning aren't as slim as you think...

1 in 300,000

The chance of you getting struck by lightning is one in 300,000. Which, while seeming quite unlikely, did not stop US park ranger Roy Sullivan from being struck a world record seven times during his lifetime.

HEAD 2 HEAD
LIGHTNING IN FILMS

MOST CLASSICAL

1. Percy Jackson & The Lightning Thief

A film in which Percy 'Perseus' Jackson, son of Poseidon, must fight mythological beasts and travel to Hades to retrieve Zeus' stolen lightning bolt in order to prevent a war.

MOST FUTURISTIC

2. Back To The Future

Protagonist Marty McFly travels back in time in Doc Brown's time travelling, lightning-inducing DeLorean, in order to ensure his parents hook-up and guarantee his own existence.

MOST IMMORTAL

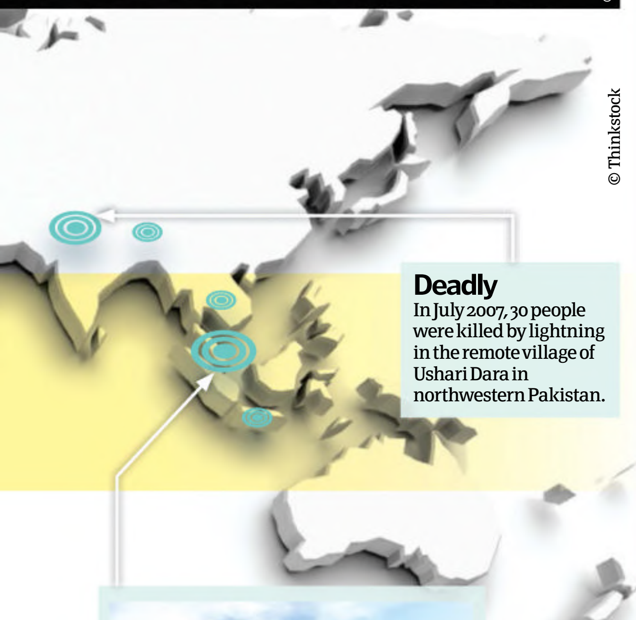
3. Highlander

An immortal Scottish swordsman must confront his last two rivals in order to win the fabled 'Prize'. Of course, each time a foe is vanquished his power is absorbed in a lightning strike.

DID YOU KNOW? *The irrational fear of lightning is referred to as astraphobia*

Cloud-to-cloud lightning streaks across the Masai Mara Game Reserve in Kenya, Africa

© Science Photo Library



© Thinkstock

Deadly
In July 2007, 30 people were killed by lightning in the remote village of Ushari Dara in northwestern Pakistan.

Singapore strikes!
Singapore has one of the world's highest rates of lightning activity.

in comparison…

1 in 14,000,000
The chance of winning the lottery in the UK is one in 14 million. That is over 45 times as unlikely as being struck.

1 in 11,000,000
Flying on a single-trip commercial air flight inflicts you to a one in 11 million chance of being killed in an accident.

1 in 12,000,000
The odds of getting hit by lightning are 40 times more likely than the chance of dying from Mad Cow Disease in the UK.

1 in 8,000
In order to get better odds, go out in your car. Over 3,000 people are killed every day on roads worldwide.

What happens when you get struck by lightning?

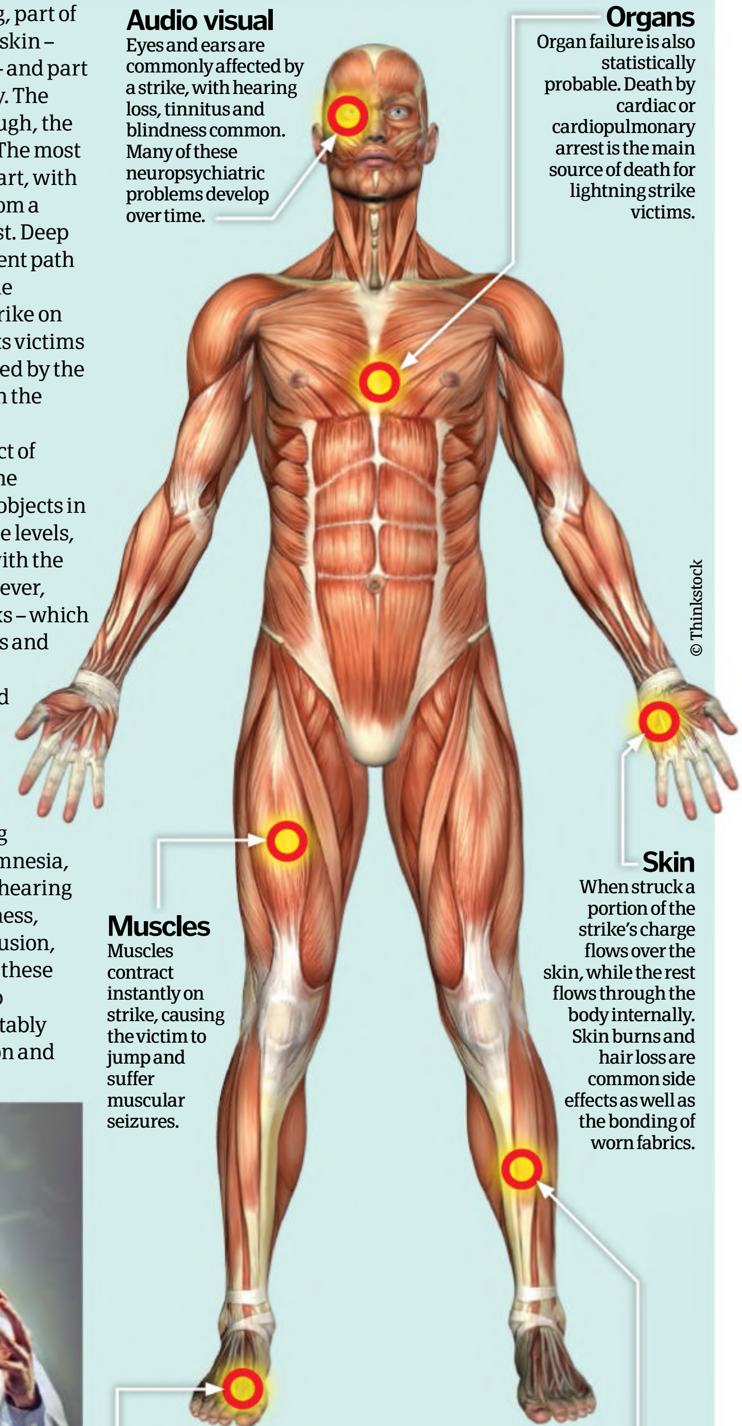
The parts of the body that feel the effect if struck by lightning

When a human is hit by lightning, part of the strike's charge flows over the skin – referred to as external flashover – and part of it goes through them internally. The more of the strike that flows through, the more internal damage it causes. The most common organ affected is the heart, with the majority of people who die from a strike doing so from cardiac arrest. Deep tissue destruction along the current path can also occur, most notably at the entrance and exit points of the strike on the body. Lightning also causes its victims to physically jump, which is caused by the charge contracting the muscles in the body instantaneously.

Burns are the most visible effect of being struck by lightning, with the electrical charge heating up any objects in contact with the skin to incredible levels, causing them to melt and bond with the human's skin. Interestingly, however, unlike industrial electrical shocks – which can last hundreds of milliseconds and tend to cause widespread burns over the body – lightning-induced burns tend to be centred more around the point of contact, with a victim's head, neck and shoulders most affected.

Post-strike side-effects of being struck by lightning range from amnesia, seizures, motor control damage, hearing loss and tinnitus, through blindness, sleep disorders, headaches, confusion, tingling and numbness. Further, these symptoms do not always develop instantaneously, with many – notably neuropsychiatric problems (vision and hearing) – developing over time.

© Science Photo Library



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Audio visual
Eyes and ears are commonly affected by a strike, with hearing loss, tinnitus and blindness common. Many of these neuropsychiatric problems develop over time.

Organs
Organ failure is also statistically probable. Death by cardiac or cardiopulmonary arrest is the main source of death for lightning strike victims.

Skin
When struck a portion of the strike's charge flows over the skin, while the rest flows through the body internally. Skin burns and hair loss are common side effects as well as the bonding of worn fabrics.

Muscles
Muscles contract instantly on strike, causing the victim to jump and suffer muscular seizures.

Body tissue
Deep tissue destruction is common along the current path, which courses through the body from cranium to feet.

Nervous system
Motor control damage is common, often permanently affecting muscle and limb movement, neural circuitry and motor planning and execution decisions.

Firestorms

From tornado-force winds to superhot flames, dare you discover nature's most violent infernos?

50,000km²

BIGGEST-EVER BUSHFIRE

The Black Thursday bushfires on 6 February 1851 burnt the largest area of any Australian bushfire in European-recorded history: a quarter of Victoria!

DID YOU KNOW? *Large wildfires have increased by 300 per cent in western USA since the mid-Eighties*

Firestorms are among nature's most violent and unpredictable phenomena. Tornado-force winds sweep superhot flames of up to 1,000 degrees Celsius (1,800 degrees Fahrenheit) through buildings and forests alike. Victims often suffocate before they can flee and entire towns can be obliterated. Survivors of firestorms describe darkness, 100-metre (330-foot)-high fireballs and a roaring like a jumbo jet. To give you an idea of the sheer heat, firestorms can be hot enough to melt aluminium and tarmac, warp copper and even turn sand into glass.

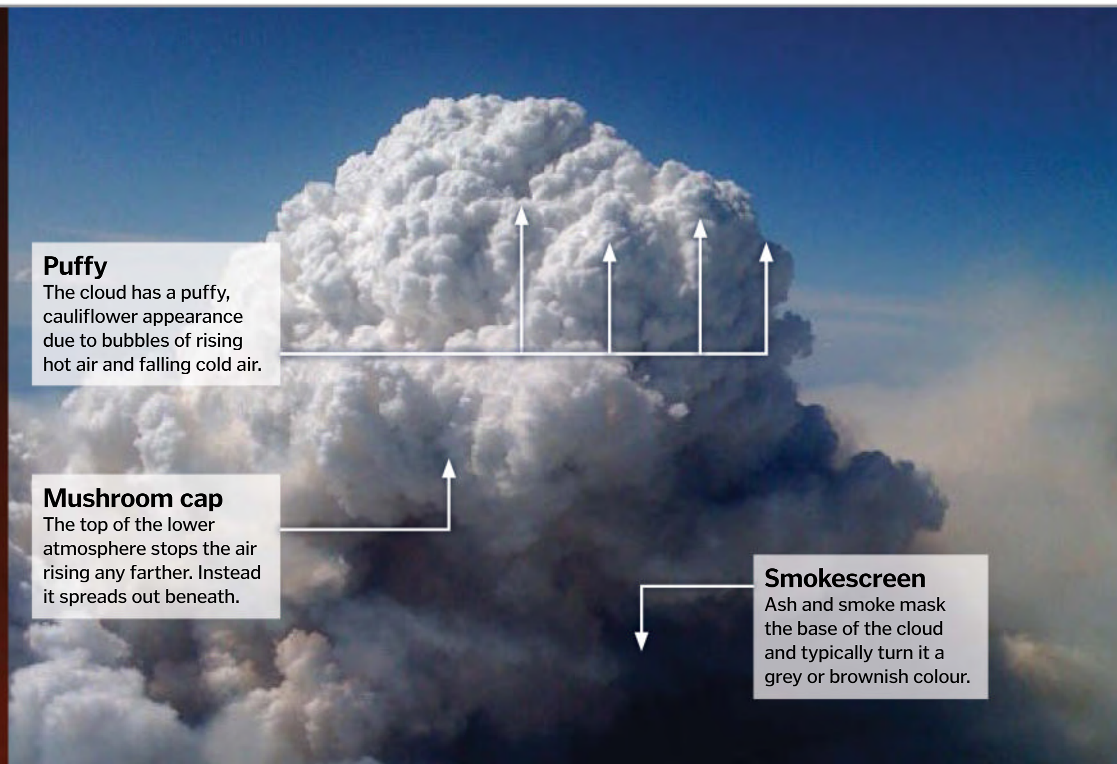
Firestorms happen worldwide, especially in the forests of the United States and Indonesia, and in the Australian bush. They occur mostly in summer and autumn when vegetation is tinder dry. Although they are a natural phenomenon, among the most devastating were triggered deliberately. During World War II, for instance, Allied forces used incendiaries and explosives to create devastating firestorms in Japanese and German cities. Firestorms also erupted after the cataclysmic impact 66 million years ago that many believe to have triggered the extinction of the dinosaurs.

Climate change may be already increasing the risk of mega-fires by making summers ever hotter and drier. The Rocky Mountain Climate Organization, for example, has reported that from 2003 to 2007, the 11 western US states warmed by an average of one degree Celsius (1.8 degrees Fahrenheit). The fire danger season has gone up by 78 days since 1986.

The risk of an Australian firestorm striking a major city has also heightened in the last 40 years. Climate change may have exacerbated this by increasing the risk of long heat waves and extremely hot days. In January 2013 alone, a hundred bushfires raged through the states of New South Wales, Victoria and Tasmania following a record-breaking heat wave. Maximum daily temperatures rose to 40.3 degrees Celsius (104.5 degrees Fahrenheit), beating the previous record set in 1972.

Firestorms can happen during bush or forest fires, but are not simply wildfires. Indeed, a firestorm is massive enough to create its own weather (see boxout). The thunderstorms, powerful winds and fire whirls – mini tornadoes of spinning flames – it can spawn are all part of its terrifying power.

The intense fire can have as much energy as a thunderstorm. Hot air rises above it, sucking in additional oxygen and dry debris, which fuel and spread the fire. Winds can reach



How do mushroom clouds form?

The terrifying mushroom clouds produced after nuclear bombs are examples of pyrocumulus, or fire, clouds. This towering phenomenon is caused by intense ground heating during a firestorm. Their tops can reach an incredible nine kilometres (six miles) above the ground. When the fire heats the air, it rises in a powerful updraft that lifts water vapour, ash and dust. The vapour starts to cool high in the atmosphere and condenses as water droplets on the ash. As a result, a cloud forms that can quickly become a thunderstorm with lightning and rain, if enough water is available. The lightning can start new fires, but on the bright side, rain can extinguish them.

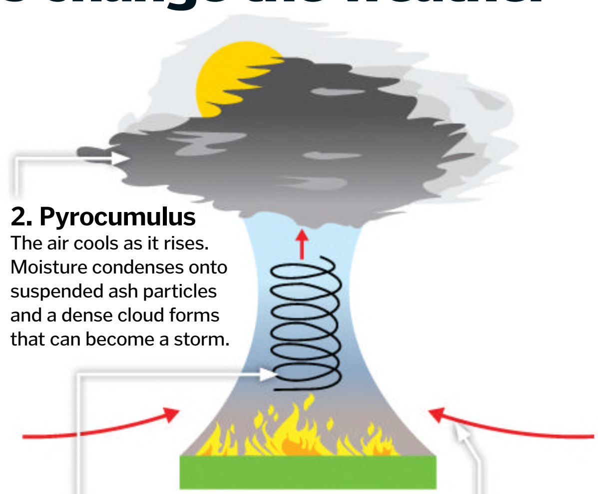
How firestorms change the weather

Firestorms can release as much energy as a lightning storm on a hot summer's afternoon.

Warm air above the fire is lighter than the surrounding air so it rises; the swirling pillar of lifting air above the fire is called a thermal column. This tornado-like structure is responsible for a firestorm's power. Under the right weather conditions, air can rise inside the column at eye-watering speeds of 270 kilometres (170 miles) per hour!

Cooler air gusts into the space left behind by the ascending air, causing violent winds that merge fires together into a single intense entity. They also blow in oxygen, wood and other flammable material that serve to fuel and intensify the blaze.

Turbulent air spiralling around the thermal column can spawn fire tornadoes and throw out sparks. These can set light to trees and houses tens of metres away, increasing the conflagration's range.



tornado speed – tens of times the ambient wind speeds. The huge pillar of rising air – called a thermal column – swirling above the firestorm can generate thunderclouds and even lightning strikes that spark new fires.

The thermal column, in turn, can spawn a number of fiery tornadoes, which can tower to 200 metres (650 feet) and stretch 300 metres (980 feet) wide, lasting for at least 20 minutes. These fling flaming logs and other burning debris across the landscape, spreading the blaze. The turbulent air can gust at 160 kilometres (100 miles) per hour, scorching hillsides as far as 100 metres (330 feet) away from the main fire. It's far more powerful than a typical wildfire, which moves at around 23 kilometres (14.3 miles) per hour – just under the average human sprint speed.

Like all fires, firestorms need three things to burn. First is a heat source for ignition and to dry fuel so it burns easier. Fuel, the second must, is anything that combusts, whether that be paper, grass or trees. Thirdly, all fires need at least 16 per cent oxygen to facilitate their chemical processes. When wood or other fuel burns, it reacts with oxygen in the surrounding air to release heat and generate smoke, embers and various gases. Firestorms are so intense that they often consume all available oxygen, suffocating those who try to take refuge in ditches, air-raid shelters or cellars.

Fighting firestorms

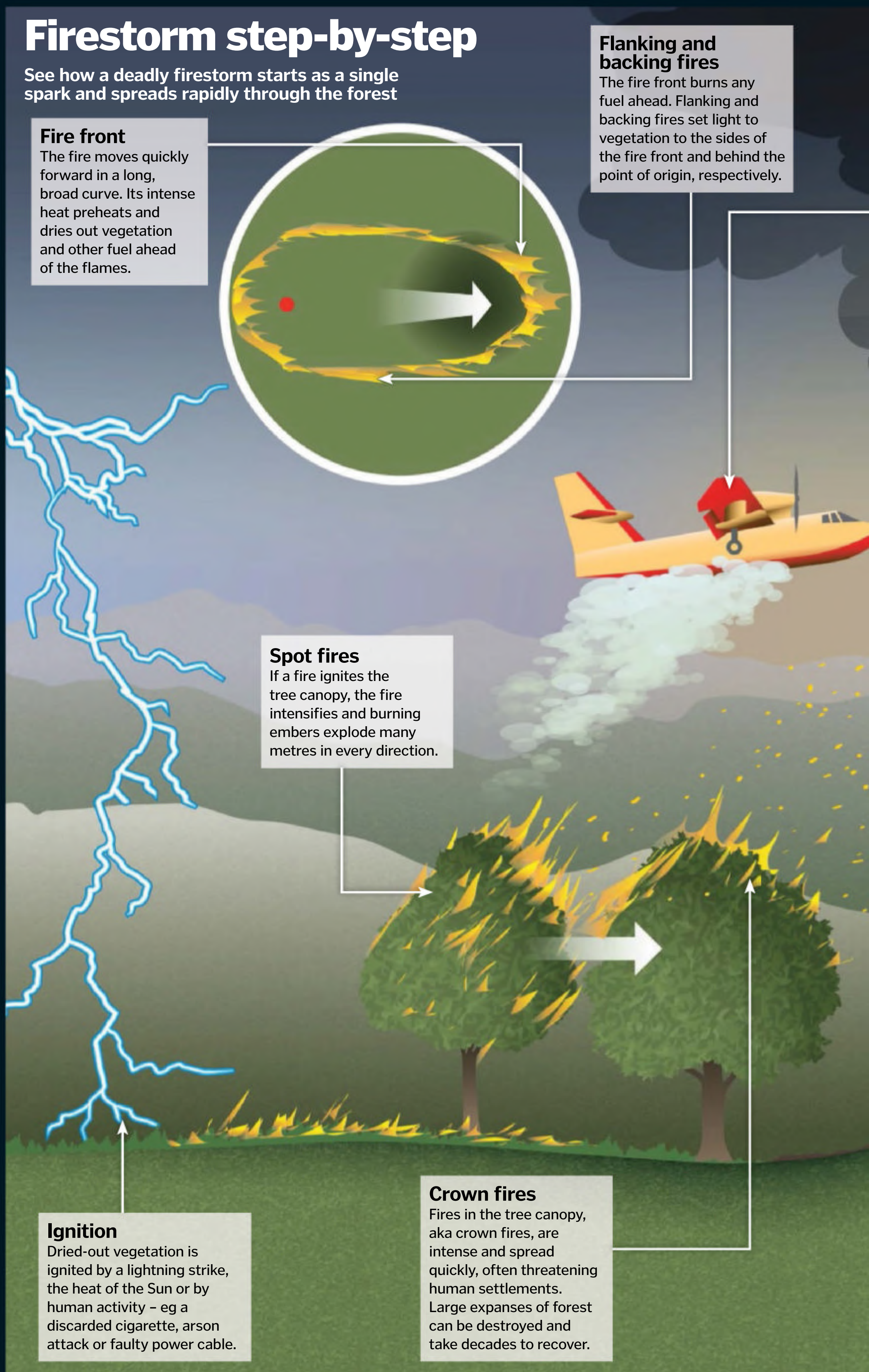
Fire wardens, air patrols and lookout stations all help detect fires early, before they can spread. Once a fire starts, helicopters and air tankers head to the scene. They spray thousands of gallons of water, foam or flame-retardant chemicals around the conflagration. In the meantime, firefighters descend by rope or parachute to clear nearby flammable material.

We can reduce the risk of fire breaking out in the first place by burning excess vegetation under controlled conditions. Surprisingly this can actually benefit certain plants and animals. Canadian lodgepole pines, for example, rely partly on fire to disperse their seeds. Burning also destroys diseased trees and opens up congested woodland to new grasses and shrubs, which provides food for cattle and deer.

Vegetation in fire-prone areas often recovers quickly from a blaze. Plants like Douglas fir, for instance, have fire-resistant bark – although it can only withstand so much heat. Forest owners help flora to return by spreading mulch, planting grass seed and erecting fences.

Firestorm step-by-step

See how a deadly firestorm starts as a single spark and spreads rapidly through the forest



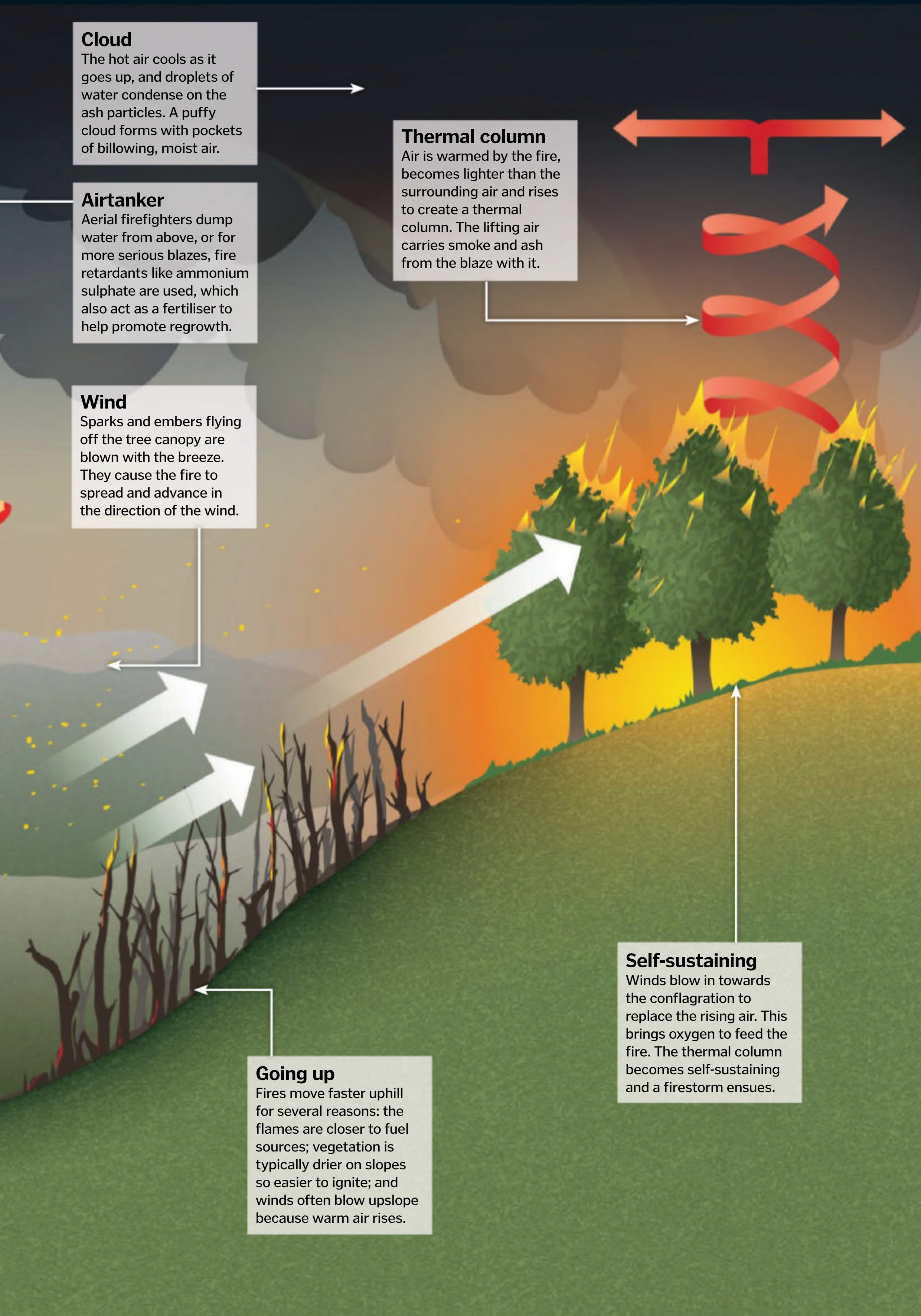
Fire front
The fire moves quickly forward in a long, broad curve. Its intense heat preheats and dries out vegetation and other fuel ahead of the flames.

Flanking and backing fires
The fire front burns any fuel ahead. Flanking and backing fires set light to vegetation to the sides of the fire front and behind the point of origin, respectively.

Spot fires
If a fire ignites the tree canopy, the fire intensifies and burning embers explode many metres in every direction.

Ignition
Dried-out vegetation is ignited by a lightning strike, the heat of the Sun or by human activity – eg a discarded cigarette, arson attack or faulty power cable.

Crown fires
Fires in the tree canopy, aka crown fires, are intense and spread quickly, often threatening human settlements. Large expanses of forest can be destroyed and take decades to recover.



Five mega firestorms

1 Black Saturday
In 2009, one of Australia's worst bushfires killed 173 people, injured 5,000, destroyed 2,029 homes, killed numerous animals and burnt 4,500 square kilometres (1,700 square miles) of land. Temperatures may have reached 1,200 degrees Celsius (2,192 degrees Fahrenheit).

2 Great Peshtigo
The deadliest fire in American history claimed 1,200-2,500 lives, burned 4,860 square kilometres (1,875 square miles) of Wisconsin and upper Michigan and destroyed all but two buildings in Peshtigo in 1871.

3 Ash Wednesday
More than 100 fires swept across Victoria and South Australia on 16 February 1983, killing 75 people, destroying 3,000 homes and killing 50,000 sheep and cows. It was the worst firestorm in South Australia's history.

4 Hamburg
This firestorm brought on by an Allied bomb strike in 1943 killed an estimated 44,600 civilians, left many more homeless and levelled a 22-square-kilometre (8.5-square-mile) area of the German city. Hurricane-force winds of 240 kilometres (150 miles) per hour were raised.

5 Great Kanto
A 7.9-magnitude earthquake on 1 September 1923 triggered a firestorm that burned 45 per cent of Tokyo and killed over 140,000. This included 44,000 who were incinerated by a 100-metre (330-foot) fire tornado.

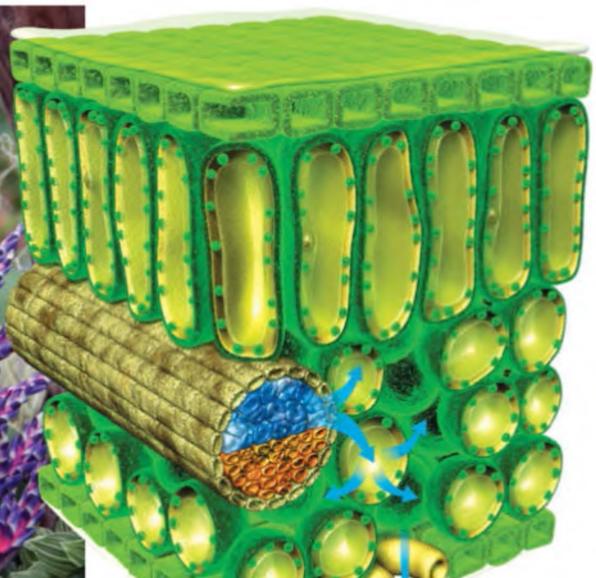
PLANTS & ORGANISMS

Cloning plants 061

How cacti survive 060

062 **How do air plants survive?**

© NOAA



048 **Life cycle of a plant**

058 **Life of an oak tree**

063 **How is coffee grown?**

057 **The world's biggest flower**

055 **The Venus flytrap**

056 **Deadliest plants**

A sunflower head comprises up to 2,000 tiny individual flowers

How plants work

Could you stay put in your birthplace for hundreds of years, surviving off whatever happens to be around?

Truly, it's not easy being green. But plants not only survive, they thrive all over the globe, without the benefit of muscles, brains or personalities. It's a good thing they do: plants head up nearly all food chains, pump out the oxygen we breathe, hold off erosion and filter pollutants out of the atmosphere. Over the past 3.5 billion years, they've diversified into an estimated 320,000-430,000 separate species, with more coming to light every year.

All this stems from one neat trick: harnessing the Sun's energy to power a built-in food factory. Through this process, called photosynthesis, plants combine carbon dioxide with water to create carbohydrates that they use to grow and reproduce. The earliest plants, similar to today's algae, didn't do much other than photosynthesise. They floated around in the ocean, soaking up water and rays and reproducing asexually. Then, around 500 million years ago, plants evolved to live on land, to obtain the power boost of more abundant sunlight. The first landlubber plants still needed to stay wet all over, however, so they were confined to perpetually damp areas. Today's mosses, liverworts, and hornworts have the same limitations.

Things got more exciting 90 million years later, when plants went vascular. Vascular plants have tissue structures that can distribute water and nutrients absorbed by one part of the body to the rest of the body. Instead of spending its days soaking in a puddle, a vascular plant can grow roots down into the ground to soak up water and minerals while sending shoots up into the dry air, topped with leaves that soak up sunshine to power the food factory. This feature allows vascular plants to evolve to a larger size than non-vascular plants.

Plants can store this food in their roots, in the form of root tubers, like carrots and sweet potatoes. Above ground, vascular plants protect themselves and retain their water supply with a waxy, waterproof covering called cuticle. Cuticle makes plants hearty enough to reach high into the air or spread far along the ground.

Plants grow at meristems, areas with cells that are capable of division – that is, making new cells. Hormones control this cell division to grow particular forms, like leaves, as well as controlling the direction of growth, guided by what the plant

5 TOP FACTS DEADLIEST PLANTS

Tobacco
1 Ranked by human death toll, the tobacco plants (multiple species in the genus Nicotiana) are easily the most notorious killers. These herbs cause one in ten adult deaths every year.

Hemlock
2 Coniine, the toxin in the poison hemlock that killed Socrates, paralyses the respiratory system. The cicutoxin in water hemlock causes seizures with violent muscle contractions.

Oleander
3 Oleander is a true heart-stopping beauty. If you chow down on this surprisingly common backyard shrub, however, it's likely to send you into cardiac arrest.

Gympie-gympie
4 This stinging tree species lurks in northern Australia and Indonesia. It penetrates your skin with tiny glass-like silicon hairs, covered in a deadly neurotoxin.

Giant pitcher plant
5 These Philippines natives are trouble for insects and rodents. Lured by nectar, victims – or nutrient sources – slip into a vat of acid with ribs that block escape.

DID YOU KNOW? Some seeds can lie dormant for years. In 1966, scientists successfully planted 10,000 year-old tundra lupine

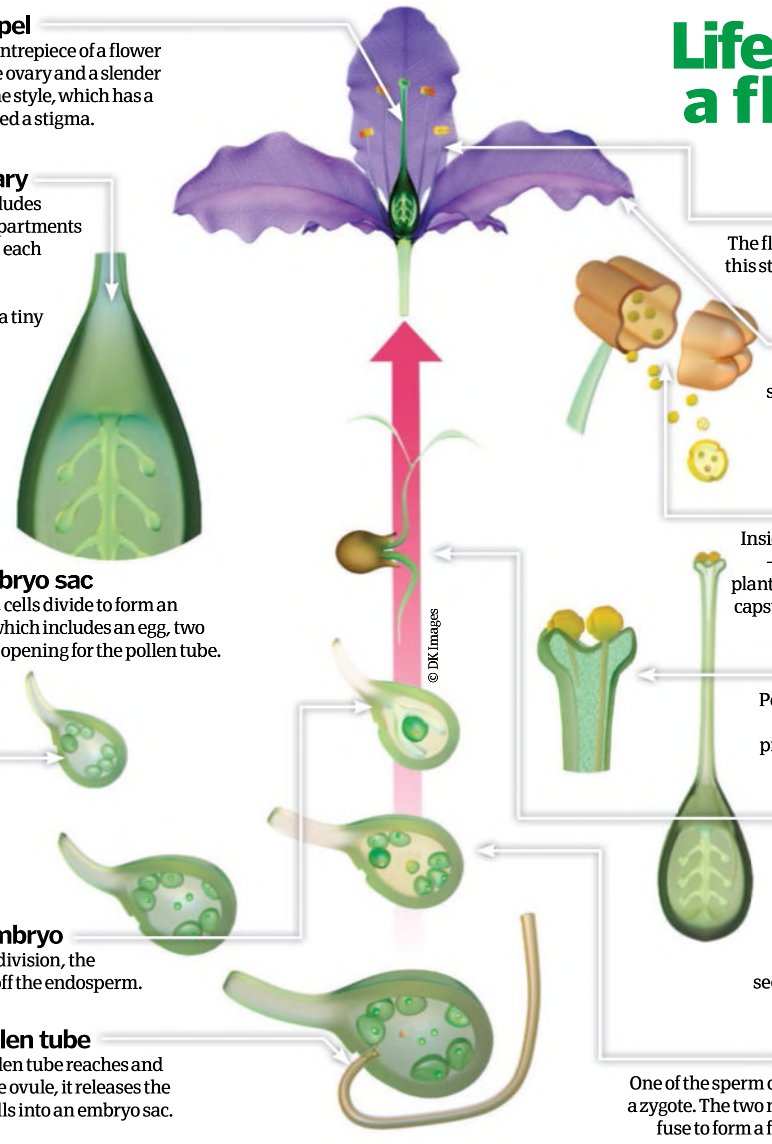
'senses'. Based on the settling of starch grains that indicate the direction of gravity, the growth hormone auxin drives stems to grow up towards the sky and roots to grow down towards water. Then, plants actually turn leaves toward the Sun. Triggered by light-sensitive cells that effectively 'see' light, the hormone auxin causes more cells to grow on the dimmer side of a stem, making the stem and attached leaf bend towards sunlight. Similarly, vines automatically curl when they come across a larger plant, causing them to wrap and climb.

Plants switch sexual orientation every generation. Each sporophyte generation produces male and female spores, which asexually yield male and female plants. In this gametophyte generation, males produce sperm and females produce eggs, which join up to create new sporophyte plants. Typically, the sporophyte generation is a large, familiar plant, while the gametophyte generation is tiny. For example, pollen is tiny male plants in the gametophyte generation. The tiny males and females produce an embryo, or seed.

When you can't walk, spreading your seed requires a little more creativity. For example, flowering plants attract insects with nectar, and then coat their legs with pollen to carry to the next plant. Plants also develop tasty fruits around plant seeds to entice animals to swallow seeds, and then defecate those seeds miles away.

Plants enrich every corner of human life, even beyond food and oxygen. From invaluable herbs – plants with medicinal or flavour value – to towering trees made from woody tissue, our original go-to construction material, plants prop up our civilisation. High-five one today.

Life cycle of a flowering plant



1. The carpel
The female centrepiece of a flower comprises the ovary and a slender neck called the style, which has a sticky top called a stigma.

2. The stamen
The flower's male members include this stalk-like filament, topped with the pollen-producing anther.

3. The petals
Flower petals are like a neon sign designed to attract insects that come for the free nectar, then unintentionally carry pollen to other flowers.

4. Gametophytes
Inside each anther, gametophytes – technically microscopic male plants – are encased in pollen grain capsules. Each includes two sperm cells and a tube cell.

5. The stigma
Pollen grains stick to the stigma at the tip of the carpel, and produce a pollen tube down the style and ovary.

6. The ovary
The ovary includes multiple compartments called ovules, each housing one gametophyte – technically, a tiny female plant.

7. The embryo sac
In each ovule, cells divide to form an embryo sac, which includes an egg, two nuclei and an opening for the pollen tube.

8. The pollen tube
When the pollen tube reaches and penetrates the ovule, it releases the two sperm cells into an embryo sac.

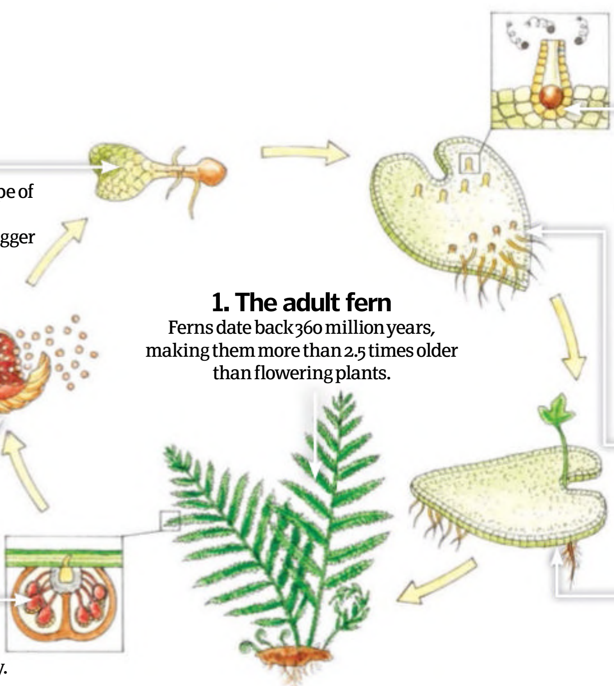
9. The zygote
One of the sperm cells fertilises the egg, creating a zygote. The two nuclei and the other sperm cell fuse to form a food supply called endosperm.

10. The embryo
Through cell division, the zygote feeds off the endosperm.

11. The seed
The casing surrounding the ovule hardens around the embryo, to form a seed. When it has ample warmth, moisture, and oxygen (typically in the spring), the seed germinates – that is, begins to grow into an adult plant.

Ferns reproduce in a different way from flowering plants

Life cycle of a fern



1. The adult fern
Ferns date back 360 million years, making them more than 2.5 times older than flowering plants.

2. Sporangia
Inside these hard pods on the underside of fern fronds, spore cells multiply.

3. Spores
When enough spores form, they burst open the pod and disperse.

4. Prothallus
Each spore grows into a type of gametophyte called a prothallus. This is much bigger than the gametophytes in flowering plants.

5. Mature gametophyte
The prothallus grows both a female sex organ (the archegonia) and a male sex organ (the antherida), which produces sperm.

6. Archegonia
Sperm from another prothallus fertilises the egg inside the archegonia, to form a zygote.

7. Young fern
The zygote grows into a young fern, and the prothallus structure withers away.

Most unusual plants

The sensitive plant

Touch a leaf on the sensitive plant, also known as mimosa pudica, and an electrical current activates sudden water loss, causing leaves to drop abruptly. This imitation of an animal scares pests away.

Myrmecophytes

Many species, collectively known as myrmecophytes, have evolved to be ideal homes for ant colonies. In return, the ants viciously attack any threats to the plant.

Sumatran corpse flower

This flower can grow to be 0.9m (3ft) wide and 11 kilograms (24 pounds). It mimics the smell of rotting meat in order to attract carrion-eating insects, which then spread its pollen.

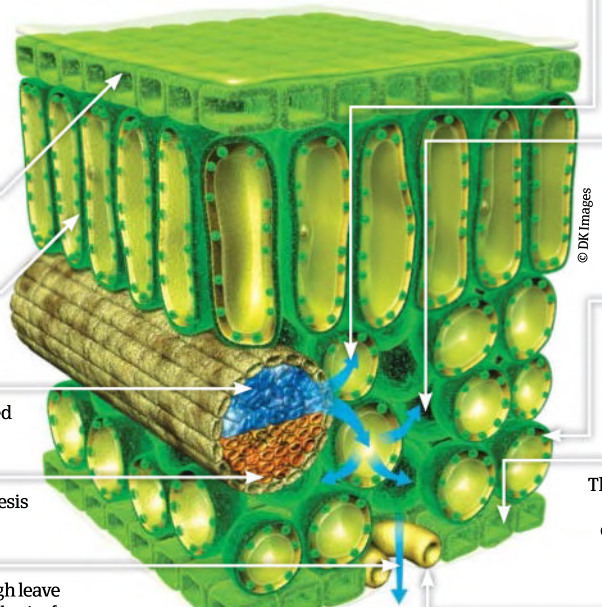
Snowdonia hawkweed

This Welsh flower is possibly the world's rarest plant. Botanists thought it extinct in the early-Fifties, but in 2002 it made a surprise reappearance near Bethesda.

Plant plumbing:

How transport works

Internal transportation systems in plants move water, food and other nutrients between roots, stems and leaves. This system is the key adaptation that allowed plants to evolve elaborate shapes and towering forms.



Upper epidermis
The waxy cuticle on the epidermis keeps the plant from drying out.

Palisade mesophyll
These cells are rich in chloroplasts, which are integral in photosynthesis.

Xylem vessel
These vessels carry water, with dissolved minerals, from the roots to leaves.

Phloem vessel
These carry food created in photosynthesis from leaves to the rest of the plant.

Diffusion
This water vapour exits the plant through leave openings called stomata. This continual exit of water creates negative pressure, which effectively pulls water up the xylem from the roots.

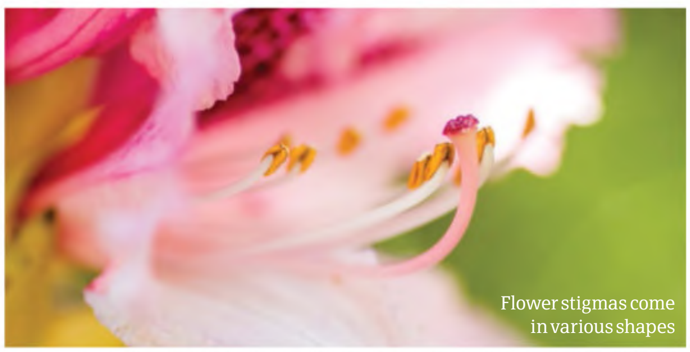
Movement of water
Water moves from the xylem vessels, which run from the roots to leaves, into the mesophyll cells.

Evaporation
Water along the walls of the mesophyll cells evaporates, forming water vapour.

Spongy mesophyll
Mesophyll cells fit together to form most of the tissue in a leaf.

Lower epidermis
The lower epidermis can be thinner than the upper epidermis, since it doesn't get direct sunlight.

Stoma
Guard cells alongside each stoma (pore in the leaf) open when sunlight and humidity are high.



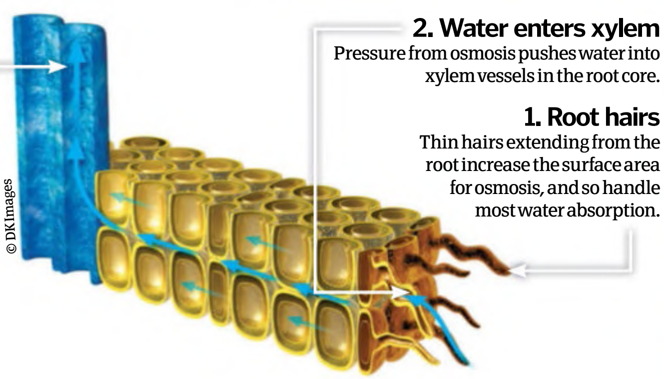
Flower stigmas come in various shapes

Insects seeking nectar pick up pollen on their legs

The root of it:

How absorption works

Roots soak up water through osmosis – the drive for water to move through a cell membrane from a less concentrated solution to a more concentrated solution, in order to achieve equilibrium. Cells in roots have a higher concentration than the surrounding water in the soil, so the water flows into the root.



3. Water enters the stem
Water continues flowing through the xylem, up into the above-ground stem, helped along by negative pressure in the leaves, created by evaporating water.

2. Water enters xylem
Pressure from osmosis pushes water into xylem vessels in the root core.

1. Root hairs
Thin hairs extending from the root increase the surface area for osmosis, and so handle most water absorption.

BIG

© Thelmadatter 2009

3. Montezuma cypress
Árbol del Tule is a massive specimen in Santa María del Tule, Mexico. With a 36.2m (119ft) girth, it may well be the world's widest plant.

BIGGER

2. Coast redwoods
Coast redwoods are the world's tallest trees. At 115.6m (379.3ft), a redwood named Hyperion is the tallest specific tree.

BIGGEST

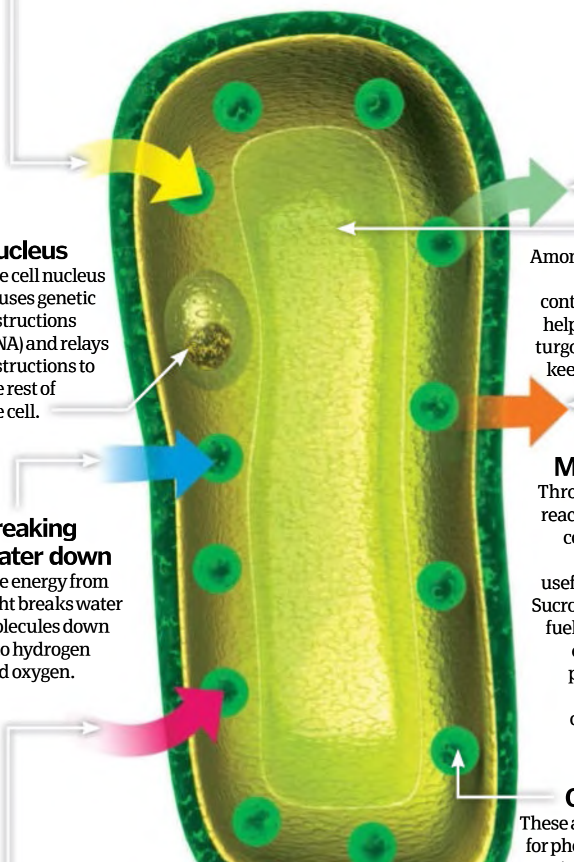
1. Giant sequoias
The biggest individual plant is Sequoia National Park's General Sherman, which weighs in at an estimated 1,900 tons.

DID YOU KNOW? *We eat only about 200 of the 3,000 known rainforest fruits, while indigenous peoples use more than 2,000*

Inside the food factory: How photosynthesis works

In Greek, photosynthesis means 'putting together' (synthesis) using 'light' (photo), and that's a decent summary of what it's all about. However, photosynthesis doesn't actually turn light into food, as you sometimes hear; it's the power source for a chemical reaction that turns carbon dioxide and water into food.

The energy of light protons temporarily boosts the electrons in pigment molecules to a higher energy level. In other words, they generate an electrical charge. The predominant pigment in plants – chlorophyll – primarily absorbs blue, red, and violet light, while reflecting green light (hence, the green colour). In some leaves, chlorophyll breaks down in the autumn, revealing secondary pigments that reflect yellows, reds, and purples. Pigments are part of specialised organelles called chloroplasts, which transfer the energy of excited electrons in pigments to molecules and enzymes that carry out the photosynthesis chemical reaction.



Harnessing sunlight
Chlorophyll and other pigments absorb energy of light photons from the Sun.

Expelling oxygen
The oxygen from the water isn't necessary to make food, so the plant releases it through pores called stomata.

Nucleus
The cell nucleus houses genetic instructions (DNA) and relays instructions to the rest of the cell.

Vacuole
Among other things, this organelle contains water that helps maintain the turgor pressure that keeps plants erect.

Breaking water down
The energy from light breaks water molecules down into hydrogen and oxygen.

Making food
Through additional reactions, the plant converts glucose into a range of useful compounds. Sucrose acts as plant fuel, starches store energy for later, protein aids cell growth, and cellulose builds cell walls.

Chloroplast
These are the engines for photosynthesis. A typical leaf palisade cell includes up to 200 chloroplasts.

Adding carbon dioxide
Plants get all the CO_2 they need from the air. CO_2 combines with hydrogen to make glucose, a simple sugar.

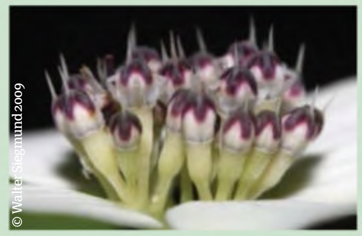
© DK Images

Colourful petals are designed to attract insects

ON THE MAP

How much of the planet is covered by forest?
40 million sq km (15,444,100 sq miles), or a third of the Earth's land area, is covered by forests.

1	34% Rest of the world
2	20% Russian Federation
3	12% Brazil
4	8% US
5	8% Canada
6	5% China
7	4% Australia
8	3% Democratic Republic of Congo
9	2% India
10	2% Indonesia
11	2% Peru



© Walter Siegmund 2009

Bunchberry dogwood
This shrub holds the 'fastest plant' record. When its flower opens, stamens fling out like a catapult, propelling pollen at 800 times the g-force astronauts experience.

Parachute flowers
The different species of parachute flower have long flower tubes lined with inward pointing hairs that temporarily hold insects trapped, to ensure they end up covered in pollen before exiting.

Welwitschia mirabilis
This so-called 'living fossil' plant of the Namib desert in Africa grows only two leaves, over hundreds of years. They grow continuously, however, and can extend more than 4 metres (13 feet).

© Science Photo Library

Flypaper plants
Also known as butterworts, these plants are coated in super-sticky digestive enzymes that absorb nutrients from all manner of bugs that happen to get trapped.

Plant cell anatomy explained

Discover how these tiny living structures function

Without the plant kingdom, life on Earth would be a very different prospect. This huge and diverse group of living organisms not only nourishes the vast majority of animal life with tasty, nutritious roughage, but it also replenishes our atmosphere with enough oxygen to keep us living and breathing. Quite simply, life on Earth depends on plants.

There are a number of characteristics that make all living things 'alive'. For instance, they require food for growth and development; they respond and adapt to their surrounding environments; they have a life cycle of growth, reproduction and death; and, importantly, they contain cells.

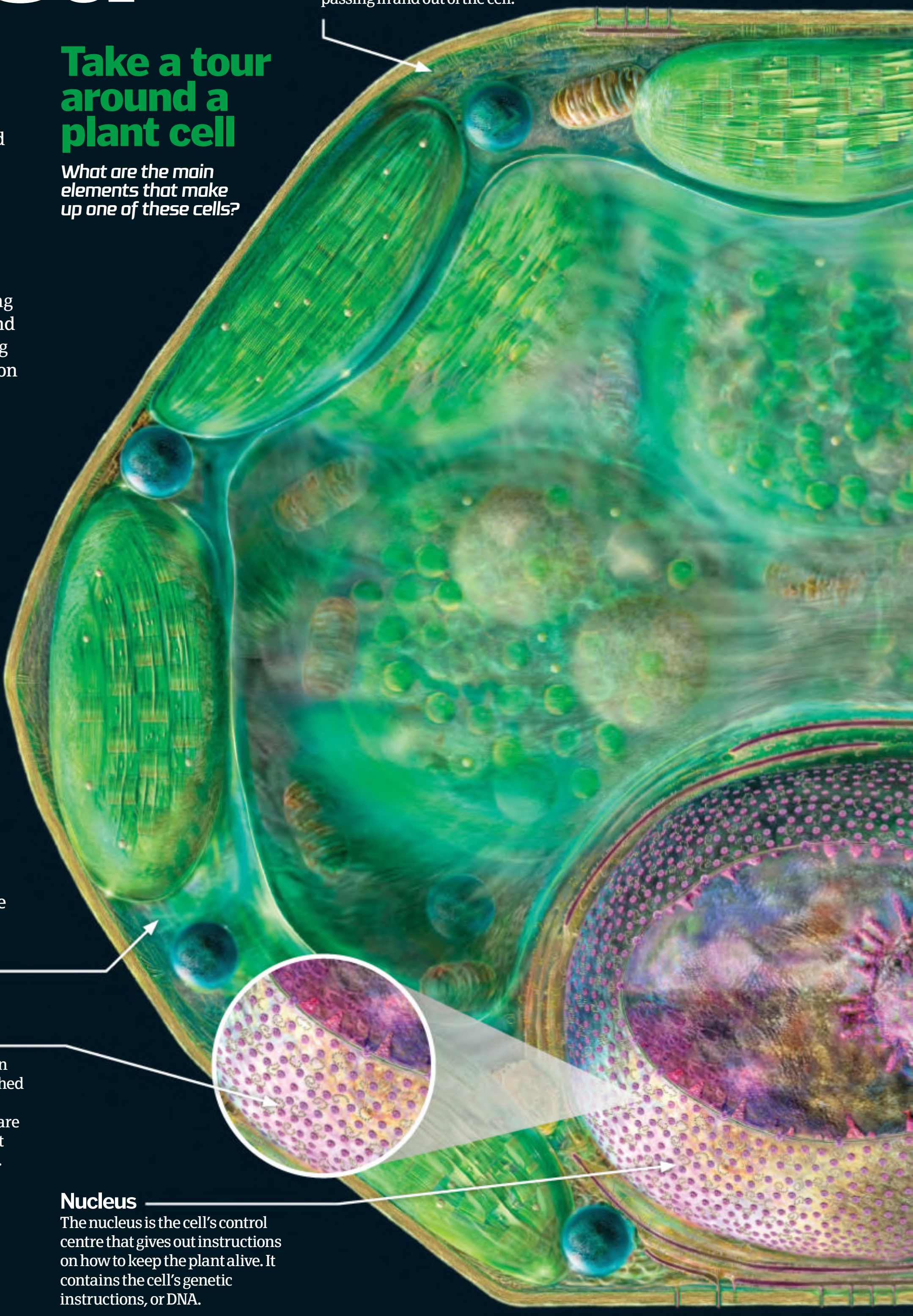
Discovered by Robert Hooke in the 1650s, plant cells are the building blocks of all plant life. Just like animal cells, they are eukaryotic, which means they contain a nucleus – a structure that acts as the cell's 'brain' or command centre. Found in the nucleus is the plant's genetic information, which is used to inform the rest of the cell which functions to carry out.

Everything inside the cell is contained within a thin, semi-permeable lining called the plasma membrane. Inside this membrane is a sea of cytoplasm, a gelatinous substance in which all the other parts of the plant cell are found – most of which have specialised functions. These 'expert' structures have dedicated roles and are known as organelles, or 'mini organs'. Surrounding the plasma membrane is a rigid outer cell wall made from a fibrous substance called cellulose.

Another characteristic of a plant cell is its large vacuole. This is an area filled with fluid and gas and it accounts for most of a cell's mass. The vacuole swells with fluid to help maintain a cell's shape. The tough cell wall is strong enough to withstand this increased pressure and ensures this organic 'balloon' doesn't burst.

Take a tour around a plant cell

What are the main elements that make up one of these cells?



Cell membrane
The cell, or plasma, membrane is the layer that covers the cytoplasm and separates the cell from its external environment. It controls all substances passing in and out of the cell.

Cytoplasm
Cytoplasm is the jelly-like substance inside the cell in which energy-producing chemical reactions occur. The cytoplasm fills the space between the cell membrane and the nucleus.

Ribosome
Found either floating in the cytoplasm or attached to the endoplasmic reticulum, ribosomes are the tiny structures that manufacture proteins.

Nucleus
The nucleus is the cell's control centre that gives out instructions on how to keep the plant alive. It contains the cell's genetic instructions, or DNA.

5 TOP FACTS PLANT CELLS

Discovery

1 17th-century scientist Robert Hooke was the first to study plant cells with a microscope. In his book *Micrographia* he described his observations and coined the term 'cell'.

Plant or animal?

2 Plant and animal DNA molecules are chemically similar, but the differences in the way the nucleotides are arranged determine whether an organism is animal or plant.

Food factory

3 Sunlight turns CO_2 and H_2O into glucose. When photons from the Sun hit the chlorophyll in a plant, electrons are excited. Chloroplasts then transfer this energy to a plant's organelles.

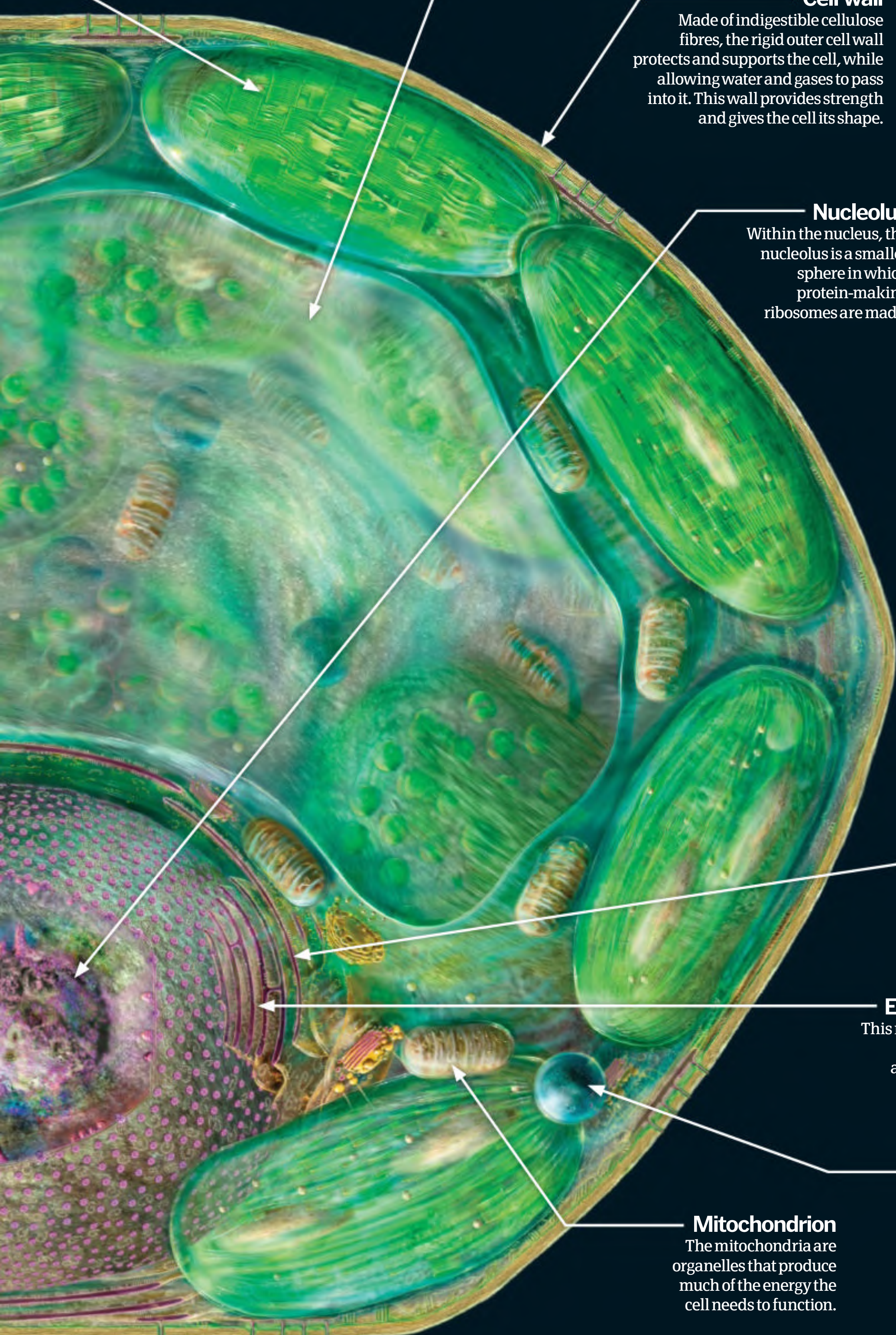
Free lunch

4 Most plants create their own food, but some parasitic plants don't have chlorophyll to photosynthesise. These species depend on a host to obtain glucose and other nutrients.

Eukaryotic vs prokaryotic

5 Plant cells have a nucleus, which makes them eukaryotic (the same as fungi). Cells that do not have a nucleus are known as prokaryotic and include single-celled organisms like bacteria.

DID YOU KNOW? While all other animal cells are eukaryotic, red blood cells are erythrocytic as they do not contain a nucleus



Plant cells vs animal cells

As we've mentioned already, there are many similarities between plant and animal cells. However, there are also several key differences. For example, animal cells are bigger and less regular in shape and size than those of plants, which are generally regimented in appearance. Take a look at the main structures in a plant cell that are absent in animal cells.

Cell wall

While both animal and plant cells have a thin cell membrane that controls what goes in and out, plants differ in that they also have a cell wall made of cellulose. This rigid outer wall enables the plant to hold a lot of moisture under pressure without popping, while also providing essential structural integrity. The contents of an animal cell, meanwhile, are held by the cell membrane alone. Animals tend to rely on endo- and exo-skeletons for support.

Single large vacuole

Plant cells also contain a single, extra-large vacuole, which takes up most of the space in the cell and keeps it plump and turgid. Some animal cells do contain vacuoles, but they are always much smaller and never take up this much space.

Chloroplasts

Plants manufacture their own food (glucose) from sunlight, water and carbon dioxide, but humans and animals must *absorb* food obtained from plants and other living creatures. The difference is that plant cells contain chloroplasts – the structures that contain the green, sunlight-absorbing chlorophyll pigment – in which photosynthesis can take place.

"There are several key differences between animal and plant cells"

Why do flowers smell?

Scents take a lot of effort to make, but they ensure the next generation

Flowers have just one biological role: to guarantee pollination. Many blooms are pollinated by insects, attracted by a flower's bright colours and the reward of energy-rich pollen or nectar. But flowers must also lure insects from farther afield – enter, scent.

The aroma of some flowers contains up to 100 different chemicals. These are modified from chemicals in leaves which deter grazing animals, but are manufactured within the flower. Warm weather stimulates their release – just when bugs are most active

Characteristic scents encourage insects to visit other flowers of the same species and so transfer pollen between them. The blooms of evening primrose and night-scented stock release their sweet aroma in the evening, attracting nocturnal moths. These moths only visit other night-scented flowers, thus reducing pollen wastage.

Some species have 'stinky' flowers, which only attract carrion-seeking insects. The clove scent of one Bulbophyllum orchid is so particular that it lures just one species of fly, thus ensuring efficient pollen transfer.

> "Scents are generally secreted from the petals"

The role of scent

This lily has been picked apart to show the different structures that ensure pollination

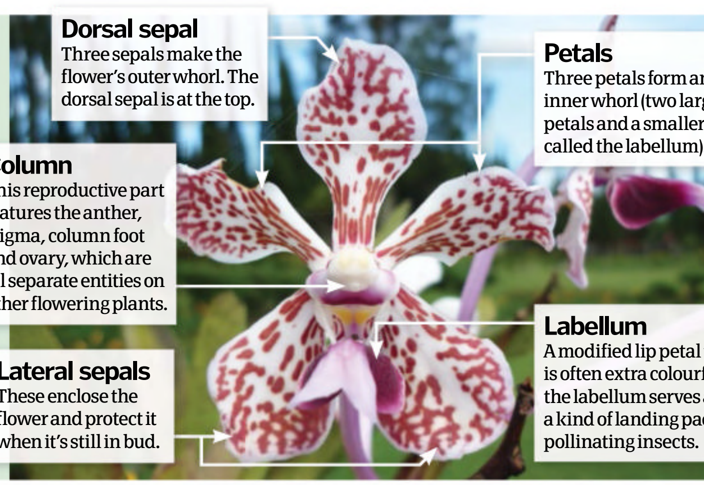
What are orchids?

Discover why they're unlike other flowers

With 25,000 species, the orchid is the largest of the planet's plant families with the most diverse species growing in the tropics and subtropics.

Orchids are found on all continents but Antarctica and can survive pretty much anywhere except true deserts and open water. Orchids grow on the ground using subterranean roots, though some have also developed the ability to grow up trees and other structures using aerial roots.

What sets an orchid apart from most flowering plants, however, is its reproductive anatomy. Orchids have three petals (including one colourful lower petal called the labellum) and three sepals. While on other plants male and female reproductive organs remain separate, on an orchid these parts are fused in a central column.



5 TOP FACTS
POISON IVY FACTS

Humans are irritated
1 The vast majority of humans (approximately 90 per cent) are sensitive to the urushiol irritant that is present in poison ivy. However, most animals are not affected by the toxin.

Indirect contamination
2 You can be indirectly contaminated by poison ivy as its toxic sap is easily transferred by animals, clothing or even gardening equipment like secateurs.

Do not burn
3 If you have poison ivy in your garden, do not burn it as the urushiol oil can become airborne in the smoke and cause damage to the nose, mouth, throat and even lungs.

Sensitivity threshold
4 Everyone has different sensitivity to poison ivy and so the time it takes for the allergic reaction to kick in and the severity of the symptoms will vary from person to person.

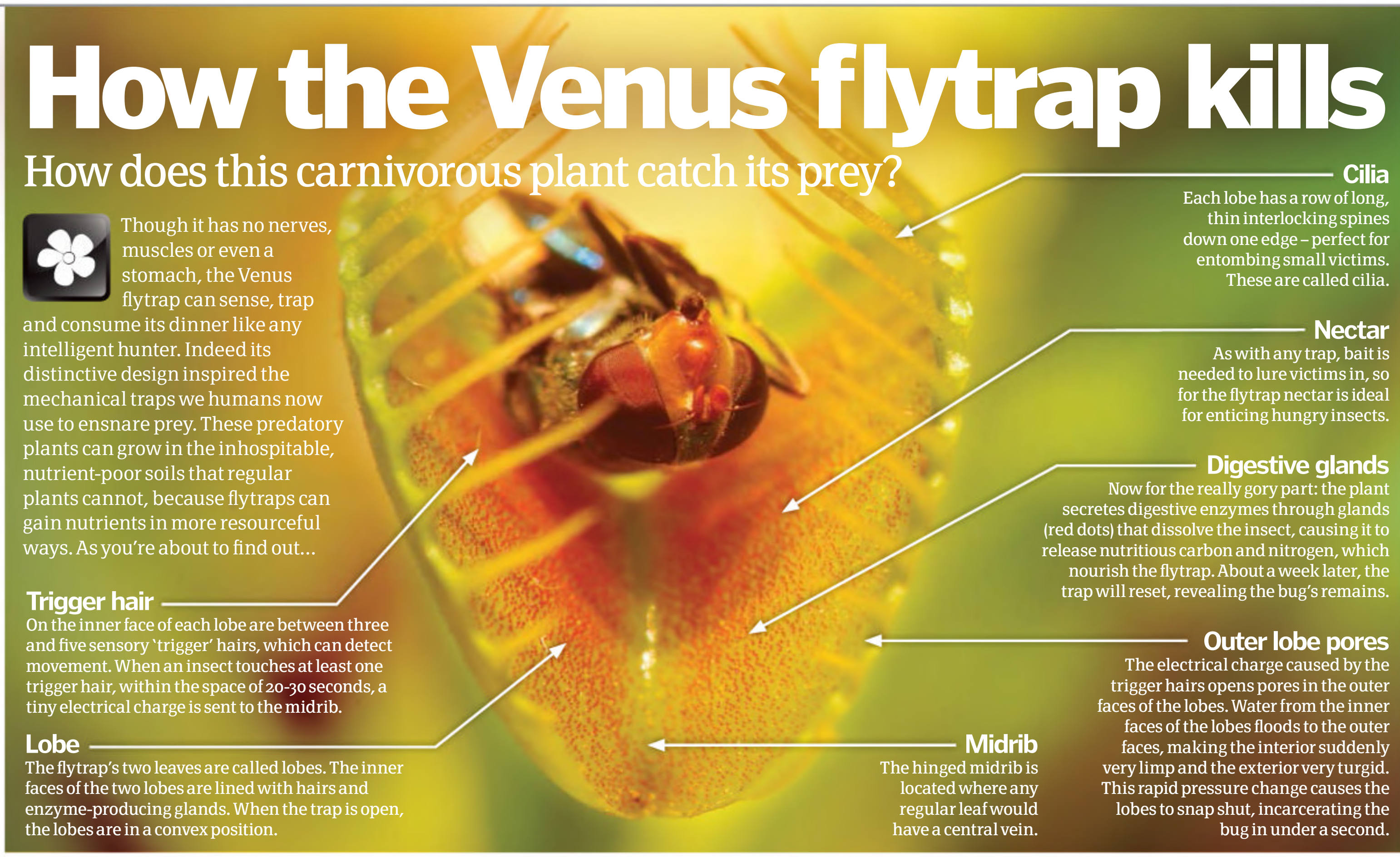
Histamines
5 The body's antibodies become sensitised to the urushiol in poison ivy so if contact is made a second time the immune system releases histamines that cause inflammation.

DID YOU KNOW? *The name, Venus flytrap, refers to Venus, the Roman Goddess of love*

How the Venus flytrap kills

How does this carnivorous plant catch its prey?

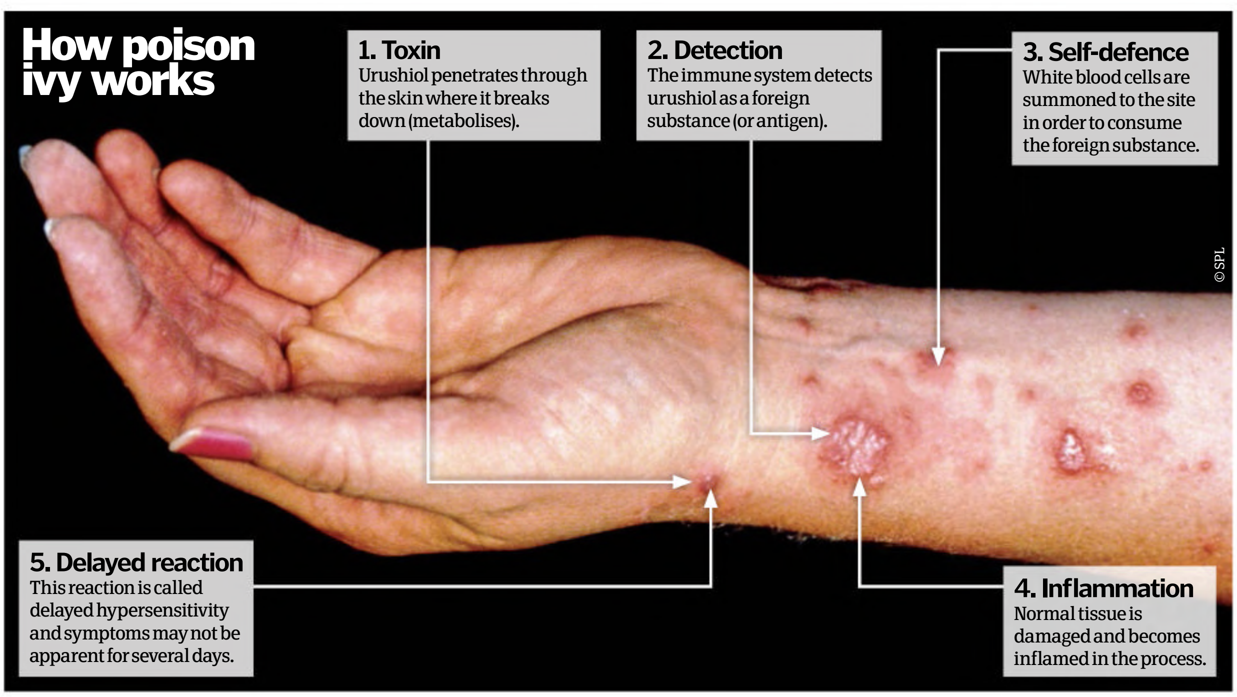
Though it has no nerves, muscles or even a stomach, the Venus flytrap can sense, trap and consume its dinner like any intelligent hunter. Indeed its distinctive design inspired the mechanical traps we humans now use to ensnare prey. These predatory plants can grow in the inhospitable, nutrient-poor soils that regular plants cannot, because flytraps can gain nutrients in more resourceful ways. As you're about to find out…



Why is poison ivy so irritating?

It may look harmless enough but poison ivy is a toxic shrub that grows in most areas of North America

Poison ivy is a plant with leaves that divide into three leaflets and often displays yellow or white berries or small white flowers. The glossy leaves, roots and stem of the plant contain an oily, organic toxin called urushiol, to which nine out of ten people are allergic. If they come into contact with this chemical their bodies overreact, causing a skin irritation known as urushiol-induced contact dermatitis. Thinking it's under attack, the body tells the immune system to take action against the foreign urushiol substance. The resulting allergic (anaphylactic) reaction produces irritation in the form of redness, rashes and itchy skin.



© Tom Murphy VII

Science Photo Library

The statistics…

Angel's Trumpets

Binomial name: Brugmansia
Genus: Brugmansia
Family: Solanaceae
Main toxins: Scopolamine, atropine
Antidote: Activated charcoal, physostigmine, benzodiazepines

Deadly rating: ☠☠☠½

© Natox

Severe mydriasis – excessive dilution of the pupil – is a common side effect of consuming Angel's Trumpets.

© Kurt Stueber

The statistics…

Deadly Nightshade

Binomial name: Atropa belladonna
Genus: Atropa
Family: Solanaceae
Main toxins: Atropine, scopolamine
Antidote: Physostigmine, pilocarpine

Deadly rating: ☠☠☠☠

The world's deadliest plants

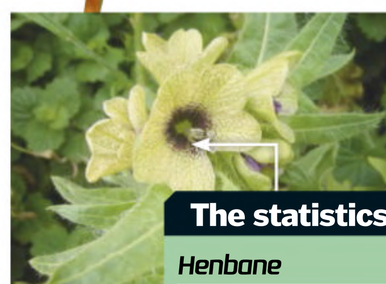
Packed with toxins and capable of delivering a range of terrible effects including paralysis and hallucinations, Earth's most deadly plants claim many lives each year

One of the most deadly plants in the western hemisphere, Deadly Nightshade is packed from root to leaf tip with toxins. These include atropine and scopolamine, which due to their anticholinergic properties (substances that effectively compromise the involuntary movements of muscles present in the gastrointestinal tract, urinary tract, lungs and other vital parts of the body), can lead to hallucinations, delirium, violent convulsions and death. Indeed, ingestion of two or more of its berries by children or five or more by adults can be fatal.

The main cause of these negative side effects to the parasympathetic nervous system (the automatic system that regulates glands and muscles inside the body) is the tropane alkaloid atropine. Atropine achieves this as it is a competitive antagonist, a drug that does not provoke a biological response itself upon binding to a receptor, but instead blocks or dampens any response reducing the frequency of activation. In simple terms, this causes the autonomous internal systems of organisms that consume it to stop working correctly, causing semi-paralysis, breathing difficulty and fluctuating heart rate.

So poisonous that they were historically used in ritual intoxification, Angel's Trumpets and Henbane contain a bounty of toxic compounds. A close relative of Datura, Angel's Trumpets contain both scopolamine and atropine as in Deadly Nightshade, however due to their wide species variety, have a larger and more exotic range of negative effects. In fact, there can be a 5:1 toxin variation across plant species. Anticholinergic delirium is standard upon an overdose, while tachycardia (rapid heart-rate exceeding normal range), severe mydriasis (excessive dilation of the pupils) and short-term amnesia are also common. Henbane is also loaded with tropane alkaloids, with the seeds and foliage of the plant containing the highest toxicity levels.

Hemlock – perhaps the most famous of the world's deadly plants – contains one of the most fatal naturally produced neurotoxins to humans: coniine. Coniine has a similar chemical structure to nicotine – the addictive alkaloid that is used in cigarettes – and works by disrupting the central nervous system, blocking the neuromuscular junction. This has the effect of an ascending muscular paralysis from toe to chest, with the eventual paralysis of the respiratory system and death due to lack of oxygen to the heart and brain. Adding to its danger, Hemlock is incredibly potent with any more than 100mg of consumption (akin to consuming six of its leaves, or less of its root or seeds) leading to death. Death can only be prevented through attaching the consumer to an artificial respiration machine until the effects wear off after 72 hours.

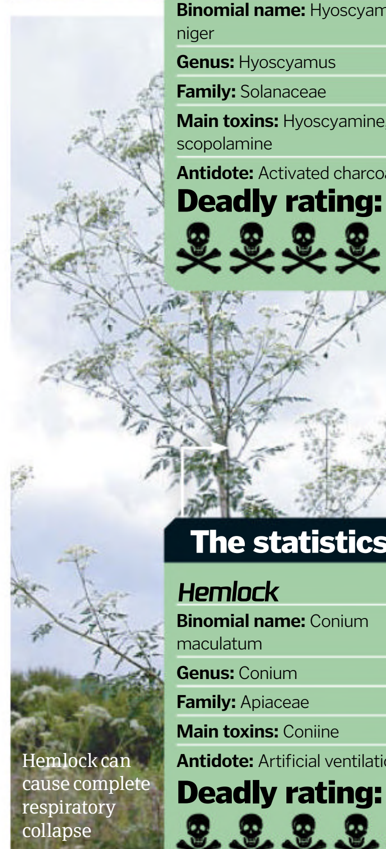


The statistics…

Henbane

Binomial name: Hyoscyamus niger
Genus: Hyoscyamus
Family: Solanaceae
Main toxins: Hyoscyamine, scopolamine
Antidote: Activated charcoal

Deadly rating: ☠☠☠☠



Hemlock can cause complete respiratory collapse

The statistics…

Hemlock

Binomial name: Conium maculatum
Genus: Conium
Family: Apiaceae
Main toxins: Coniine
Antidote: Artificial ventilation

Deadly rating: ☠☠☠☠☠

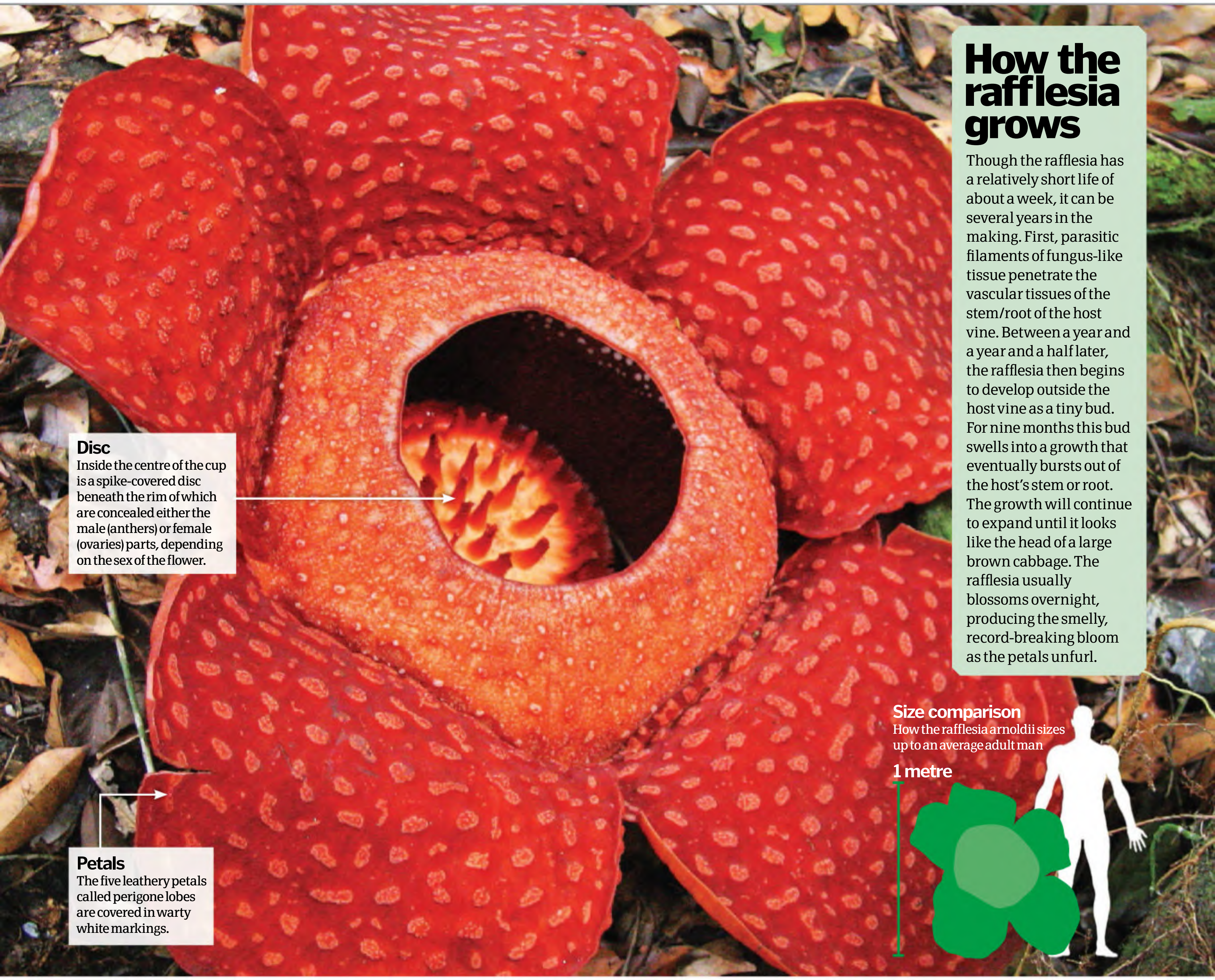
RECORD BREAKERS
TALLEST PLANT

115.54M

HYPERION, THE COAST REDWOOD

The world's tallest living tree is 115.54m (379.1ft). Known as Hyperion, this coast redwood (sequoia sempervirens) was measured by climbing to the top and dropping a tape measure.

DID YOU KNOW? *Another plant native to Sumatra that's also known as the corpse flower is the equally stinky titan arum*



How the rafflesia grows

Though the rafflesia has a relatively short life of about a week, it can be several years in the making. First, parasitic filaments of fungus-like tissue penetrate the vascular tissues of the stem/root of the host vine. Between a year and a year and a half later, the rafflesia then begins to develop outside the host vine as a tiny bud. For nine months this bud swells into a growth that eventually bursts out of the host's stem or root. The growth will continue to expand until it looks like the head of a large brown cabbage. The rafflesia usually blossoms overnight, producing the smelly, record-breaking bloom as the petals unfurl.

The world's biggest flower

Discover the enormous corpse flower, and find out why this is one of the heaviest, rarest and smelliest blooms found on Earth

Rafflesia arnoldii, with its massive one-metre (3.3-foot)-diameter bloom, is the largest individual flower yet found on the planet – usually in the tropical rainforests of Indonesia.

The plant has neither a stem, roots, nor leaves, and it doesn't even contain chlorophyll, which means it's incapable of photosynthesis to produce food for itself. Instead this endoparasitic plant survives by growing inside the damaged stems or roots of a host plant, a kind of grape vine known as tetrastigma, and draining nourishment from this.

Once the flower is ready to bloom it bursts out of the host to reveal a vibrant yet foul-smelling blossom. And it's this odour of rotting flesh that justifies rafflesia arnoldii's other, more familiar moniker: the corpse flower. This, together with its distinctive red-and-white polka-dot appearance, attracts carrion flies, which help to pollinate the giant flower.

The statistics…

Rafflesia arnoldii (corpse flower)

Genus: Rafflesia

Habitat: Rainforests of Southeast Asia

Diameter: 1m (3.3ft)

Weight: 10kg (22lb)

The life of an oak tree

Discover the amazing way mighty oak trees keep on surviving

All oak trees begin their life cycle as an acorn. This is the seed of the oak tree, which falls as the tree reaches maturity or is dislodged by weather or animals. Acorns that fall at least 27 metres (89 feet) from the tree have the best chance of surviving long enough to grow, as there is less competition for space and nutrients. Once on the ground, the acorn will begin to germinate, absorbing water to hydrate its enzymes. Hydration instigates growth by causing the enzymes in the acorn to become more active. A tap root begins to form, burying down into the earth. This root absorbs nutrients and water from the soil, allowing a shoot to begin growing upward. This is known as the seedling stage.

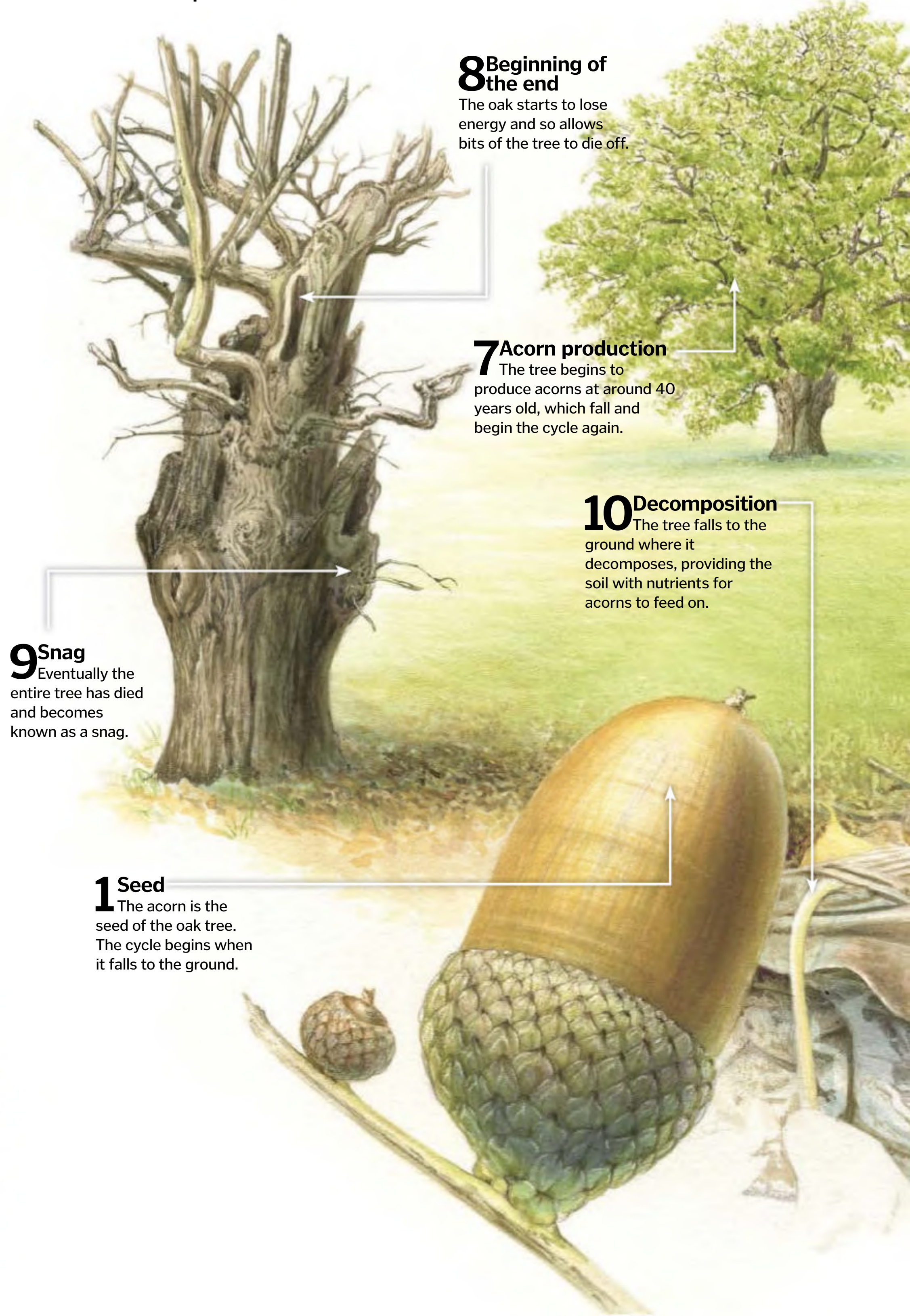
It continues to grow upward and outward, thickening its shoot until it has a trunk diameter of 7.5 centimetres (three inches), where it officially becomes a sapling. After around a year, it will have grown to a height of 30.5 centimetres (12 inches) when it is classified as a pole. The oak will begin to produce acorns after around 40 years when it should be approximately 10.5 metres (34 feet) tall and is fully matured.

The oak's growth will begin to slow, but this shouldn't happen until over 80 years or so have passed. Acorn production eventually stops, but the tree can comfortably live for over 1,000 years. Eventually parts of the tree begin to die as the oak is forced to conserve what energy it has left. A dead oak is known as a snag and will fall to the ground, decomposing and providing the soil with nutrients that will feed the next generation of oak trees.

The mighty oak tree in the prime of its cycle

The oak tree from seed to snag

How the oak tree keeps its own circle of life intact

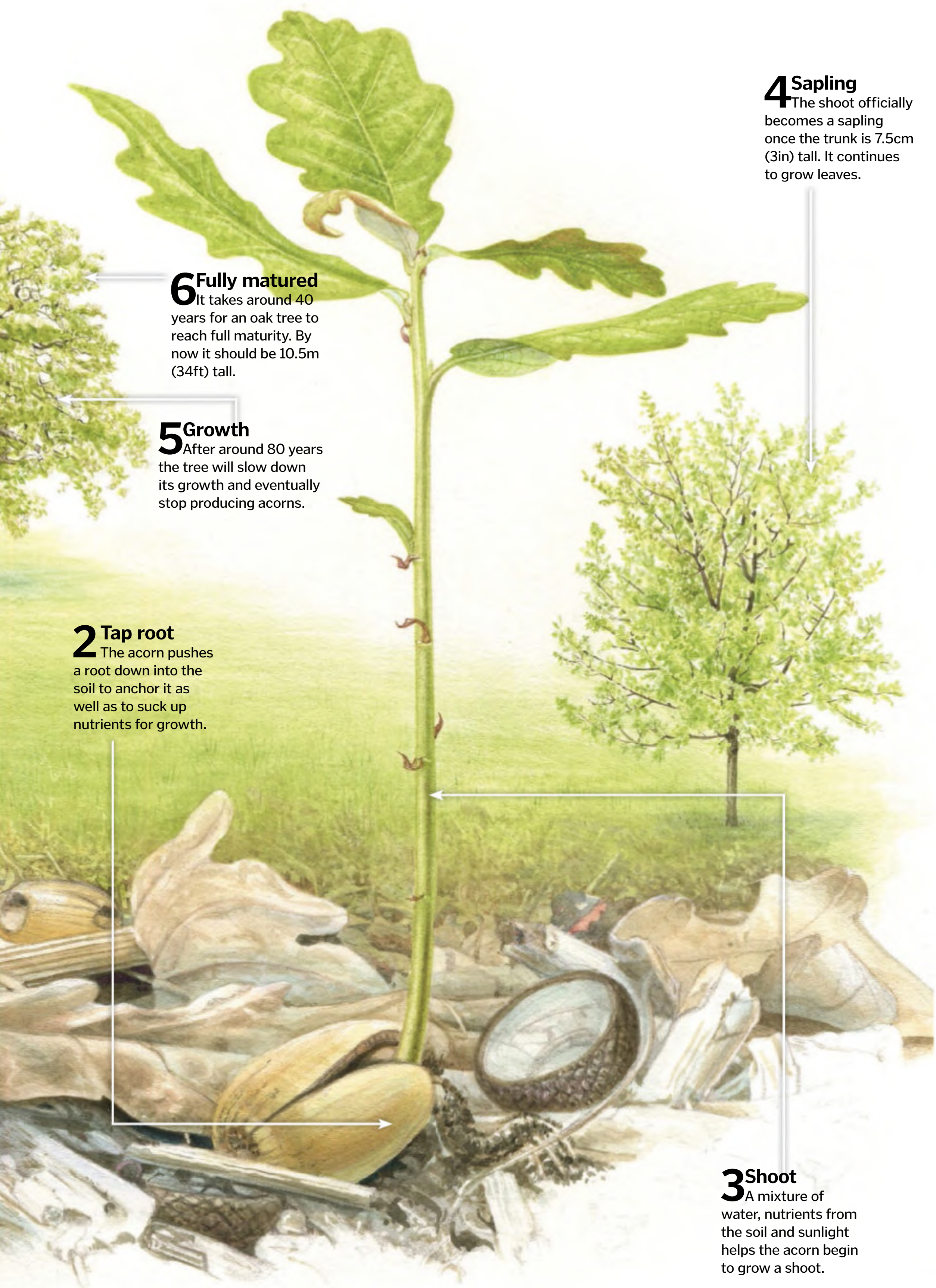


13,000 years

OLDEST OAK

The Jurupa Oak is the oldest living oak colony in the world at 13,000 years old. It has lived this long by constantly cloning itself.

DID YOU KNOW? *The oak tree is the most common species of tree in the UK and is a national symbol*



Uses for oak

Before the Industrial Revolution oak was the most commonly used material for boat building. Its strength and durability made it perfect for constructing ships. It was replaced by iron partly because iron is stronger, but also because oak has to grow for 150 years before it can be used. It is still used as a material for furniture and floor wood, as well as barrels for storing wine, as the wood imparts the unique and distinctive flavours that differentiate types of wine. The bark of the oak tree contains both main types of tannin, a crucial ingredient in turning animal hides into leather. Tannins are extracted from the bark and rubbed into the hides. This alters the collagens in the hides, pulling them together, drawing out water and strengthening the hide into leather. This method has been in force since Roman times.


Ships such as the HMS Victory were constructed from oak timber

Britain's favourite tree

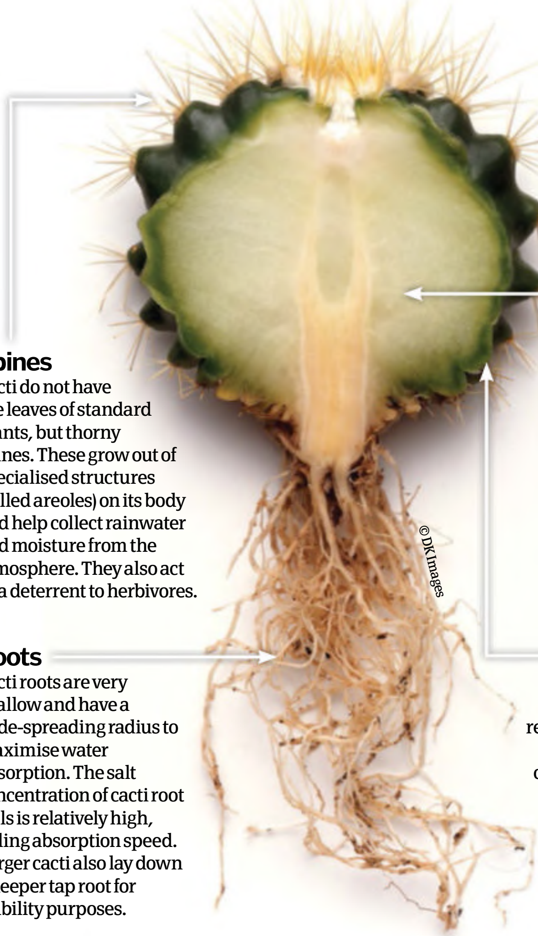
In 2002, The Major Oak in Sherwood Forest was voted Britain's favourite tree. The Quercus robur is over 800 years old and legend has it that it hid Robin Hood and his merry men from the Sheriff of Nottingham.

The tree's branches spread across 28 metres (92 feet) long and have been held up – first by metal chains and now by wooden struts – for over 100 years to stop them sagging under their enormous weight.

The Major Oak weighs around 23 tonnes, about the same as four fully-grown African elephants, and its ten-metre (33-foot) circumference trunk would need six adults to create a ring around it while holding hands.

How do cacti live?

Take a closer look at the materials and mechanisms cacti use to survive in the world's harshest environments



Spines
Cacti do not have the leaves of standard plants, but thorny spines. These grow out of specialised structures (called areoles) on its body and help collect rainwater and moisture from the atmosphere. They also act as a deterrent to herbivores.

Tissue
The main bulk of the cacti's body comes in the form of a water-retentive tissue, often in the optimal shape for storage (a sphere or cylinder). At the centre of the body tissue lies the stem, the main organ for food manufacturing and storage.

Roots
Cacti roots are very shallow and have a wide-spreading radius to maximise water absorption. The salt concentration of cacti root cells is relatively high, aiding absorption speed. Larger cacti also lay down a deeper tap root for stability purposes.

Skin
The skin of a cactus is specially adapted to reduce the harsh effects of constant sunlight. It is constructed from a tough and thick fibrous sheath and coated with a thin layer of wax. These factors, in conjunction with its optimal shape, aid water retention.

Spines gather moisture and also serve as a defence mechanism

Flowers
All cacti have a floral tube that grows above a one-chamber ovary. Cacti flowers tend to be solitary, large and very colourful, and are pollinated by both wind power and animals. After pollination, the entire floral tube detaches from the body.

Cacti are hardy, flowering plants in the caryophyllales order that have evolved to survive in some of the Earth's driest and most barren landscapes. This unceasing survival is achieved through the specialised tailoring of two main principles: form and function.

First, all cacti have developed optimal forms for retention of internal water supplies (spheres and cylinders), combining the highest possible volume for storage with the lowest possible surface area for loss. This allows cacti to store vast quantities of water for elongated periods – for example, the species Carnegiea gigantea can absorb 3,000 litres in a mere ten days. This ability directly correlates to the typical weather patterns of Earth's barren, dry environments, where cacti are predominantly found, with little water being deposited for months on end, only for a short monsoon to follow in the rainy season. This optimal structural form also grants much-needed shadow for lower areas of the plant, shielding them from the harsh sunlight.

Second, cacti have evolved unique mechanisms and adapted traditional plant functions to grow and thrive. Foremost among these changes are the cacti's spines, elongated spiky structures that grow out from its central body though areoles (cushion-like nodes). These act as a replacement for leaves, which would quickly die if exposed to high levels of sunlight. The spines have a membranous structure and can absorb moisture directly from the atmosphere (especially important in foggy conditions) and also from deposited rainwater, capturing and absorbing droplets throughout the body's spiny matrix. In addition, due to the lack of leaves, cacti have evolved so as to undertake photosynthesis directly within their large, woody stems, generating energy and processing stored water safely away from the intense sunlight.

Finally, cacti have modified their root structures to remain stable in brittle, parched earth. Cacti roots are very shallow compared with other succulents and are spread out in a wide radius just below the Earth's crust. This, in partnership with an intense salt concentration, allows cacti to maximise their access to and absorbability speed of ground water, sucking it up before it evaporates or trickles down deeper into the Earth. For stability, many cacti also extend a main 'tap root' further into the Earth, in order to act as an anchor against high winds and attacks by animals.

KEY DATES
CLONING OVER TIME

1894 Hans Driesch proves separated cells retain enough DNA data to create life.

1902 Physiologist Gottlieb Haberlandt (right) isolates a plant cell and attempts to culture it.

1922 Kolte and Robbins manage to create root and stem tips respectively from plant-tissue cultures.

1952 A viable frog embryo is successfully cloned from the embryo of a tadpole.

1996 Dolly the sheep is created, cloned by using a cell from an adult sheep.

DID YOU KNOW? *The first commercially cloned animal was a cat, Little Nicky. Born in 2004, it cost its owner £30,000 ($50,000)*

How are plants cloned?

Find out how we make identical copies of plants and what benefits this offers

The process of cloning plants has been used in agriculture for centuries, as communities split roots and took cuttings to efficiently create multiple plants.

Taking a cutting from near the top of a plant, placing it in moist soil and covering it will enable a new offspring to grow with the same genetic code as the parent from which it was taken. This method of cloning is very easy to do and is common among casual gardeners and industrial farmers alike. However, in more recent years the cloning of plants has made its way into the laboratory.

Responsible for that shift is German physiologist Gottlieb Haberlandt who was the first to isolate a plant cell and then try to grow an exact replica of the parent. His attempt ultimately failed, but the experiment showed enough promise to convince others to follow in his footsteps. The likes of Hannig in 1904 and Kolte and Robbins in 1922 ran successful experiments in which they also cultured plant tissue to create new versions.

The main benefit of cloning flora is that growers are able to guarantee disease-free plants by cultivating cells from strong and healthy ones, leading to higher and more reliable crop yields. By taking cuttings from proven strains, a farmer can be sure his next generation of crops is equally successful.

Back inside the lab, the development of cloning through cultivating plant tissue allows for species to even be adapted and improved. However this genetic modification remains a controversial topic, as some experts argue we can't predict what the consequences of this human interference will be.

Plant cloning can be as basic as snipping off a stem from a begonia or as complex as growing a tomato plant in a solution of inorganic salts and yeast extract, but nevertheless the process by which you can create two plants out of one remains a triumph of natural science.

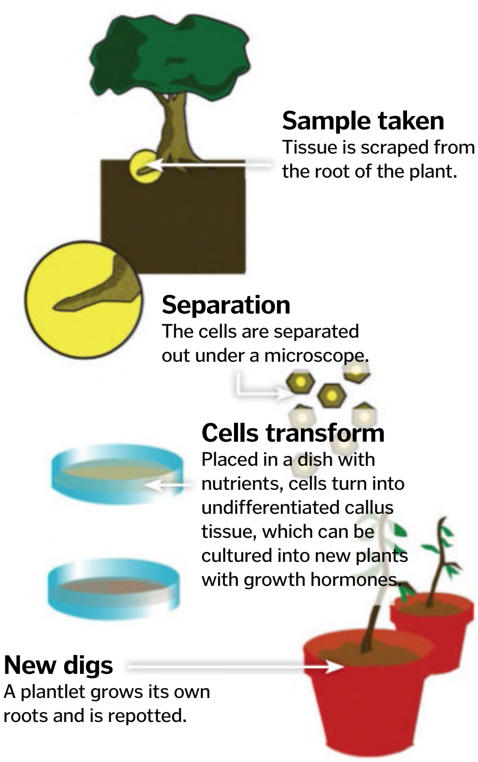
Dolly lived to be almost seven years old

What about animals?

Most of us are aware of Dolly the sheep, the first animal cloned from an adult cell, but artificial cloning dates back to the late-19th century. Hans Dreisch created two sea urchins by separating two urchin embryo cells from which two offspring grew, proving that DNA is not lost through separation. The next big development came in 1952 when a frog embryo was cloned by inserting the nucleus from a tadpole's embryo cell into an unfertilised frog egg cell. But the creation of Dolly in 1996, cloned using a mammary cell from an adult sheep, led to hopes that one day we might be cloned as well. There's still a while until a human can be replicated, but Dolly represented a huge leap forward in terms of cloning possibilities.

Plant duplication guide

Discover how plants can be cloned in the lab through the process of cell separation



Laboratory plant cloning is used for scientific research and to develop stronger strains

How do air plants survive?

Learn about epiphytes, the remarkable plants that grow without any need for soil

Garden centres often call them 'air plants' because they seem to grow in mid-air. Dangling roots help them to develop without any need for soil – however, these fascinating plants do need to be watered: they live in air, not on air.

In nature, these plants grow as epiphytes (derived from the Greek for 'upon plant'). That means they essentially piggyback on other plants, typically growing on the branches of trees high above the ground, with no direct connection to the earth. Without any soil to store water, epiphytes can only grow in places that are constantly moist, so they are most common in tropical rainforests.

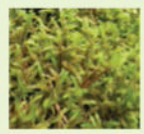
They take nothing from the host tree, in contrast to parasitic plants. Instead they rely on nutrients from dead leaves falling from above. They use their roots only as anchors and to gather water. Many ferns and mosses also grow as epiphytes on damp, shady tree trunks, even in more temperate countries.

Plants that like the high life

Pink quill *Ecuador*
Tillandsia species are the classic air plants. So many pink quills were collected from the rainforest as houseplants that they became endangered. Thankfully, most can now be mass cultivated, even in temperate regions.

Cattleya orchid
South America
The beautiful flowers of Cattleya orchids are a horticulturalist's favourite. Most of the 70 species live as epiphytes on trees and they take great skill to grow.

Bromeliads
Tropical Americas
The narrow leaves of bromeliad plants typically form a cup shape, which sometimes traps water at its base. They can even grow on telephone lines.

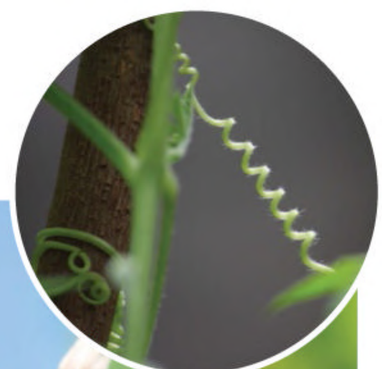


Mosses
Worldwide
Mosses often live on tree trunks. To keep moist, they grow on the side away from the Sun's heat – eg the north side in the northern hemisphere.

Basket fern
South-east Asia/Australia
Small fronds wither into a brown basket that protects the green fertile fronds and collects leaf litter to feed the fern.

Climbing plants explained

Meet the plants that have developed some sneaky tactics in their quest for sunlight



Without sunlight few plants are able to photosynthesise in order to grow. A plant in deep shade is therefore starved of food. All plants have some mechanism of growing towards the light, just like an animal going in search of food, but some 'cheat' in their quest to catch some rays.

The best way for a plant to ensure plentiful light for its leaves is to grow taller than its neighbours. To stand tall, a plant needs a strong, usually woody stem, but it takes rather a lot of energy to manufacture such a sturdy structure, so other plants use an alternative strategy. They have only flimsy stems, which require less energy to produce, but have developed ways of climbing or scrambling over their rivals to reach the light from above. They rarely harm the plant they are growing over, because if they killed it, they would lose the climbing frame taking them to the top.

Climbing plants have evolved to use other plants, rocks or man-made structures for support. Vines have flexible, soft stems, while lianas are tougher climbers with woody stems

FIVE TECHNIQUES PLANTS USE TO GET TO THE TOP...

Hooks & thorns
These help the floppy stems of scrambling or trailing plants to grapple onto surrounding vegetation and hold them firmly in place. Roses are a prime example of this.

Twining stems
Some climbers (eg honeysuckle) produce stems that twist in a spiral as they develop. When the stem makes contact with another plant, it twines around it for support.

Twining leafstalks
Other climbers (eg clematis) have leaves that are sensitive to contact. If they brush against other vegetation or a fence, the leafstalks wrap around it like grapples.

Tendrils
These are grasping or twining extensions from the leaves or leafstalks (like pictured above). Some tendrils even have adhesive pads at their tips (eg Virginia creeper).

Aerial roots
Growing from swollen nodes along stems and branches, some wrap around another plant; others grow into the mortar of walls or under tree bark to anchor the plant in place (eg ivy).

Climatic
1 Temperature and rainfall affect growth, with no variety capable of surviving around 0°C (32°F) and 150-200cm (60-80in) of rain per annum necessary for healthy growth.

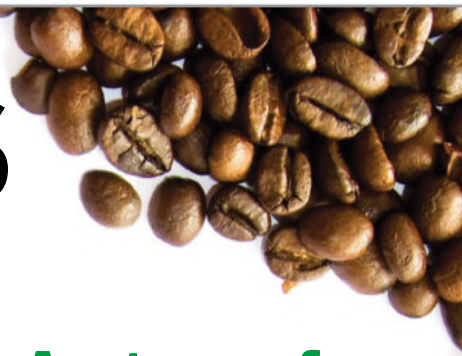
Species
2 There are two main species, the arabica and robusta. These are grown worldwide, with the arabica cultivated mostly in Latin America and robusta in Africa.

Time
3 Plants' fruit blooming and maturing varies. Generally, the arabica species takes seven months and the robusta about nine. Berries are ripe when they're red-purple.

Disease
4 Coffee plants are prone to disease and parasites, which attack plantations yearly. The fungus hemileia vastatrix and colletotrichum coffeanum are common.

Optimal
5 Today up to 1.3 tons of coffee can be yielded per 0.4 hectares (one acre) of plantation. This is more than traditional methods, which only yielded 0.2-0.4 tons.

DID YOU KNOW? *Ancient Ethiopians are credited as first recognising the energising effect of the coffee plant*



Coffee plants

From seed to a steaming hot cup of tasty beverage, we explain how coffee is grown and cultivated

Coffee production starts with the plantation of a species of coffee plant, such as the arabica species. Plants are evenly spaced at a set distance to ensure optimal growing conditions (access to light, access to soil nutrients, space to expand). Roughly four years after planting, the coffee plant flowers. These flowers last just a couple of days, but signal the start of the plant's berry-growing process.

Roughly eight months after flowering, the plant's berries ripen. This is indicated by the change in shade, beginning a dark-green colour before changing through yellow to a dark-red. Once dark-red, the berries are then harvested by strip picking or selective picking. The former is an often mechanised technique where an entire crop is harvested at once, regardless of being fully ripe or not. By doing this, the producer can quickly and cheaply strip a plantation but at the expense of overall bean quality. The latter technique is more labour-intensive, where workers handpick only fully ripe berries over consecutive weeks. This method is slower and more costly, but allows a greater degree of accuracy and delivers a more consistent and quality crop.

Once the berries have been harvested, the bean acquisition and milling process begins. Processing comes in two main forms, wet and dry. The dry method is the oldest and most predominant worldwide, accounting for 95 per cent of arabica coffee. This involves cleaning the berries whole of twigs, dirt and debris, before spreading them out on a large concrete or brick patio for drying in the sun. The berries are turned by hand every day, to prevent mildew and ensure an even dry. The drying process takes up to four weeks, and the dried berry is then sent to milling for hulling and polishing.

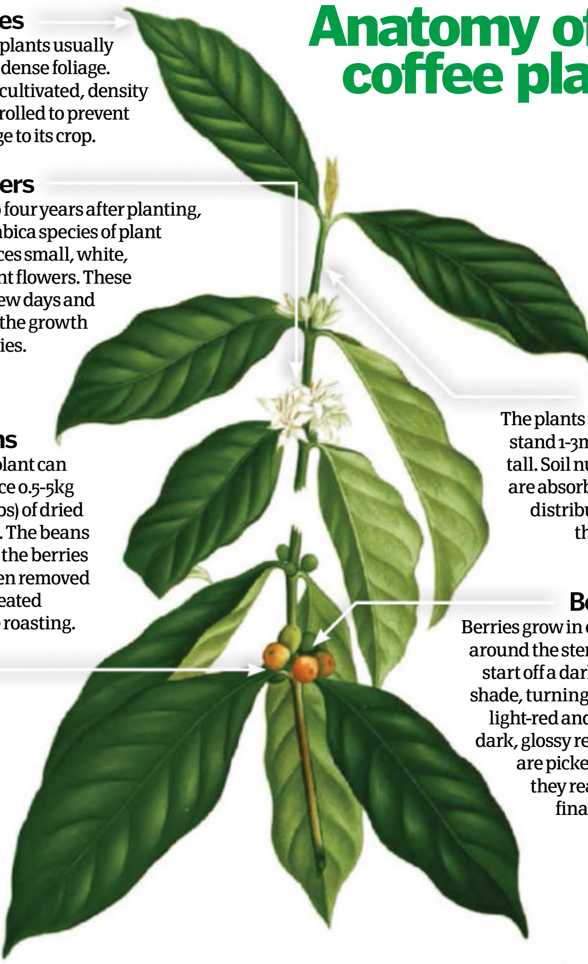
The wet method undertakes hulling first, with the beans removed from the berries before the drying process. This is undertaken by throwing the berries into large tanks of water, where they are forced through a mesh mechanically. The remainder of any pulp is removed through a fermentation process. As with


Workers pick large quantities of coffee berries

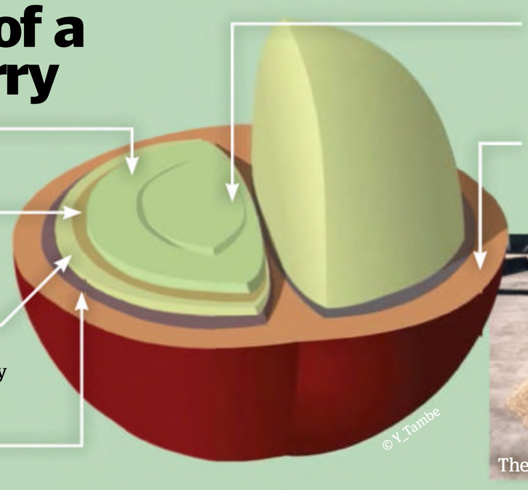
the dry method, the beans are then spread out on a patio for drying.

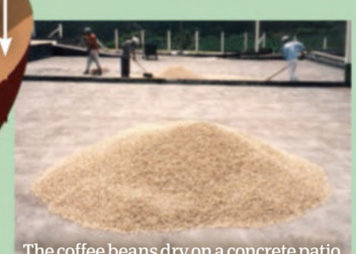
The final stage is milling. This is a series of four processes to improve the texture, appearance, weight and overall quality. Beans that have been prepared the dry way are first sent for hulling to remove the remaining pulp and parchment skin. Next, the beans are sent for polishing. This is an optional process, in which the beans are mechanically buffed to improve their appearance and eliminate any chaff produced during preparation. Third, the beans are sent through a battery of machines that sort them by size and density (larger, heavier beans produce better flavour than smaller and lighter ones). Finally the beans are graded, a process of categorising beans on the basis of every aspect of their production.

Anatomy of a coffee plant



Anatomy of a coffee berry

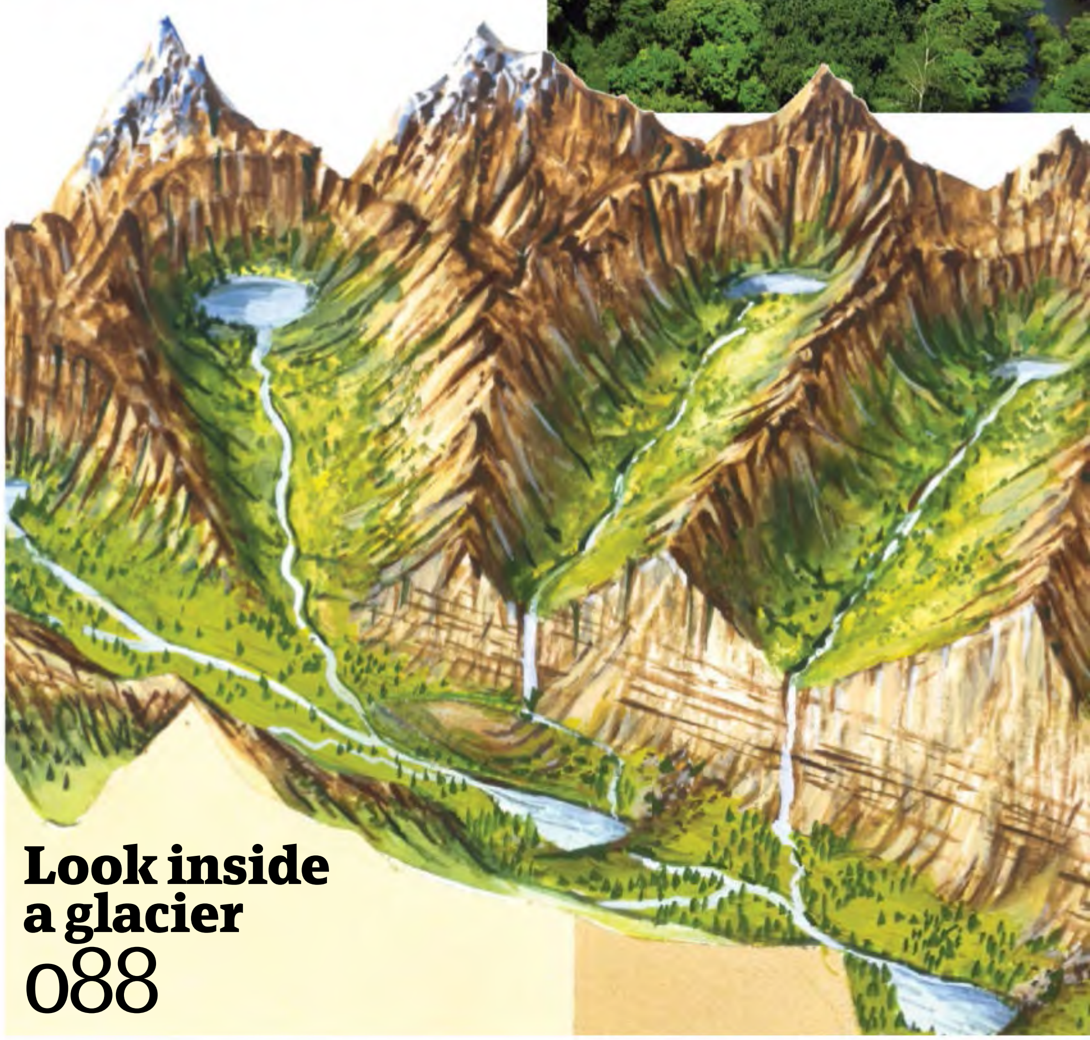



The coffee beans dry on a concrete patio

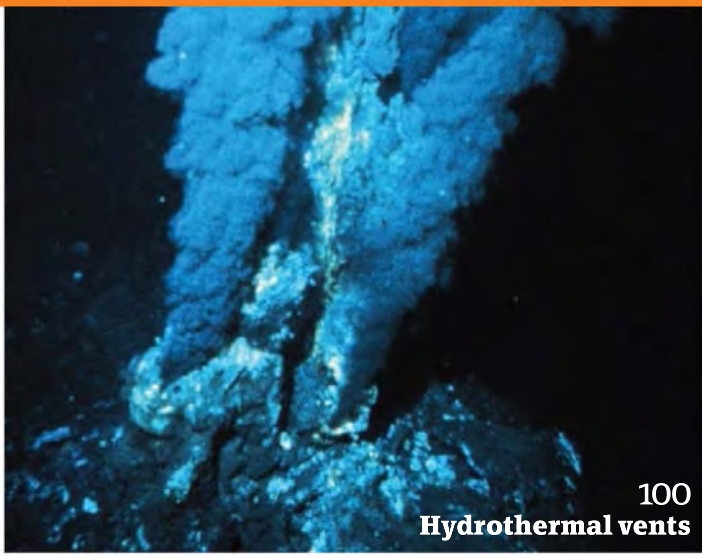
EARTH'S LANDSCAPES

096
Marine habitats

076
Waterfall wonders



Look inside a glacier
088



KEY DATES
ROALD AMUNDSEN'S EXPEDITION

Aug 1910
Amundsen and his team set off from Christiania, Denmark with nearly 100 Greenland dogs.

Jan 1911
The boat reaches the Ross Ice Shelf, sailing closer to the Pole than Scott's team, giving them an advantage.

Sept 1911
In their first bid to get closer to the Pole, bad weather forces them to race back to their base.

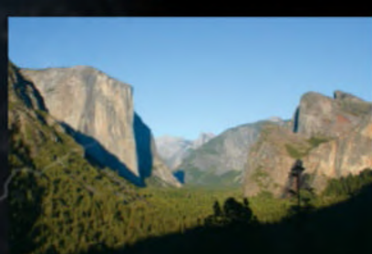
Dec 1911
By reaching 88°23'S, the team is further south than anyone has ever travelled before.

Dec 1911
Amundsen reaches the South Pole where he and his team place a Norwegian flag at the site.

DID YOU KNOW? *Roald Amundsen beat Robert Scott to the South Pole by 34 days, despite Scott beginning eight weeks earlier*

SURVIVING EXTREME EARTH

The skills you need to journey into the wilderness and get out again alive



For many of us, the toughest conditions we'd ever have to face would probably be walking the dog in the bucketing rain. However, outside of the urban sprawl there are some places on Earth that aren't so hospitable to humans. While mankind has successfully populated large areas of the planet's land surface, there are still many places you wouldn't dare to venture unless you really enjoy a challenge or have just got horribly, horribly lost.

History is littered with people who have faced the biggest tests this planet has to offer, whether deliberately or accidentally, and lived to tell the tale, but many have fallen victim to frozen wastes or scorching plains. Even the best-prepared adventurers can come unstuck in the face of the amazing force of nature.

Over the next few pages we trek across deserts in search of water, dredge through jungles and scale icy mountains to uncover the dangers you're likely to come up against. Find out the equipment and skills needed to survive some of the most mind-boggling environments, where temperatures can plummet in hours, winds can reach breath-taking speeds and poisonous frogs can kill you where you stand.

We're not saying we will instantly turn you into the next Ranulph Fiennes, but it will hopefully give you a fighting chance should you find yourself in the depths of the Arctic Circle or in the middle of the Sahara.

Beat the freeze

How to stay alive when you're freezing to death

Earth's north and south extremities are among the most inhospitable places on the planet. Even in the summer, temperatures are freezing and winds can reach up to 327 kilometres (200 miles) per hour, so it's no wonder the cold is the biggest killer here. If you're trekking across snowy wastes, better pack your thermals. Shrug on multiple layers of breathable fleeces and keep them dry. Any water will instantly freeze, as will any exposed flesh. Even nose hairs and eyelashes start icing over in minutes, so covering up is key.

Your body will respond quickly to the heat loss by tightening blood vessels near your skin. This is the reason we look paler when we're cold and why our fingers and toes become numb. Meanwhile, your muscles will start moving involuntarily, causing you to shiver. It can boost heat production by up to five times, but that uses up a lot of energy so you'll need to keep eating and drinking. Consume six to eight litres (10.6 to 14 pints) of water every day and around 6,000 calories, three times the typical recommended daily allowance. You can get this by melting butter into your food or munching on chocolate and bacon, so it's not all bad!

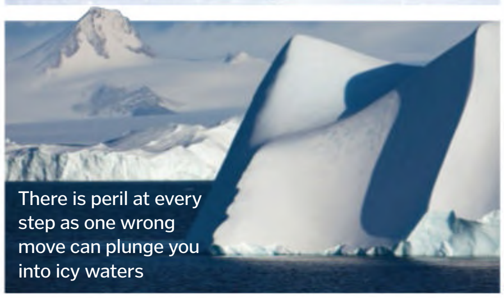
A word of warning, though: keep your eyes peeled. Hungry polar bears, particularly those with cubs to feed, can be aggressive and are masters of disguise. Flares and loud noises will often be enough to scare them away. You'll also need to watch your step, as slipping through a crack in the ice can send you plummeting into the freezing cold ocean. It's generally safe to walk on white ice, but grey ice is only ten to 15 centimetres (four to six inches) thick and prone to cracking, while black ice is to be avoided at all costs since it will have only just formed. Tread carefully, stay wrapped up and keep on the move if you want to have any hope of survival.

Amazing animal

The arctic fox is an incredible little animal, well adapted to living in one of the harshest environments on Earth. Its furry feet and short ears are ideally suited to conserving heat in the unforgiving, freezing environment. Its coat is also adaptable; while its habitat is snowy its fur is brilliant white, hiding it from both prey and predators. However, as the ice melts, its coat turns brown or grey to hide among the rocks of the region. The arctic fox is an omnivore, feasting on rodents, fish and birds, but it will also eat vegetation when meat is difficult to find.

The snowy wastes of the polar regions are difficult to navigate

Polar bears are the Arctic's deadliest hunters

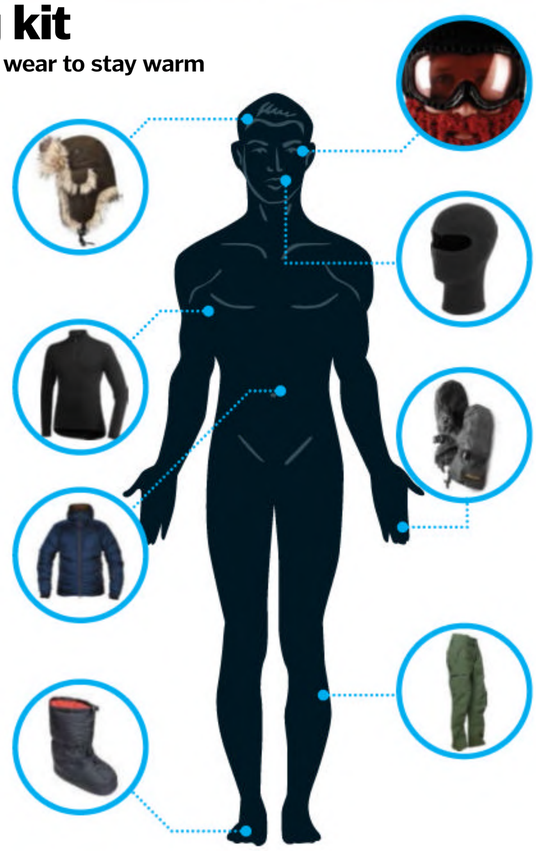


There is peril at every step as one wrong move can plunge you into icy waters

Little grows in this area so finding food is tough

Life-saving kit

A rundown of what to wear to stay warm



Hat
A hat with ear flaps that covers the head and neck is vital. A strap to secure it on the head will be useful in high winds.

Thermal shirt
Your base layer should be a thin, thermal insulating top that wicks any sweat away from your body.

Jacket
Your jacket will need to be both wind and waterproof to keep you dry and warm. Wrist holes in the cuffs keep it secured.

Boots
Warmth is vital – literally – so fleece-packed boots are good. Straps are better than laces but don't fasten them so tight it cuts off the blood supply.

Goggles
The best goggles have a photochromic lens to help ward off glare from the ice and make sure you see cracks and holes.

Balaclava
You'll need to cover up as much as possible, so a woollen balaclava will keep the most heat in.

Mittens
Although gloves offer more dexterity with actions, mittens are better as they keep your fingers together and much warmer.

Trousers
Waterproof and windproof trousers are a must. Make sure they are also breathable, however, as you don't want your legs to become sweaty and lose valuable fluid.

-93.2°c

COLDEST PLACE ON EARTH

A bone-chilling temperature of -93.2°C (-135.8°F) was recorded in Antarctica in 2010 by satellite, making it the lowest temperature ever recorded on Earth.

DID YOU KNOW? USA, Russia, Norway, Canada and Denmark all lay claim to territory in the Arctic, but none are allowed to own it

Ice fishing

Make a hole in the ice with an auger – a kind of drill that bores large holes. The ice you bore on should be light grey and about 15 centimetres (six inches) deep. Produce a hole approximately 0.5 metres (1.5 feet) in diameter. Set up your chair one metre (three feet) away from the hole and hold your rod over the top of it, with the line dangling in the water. The rod should only be about a metre (three feet) long and made of a sturdy material. Drop the baited line down around two metres (seven feet) and wait for a bite. Reel it in and keep it chilled before cooking!

This simple tool can find you a life-saving source of food

AVERAGE DEPTH OF ICE IN ANTARCTICA – 2,126 METRES (6,975 FEET) EQUIVALENT TO 6.5 EIFFEL TOWERS

70% ANTARCTICA'S ICE ACCOUNTS FOR 70 PER CENT OF THE WORLD'S FRESH WATER

4 MILLION PERMANENT INHABITANTS IN THE ARCTIC, NONE IN ANTARCTICA

IF ALL THE ICE IN ANTARCTICA MELTED, THE SEA WOULD RISE 58M (190FT). THE STATUE OF LIBERTY IS 93M (305FT) TALL

Survive the night

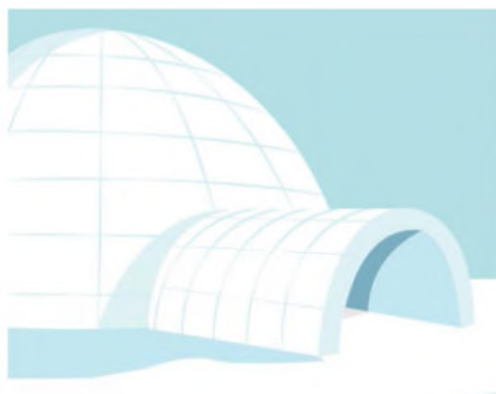
Build an igloo for protection

Find your spot

The first trick to making your igloo is to build it on the side of a slope. This will mean less building for you to do. Dig a trench in the snow around 0.6m (2ft) deep. Get in and slice out blocks of packed ice from either side of the trench to ensure they are nice and uniform.

Dig yourself in

Dig another trench into the side of the hill. It should be about 0.5 metres (1.6 feet) wide. This is the entrance trench. Leave a gap and dig another hole, but don't make it as deep as the entrance trench. This is your sleeping chamber, so make sure you fit in it!



Construct the walls

Stack the ice blocks in a circle around the sleeping trench, leaving a gap around the entrance trench. Over the entrance trench, stack the blocks in a semicircle. Make the entrance tunnel as small as possible to minimise heat loss. Rub water over the blocks to fuse them together.

Get out alive

Uncovering the dangers that lurk beneath the canopy of trees

Few places on Earth house quite as many things that can kill you in so many ways as the jungle. From snakes to poisonous frogs, berries to rivers, anyone walking through the jungle needs to have their wits about them at all times.

The most obvious threat will come from big animals like tigers and jaguars that inhabit the jungles of India and the rainforests of South America respectively. Your best bet for evading these huge predators is to stand still and hope you weren't seen, or run and hide. If you are spotted, make yourself as big as possible and shout loudly as this will surprise and intimidate them.

Don't be fooled into thinking the smaller critters pose less of a threat, though. Many can be deadlier than the big cats. The golden poison dart frog is particularly lethal to humans, as it has enough poison to kill ten adults. The poison is held in their skin, so eating or even touching one could have disastrous consequences. Add in the dangers of snakes, mosquitos, piranhas, crocodiles and bears, the jungle is not a place for the faint of heart. Take plenty of DEET-based insect repellent and make lots of noise as you travel so as to ward off creatures that would attack you out of fear or surprise.

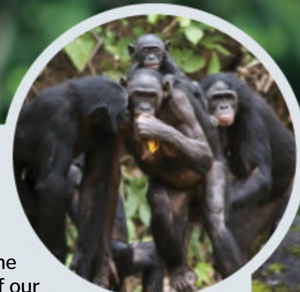
While on your travels, be on the lookout for your next meal. On the menu will be fruit, plants, insects and fish, but you'll need a book to help weed out the edible from the poisonous. Avoid anything that's brightly coloured, because this is often an evolved defence mechanism to warn against eating that particular plant.

But while it's possible to survive for about 60 days without food in warm conditions, you'll last less than 72 hours without water. Always ensure you have a filtration device or water purification tablets to make the water safe, or catch rain before it has hit the ground to prevent catching diseases like cholera.

Although there are a multitude of things that can kill you in the jungle, being clued up on what you can and can't eat and how to avoid predator attacks will help enormously. If you're lost and ready to scream "Get me out of here!" then following water will take you out of the jungle to the end of the waterway. Ant and Dec almost certainly won't be there to meet you.


Tigers in the jungles of India are deadly predators

Amazing animal



Bonobo monkeys are found in the jungles of the DR Congo and are one of our closest relatives. They share over 98 per cent of our DNA and have an astonishing ability to mimic human behaviour, including using tools and solving problems.

They have adapted superbly to life in the jungle, surviving on a varied diet of fruit, plant life small rodents, insects, and even soil. This flexibility means they will never go hungry.

They are extremely social animals, living together in groups of up to 100. The females move from group to group to prevent inbreeding and the males stay in their social groups for life.

What tells a sun bear's age?

A Rings on their teeth **B** Length of their tongue **C** Wrinkles on their forehead

Answer:
Much like you can do with trees, you can determine the real age of a sun bear by counting the rings on their teeth. Their jaws are incredibly strong and can break open nuts and coconuts quite easily, which also requires considerably strong teeth.

DID YOU KNOW? Earth's largest rodent, the capybara, lives in South American jungles and can weigh as much as an adult human

Avoid man-eating predators

Three steps to remaining undetected in the jungle

Cover your tracks

Predators like big cats are excellent trackers and they'll be keen to find you, especially if it's dinnertime. Walking in water will stop physical evidence of your movements, giving you a better chance of going undetected.

Camouflage

Hide yourself as you walk through the jungle using camouflage. If you don't have a specific outfit, coat yourself with mud and attaching leaves and foliage to your body will make you less likely to be spotted.

Cover your scent

Jackets lined with charcoal are excellent for preventing your natural odours from escaping into the environment. Otherwise, cover yourself in things like mud and strong smelling plants to mask your scent.

Jungle protection

The clothes and kit to keep you hidden, cool and safe

Sunglasses

The sunlight can be incredibly strong so you'll need some sunglasses with UV filters.

Long sleeve shirt

A light, breathable fabric will keep you cool, but make it baggy so mosquitos can't get to your skin.

Bug spray

Mosquitos carry a huge array of diseases, not least malaria, so 100 per cent DEET spray is vital.

LifeStraw

This device really could save your life. The filter inside the straw wipes out 99.99 per cent of bacteria in dirty water.

Trousers

Length is key here. You can't let your ankles get exposed because that's where mosquitos especially love to bite.

Hat

A large brimmed hat will protect you from bugs falling from the trees and keep you relatively hidden from animals above you.

Backpack

You'll need your hands free so a backpack is crucial. It needs to be waterproof, blend in with the environment and be comfortable.

Poncho

Sudden downpours are features of jungle and rainforest life, so a lightweight, quick-drying poncho is useful.

Machete

The jungle is a tough landscape to negotiate, so a large knife or machete will help you work your way through the thick and difficult undergrowth.

Boots

Your shoes don't want to be too thick and heavy because they'll wear you down. Sturdy trainers or Wellington boots will surprisingly be enough.

The edibility test

If you aren't a trained botanist, you might struggle to identify which plants are safe to eat. That's where the universal edibility test comes into play. Eat nothing and drink only water for eight hours before the test.

Your first task is to split up the plant you are testing into its individual components, such as the stem, root, leaf, flower and bud. Crush each part of the plant and, one-by-one, rub them on your skin to see if you have a bad reaction to it. If your skin blisters or forms a rash, it's unlikely to be good to eat.

If it's good, the next stage is to boil the plant, if possible. Hold the plant on your lip for a few minutes, removing instantly if it begins to burn. Finally, if the plant has passed the test so far, place it on your tongue. Again, if it begins to feel painful or look bad, spit it out and wash your mouth thoroughly. Remember though, tasting bad isn't the same as being poisonous!

Chew it for around 15 minutes and, if all still feels good, swallow it. Don't eat anything else for eight hours and see if you have any bad reaction to what you've eaten. If you're good, you've found a potentially life-saving food source!

Escape scorching heat

How to survive the extreme temperatures of the desert

While the polar regions are always bitterly cold no matter what time of day it is, one of the major challenges in surviving the desert is dealing with the ridiculous changes in temperature. In the midday Sun, the mercury can reach as high as 50 degrees Celsius (122 degrees Fahrenheit) in the Sahara, but drop to below freezing by night. Your best bet is to wear a loose-fitting robe. This will let air circulate around the body and you won't get nearly as hot and sticky. At night, when the temperature plummets, you can wrap it around you for warmth.

It is vital that you protect your head. If you think a touch of sunburn from staying by the pool on holiday is bad, that's nothing compared to the effects of walking all day in the parched desert. Even if it means burning another part of your body, wrap something around your head and neck so you don't succumb to sunstroke, which can lead to hallucinations and fainting.

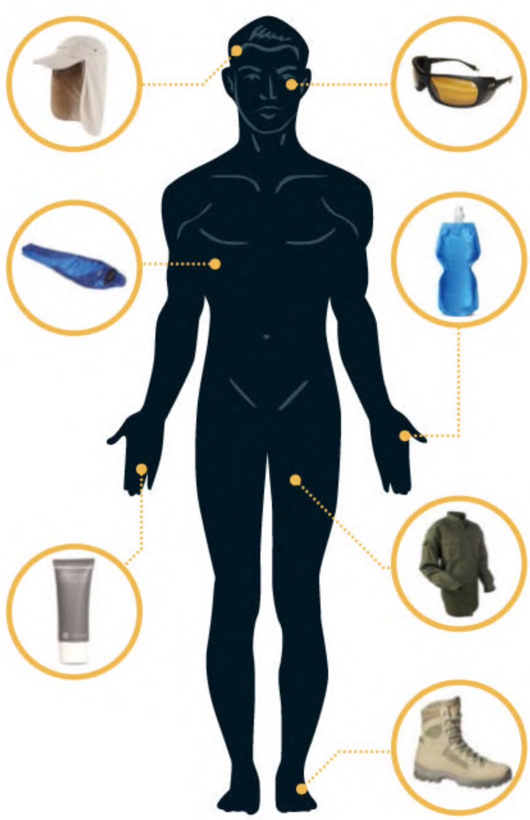
Other dangers in the desert will mostly come from scorpions. They hide in the sand and deliver a sting with their tail that can paralyse and eventually kill. Sturdy boots will protect you from these creepy crawlies, as well as make travelling over sand much easier. While they don't make great pets, scorpions do provide a crucial source of nutrition. Picking them up by the tail just behind the stinger is the safest method and it will give you vital protein for your journey. Just don't eat the tail.

In the desert, you'll need to adjust your body clock. Aim to shelter during the day and travel at night. This has the dual benefit of avoiding the scorching sun and keeping you active during the freezing night. It also means you can keep on the right track easily by following the stars, hopefully leading to civilisation.

Shelter can come in the form of large rocks or cliffs. Alternatively, you can dig a trench down into the cooler sand and use clothing or some other material you have available to form a canopy over the top, secured by rocks or sand. As long as it is at an angle and not touching you, you'll be protected from the Sun's glare.

Desert dress

The essentials to surviving in the hottest places on Earth



Headwear
If you don't have any headwear, you could suffer with heatstroke, so protect your face and neck.

Sleeping bag
A brightly coloured blanket will be useful as it would enable any search party to find you, will keep you protected in the day and warm at night.

Sun cream
The baking temperatures will burn you in no time at all, so a high factor sun cream will provide at least some protection.

Sunglasses
The desert throws up an awful lot of sand and glare, so sunglasses will be absolutely vital.

Water bottle
This will be your greatest friend. Take small, regular sips and if you ever find a water source, fill it up as much as possible.

Shirt
Your clothes will need to be as loose fitting as possible to minimise sweating and dehydration.

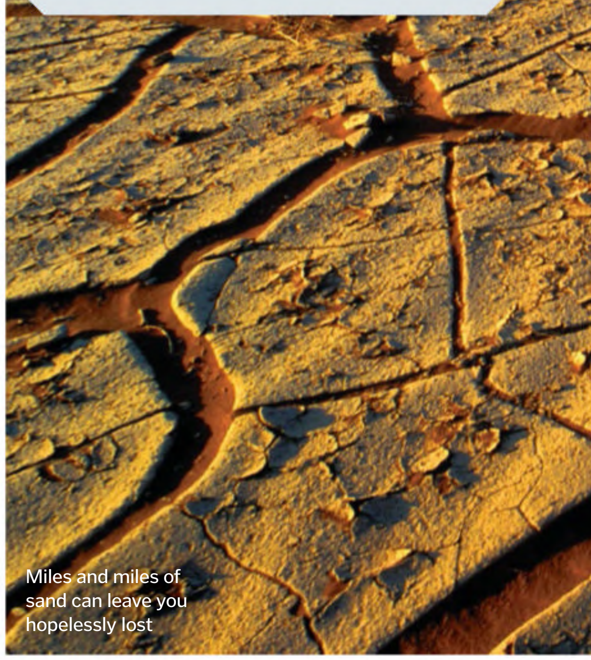
Footwear
Even though you'll be desperate for sandals, trainers or walking boots will give you grip and necessary protection.

Amazing animal

The camel is known as the ship of the desert, as this remarkable creature can travel without food or water for a long time.

Domesticated 3,000 years ago, camels have been an invaluable help to those who make their livelihood travelling the desert. They can carry 90kg (200lb) on their backs effortlessly and can travel up to 32km (20 mi) a day, with the added bonus of being able to last for at least a week without water and months without food.

Camels store fat in their hump to use as a food source and consume 145l (32gl) of water in one go, which they also store for later use. They have adapted wonderfully to the desert, developing a membrane across the eye and extra-long eyelashes to counteract sand storms. Their feet also are incredibly well protected with calluses and spread out for walking on sand.



Miles and miles of sand can leave you hopelessly lost

Finding your way around

The desert is not only barren and featureless, but it is also a moving entity. Therefore, finding your way around is tough. The easiest way to find your way around is with a compass, but if that isn't available, travel at night and use Polaris, the North Star, as your makeshift compass.

Even though they are always shifting, sand dunes can also provide useful navigation hints. They always build up at 90 degrees to the direction of the wind, as the wind pushes sand upward to form them, so even when there's no wind, if you know the wind is northerly, the dunes will go east to west and you can use that information to navigate.

If you are lucky enough to have any landmarks, try and make a straight path between them so you know you are going in a straight line.

HEAD 2 HEAD

LARGEST NON-POLAR DESERTS

1. BIG

Gobi Desert

This 1.3mn km^2 (502,000mi^2) rocky desert covers a large portion of China and Mongolia, experiencing harsh and dry winters.

2. BIGGER

Arabian Desert

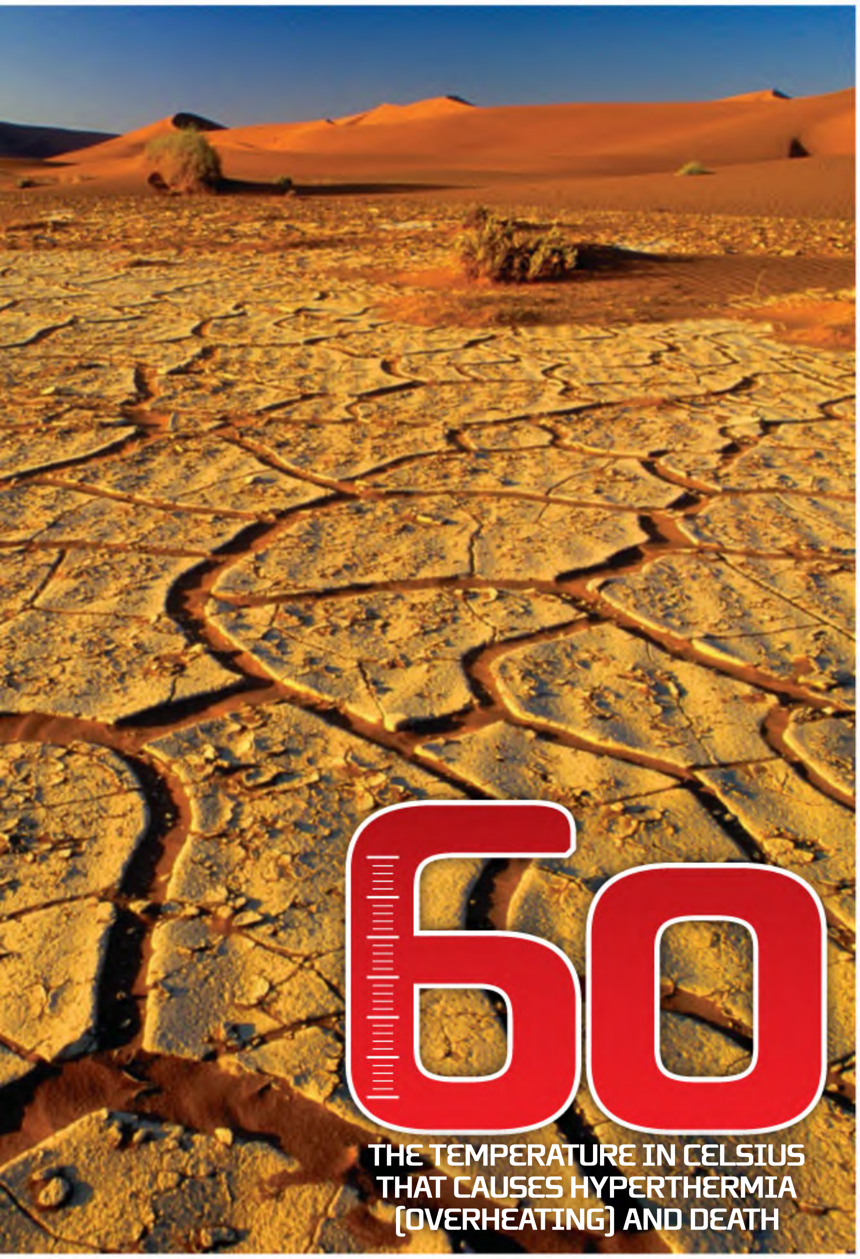
At a staggering 2.3mn km^2 (888,000mi^2), the Arabian Desert takes up most of the Arabian Peninsula.

3. BIGGEST

Sahara Desert

The most famous desert in the world measures 9.1mn km^2 (3.5mn mi^2), making it over three times bigger than any other non-polar desert.

DID YOU KNOW? *Contrary to popular belief, drinking cactus water won't quench your thirst but make you very ill*



The plunging temperatures can leave you freezing cold without the right preparation

Fight extreme thirst

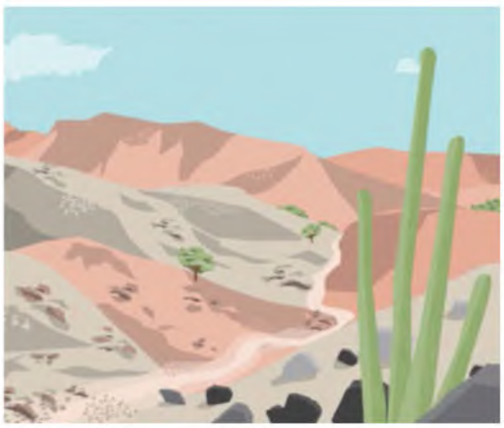
Locate the desert's most precious resource

Follow the wildlife

There are a number of birds and land animals that live in the desert and they all need water. Try and follow them wherever possible and hopefully they should lead you to a water source.

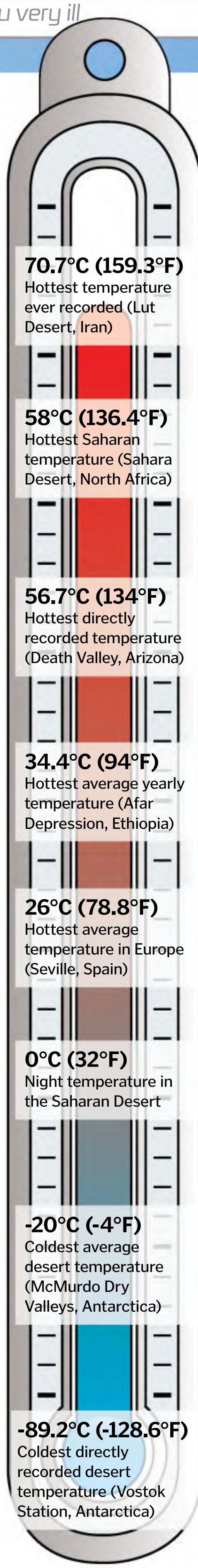
Shady cliffs

In your quest for precious shade, you might also be lucky enough to find water. Dips and ridges that face north could be housing puddles and pools in their shaded, cooler spots.



Grass is always greener

Plant life and vegetation means there is water around somewhere. Head down into valleys where there is plenty of greenery and even if there isn't a spring or pool around, you should be able to extract water from leaves or roots.



Battle life-threatening altitude

How to cross the world's most treacherous terrain

Mountains are the ultimate test of survival. They're prone to rapid changes in weather and it's near impossible to predict. Even if the base is warm and sunny, by the time you reach the summit, low cloud can blind you, rain can make the terrain slippery and the cold can freeze you.

Good preparation is essential and you'll need a lot of kit. Pack a rucksack with a map, compass and a flashlight or headtorch, along with a brightly coloured emergency blanket, and dress in thermals and waterproof and windproof clothing. You'll also need to keep well hydrated. A lack of fluid at high altitude will result in dizziness, intense headaches and even frostbite. If you don't have any water to hand, try to find a stream or melt some snow or ice to drink.

The altitude is a real issue for many mountaineers. As you climb higher, the air pressure reduces, meaning there is less oxygen for you to breathe. This lack of oxygen will cause your brain to reduce activity in all but the most important organs, making your limbs heavy and head dizzy. The most important thing to do is rest and re-oxygenate your body.

If you are trying to escape the mountain, the best way is to head downward, but this isn't always possible. Mountains have complicated structures and often there isn't an easy path down. If possible, put markers along your route to show where you have already been, to avoid walking in circles. As well as being potentially confusing, mountains also hide dangerous crevices. Keep your eyes peeled for breaks in the snow or ice and if you are ever unsure, try to find rocks or stones to throw in front of you that could give away a hidden abyss.

If the visibility does become too poor, the safest thing might be to bed down. Find a spot out of the wind and protected from any snow or rainfall, like a cave or overhanging cliff. Even though it might sound strange, pack your surroundings with snow, because it does have insulating properties. Pile yourself with as many layers as possible and this should provide the warmth so you can make it through the night and try to find your way out in the light.

Amazing animal

The mountain goat is amazingly adapted to life on the mountainside. Their hooves are curved and flexible to provide them more grip and traction on the treacherous slopes. Despite looking spindly and thin, their legs are actually very strong and they can leap surprisingly large distances.

They have two coats, a warm, woolly undercoat and a thinner but longer overcoat, which keeps the insulating undercoat dry. This system is how they can stand the cold temperatures long after bigger animals have given up and descended down the mountain in cold weather.

GoPros are a great way to record your adventure

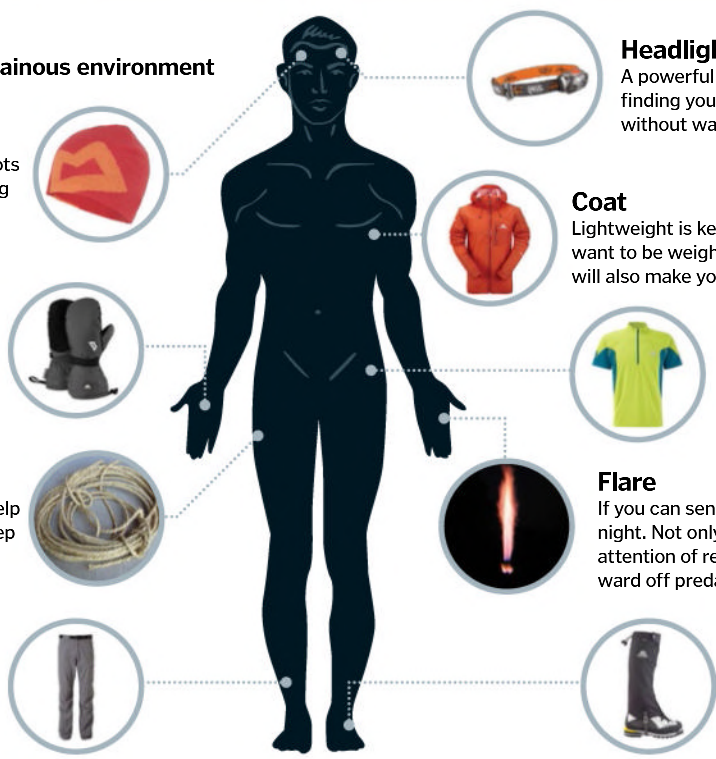
Keep a record

It's always handy to have a visual record of your travel by using a video recorder like the Hero3+ from GoPro. This camcorder is incredibly robust, lightweight and waterproof. It can also be attached onto helmets or bags, leaving your hands free to scale the treacherous mountainside.

Using a GoPro camera will also be useful as, once you get off the mountain to safety, you and a professional will be able to look over the footage, determine what went wrong and see how you could avoid getting stuck in the same situation again. The Hero3+ is available at **www.camerajungle.co.uk**.

Mountain gear

What you need to brave the harsh, mountainous environment



Beanie
A tight-fitting hat will keep lots of heat in as well as not being likely to fly away!

Mittens
Although it would be useful to have fingers available for gripping ledges, it's more important to have your fingers warming each other.

Rope
A strong and sturdy rope will help you protect yourself while asleep and also aid you in climbing or negotiating dangerous paths.

Trousers
You need to keep dry and have items accessible, so a pair of waterproof trousers with zipped pockets will be the most useful.

Headlight
A powerful headlight will be essential for finding your way around in darkness without wasting a hand on a torch.

Coat
Lightweight is key here because you don't want to be weighed down. Bright colours will also make you visible to rescuers.

T-shirt
A tight-fitting T-shirt made of breathable material will keep body heat in without making you sweat.

Flare
If you can send up a flare, do so at night. Not only will it attract the attention of rescuers, it might ward off predators.

Boots
A high-legged boot will keep the worst of the snow and water out, while the sole will need to be rugged and have tons of grip.

DID YOU KNOW? *The tallest volcano is Mauna Kea, as it starts 6,000m (19,685ft) below sea level, making it 10,205m (33,480ft) tall*

Keep the fire burning

How to warm up on the mountainside

Find some wood

You'll want a variety of wood, from small sticks and twigs, all the way up to sizeable branches and logs. The smaller bits will light much more quickly while the bigger pieces will burn longer, hotter and form the bulk of the blaze.

Build your base

Dig a small pit in the ground. Surround it with stones so the fire doesn't get out of control. Place the smallest bits of wood at the bottom of the pile, but leave some gaps to keep the fire supplied with the oxygen it needs to burn.

Light the fire

Place the larger branches and logs at an upwards angle, allowing the air to circulate and ensuring all the wood is getting burned evenly. Make sure everything is connected so fire can transfer from one piece of wood to another.

The weather can turn in an instant, so make sure you're prepared for anything

7500

HEIGHT IN METRES AT WHICH NEARLY A THIRD OF CLIMBERS GET HALLUCINATIONS

Crevices and cracks await the unwary traveller

Waterfall wonders

The story behind the world's greatest waterfalls

Big waterfalls are among the most spectacular geological features on Earth. The thundering waters of Niagara Falls can fill an Olympic-sized pool every second. Visitors are drenched with spray and deafened by volumes reaching 100 decibels, equivalent to a rock concert.

A waterfall is simply a river or stream flowing down a cliff or rock steps. They commonly form when rivers flow downhill from hard to softer bedrock. The weak rock erodes faster, steepening the slope until a waterfall forms. The Iguazú Falls on the Argentina-Brazil border, for example, tumble over three layers of old resistant lava onto soft sedimentary rocks.

Any process that increases the gradient can generate waterfalls. A 1999 earthquake in Taiwan thrust up rock slabs along a fault, creating sharp drops along several rivers. A series of new waterfalls appeared in minutes, some up to seven metres (23 feet) high – taller than a double-decker bus.

Many waterfalls were created by rivers of ice during past ice ages. These glaciers deepened big valleys, such as Milford Sound in New Zealand. The ice melted and shallow tributaries were left 'hanging' high above the main valley. Today the Bowen River joins Milford Sound at a waterfall 162 metres (531 feet) high, almost as tall as the Gherkin skyscraper in London.

Waterfalls vary enormously in appearance. Some are frail ribbons of liquid while others are roaring torrents. All waterfalls are classed as cascades or cataracts. Cascades flow down irregular steps in the bedrock, while cataracts are more powerful and accompanied by rapids.

Gigantic waterfalls seem ageless, but they last only a few thousands of years – a blink in geological time. Debris carried by the Iguazú River is slowly eroding the soft sediments at the base of the falls, causing the lava above to fracture and collapse. Erosion has caused the falls to retreat 28 kilometres (17 miles) upstream, leaving a gorge behind.

The erosional forces that birth waterfalls eventually destroy them. In around 50,000 years, there will be no Niagara Falls to visit. The Niagara River will have cut 32 kilometres (20 miles) back to its source at Lake Erie in North America and disappeared.

The sheer force and power of waterfalls makes them impossible to ignore. Daredevils across the centuries have used them for stunts. The first tightrope walker crossed the Niagara Falls in 1859. Risk-takers have ridden the falls on jet skis, in huge rubber balls or wooden barrels and many have died. The steep drops

HEAD 2 HEAD
THE BIGGER THE FALL…

1. TALLEST

Angel Falls
The world's highest waterfall drops 979m (3,212ft) from a flat plateau in Venezuela, barely making contact with the underlying rock.

2. WIDEST

Khone Falls
These waterfalls in Laos are about 10.8km (6.7mi) across. They also have a very high average flow rate of over 10,000m^3/s (353,147ft^3/s).

3. LARGEST

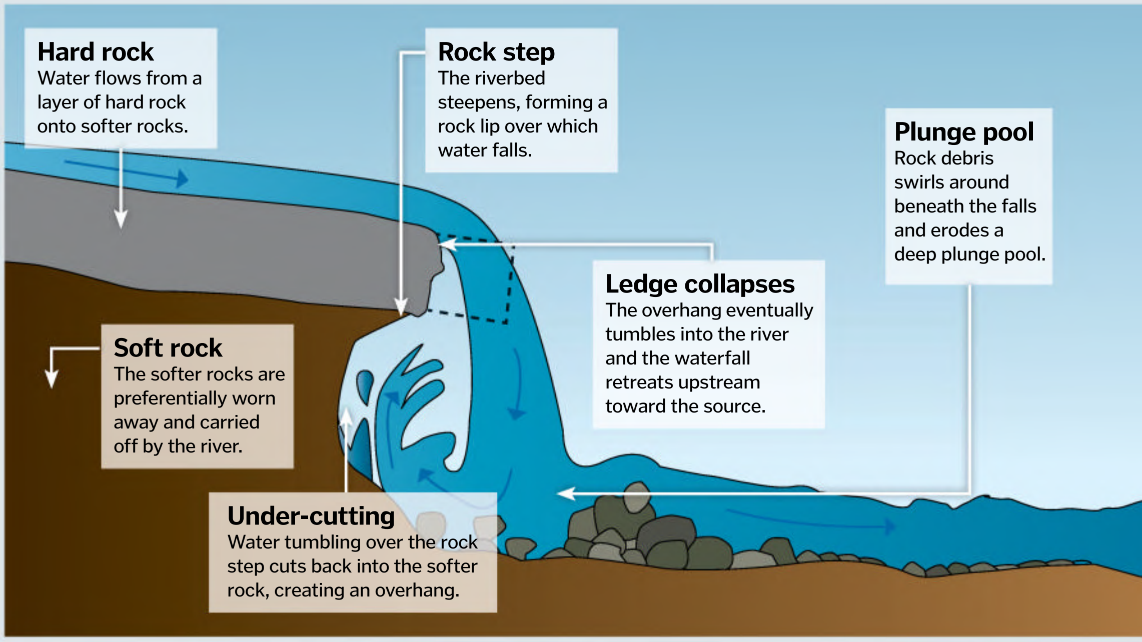
Victoria Falls
Known as the 'smoke that thunders', Victoria Falls spans the African Zambezi River and produces the largest sheet of falling water.

DID YOU KNOW? *Fictional detective Sherlock Holmes fell into the Reichenbach Falls while fighting his nemesis Professor Moriarty*

Erosion power

Waterfalls appear to be permanent landscape features, but they are constantly changing thanks to the geological process of erosion. Erosion is the gradual wearing down of rock. Rivers transport sand, pebbles and even boulders, which act like sandpaper to grind down rock.

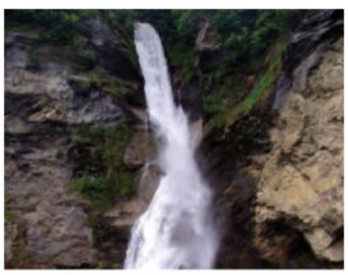
Waterfalls often form when rivers flow from hard to softer rocks. Over thousands of years, the softer rocks erode and the riverbed steepens. The river accelerates down the steep slope, which increases its erosive power. Eventually the slope is near vertical and the river begins cutting backward. As sections of the overhang collapse, the waterfall gradually moves upstream toward the river's source.



What is the biggest waterfall on Earth?

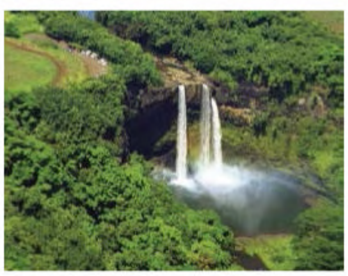
This is a tricky question as there is no standard way to judge waterfall size. Some use height or width, but the tallest one, Angel Falls, is only a few metres across at its ledge so is nowhere near the widest. Others group waterfalls into ten categories based on volume flowing over the drop.

Every method has problems. Boyoma Falls in the Congo is one of the biggest waterfall on Earth by volume, but some argue the turbulent waters are simply river rapids. Shape is a popular and easy-to-digest, but unscientific, way to classify waterfalls, as many of them fall (literally) into several different categories.



Horsetail
In horsetail waterfalls, the water stays in constant contact with the underlying rock, as it plunges over a near-vertical slope. One example is the famous Reichenbach Falls in Switzerland.

Block
A wide river tumbles over a cliff edge, forming a rectangular 'block' waterfall that is often wider than it is high. Famous examples include Victoria Falls in Africa and the Niagara Falls in North America.



Punchbowl
A river shoots through a narrow gap and cascades into a deep plunge pool. The name 'punchbowl' refers to the shape of the pool. An example of a punchbowl fall is Wailua Falls, Hawaii.

Plunge
Water spills straight over a ledge while barely touching the rock beneath. Angel Falls in Venezuela, the world's highest uninterrupted waterfall, is a member of this category.

Tiered
The waterfall has several drops, each with their own plunge pool. One example is Gullfoss, Iceland. Some tiered waterfalls, such as the Giant Staircase, USA, resemble several separate falls.

Chute
These resemble extreme rapids more than waterfalls. A pressurised frothy mass of water is forced through a suddenly narrower channel. An example is Barnafoss, a waterfall in Iceland.

Frozen waterfalls

Ice climbers in Colorado every winter tackle a frozen waterfall called the Fang – a free-standing icicle over 30m (100ft) tall and several metres wide. The idea of a frozen waterfall may seem strange. Rivers are slow to cool because their moving waters constantly mix and redistribute heat. When temperatures drop below freezing, water cools and ice crystals called frazil form. Only a few millimetres across, these start the freezing process by gluing together. Ice sticks to the bedrock or forms icicles on the rock lip. After a lengthy cold spell, the entire waterfall will freeze.

mean waterfalls often pose a navigation problem. In the 19th century, the Welland Canal was built to bypass Niagara Falls.

People have long dreamed of harnessing the power and energy of the biggest falls. The first recorded attempt to use the swift waters above Niagara, for example, was in 1759 to power a water wheel and sawmill. Today many hydroelectric plants generate electricity near big waterfalls, such as the Sir Adam Beck Power Plants above Niagara Falls. River water is diverted downhill past propeller-like turbines. The rushing flow spins the turbine blades, creating renewable electricity. The bigger the drop, the faster the water, and the more energy it contains as a result.

Harnessing rivers for electricity can conflict with the natural beauty of their waterfalls. The Guaíra Falls on the Paraná River, probably the biggest waterfall by volume, were submerged in the 1980s by the building of the Itaipu hydroelectric dam.

These days, the conflict between power and nature is greater than ever. Dr Ryan Yonk is a professor of political science at Southern Utah University. According to him, "the demand for electricity generation in the developing world is not going away and it's going to ramp up."

Controversial hydroelectricity projects, like some in Asia, involve a trade-off between beauty and tackling climate change. Dr Yonk believes "the alternatives in those countries are likely to be very dirty coal."

Above Niagara Falls, treaties have balanced energy generation with iconic scenery since all the way back in 1909. During the summer, when most of the 12 million annual tourists visit the site, about half of the total water carried by the river must flow over the falls – an incredible 2,832 cubic metres per second (100,000 cubic feet per second).

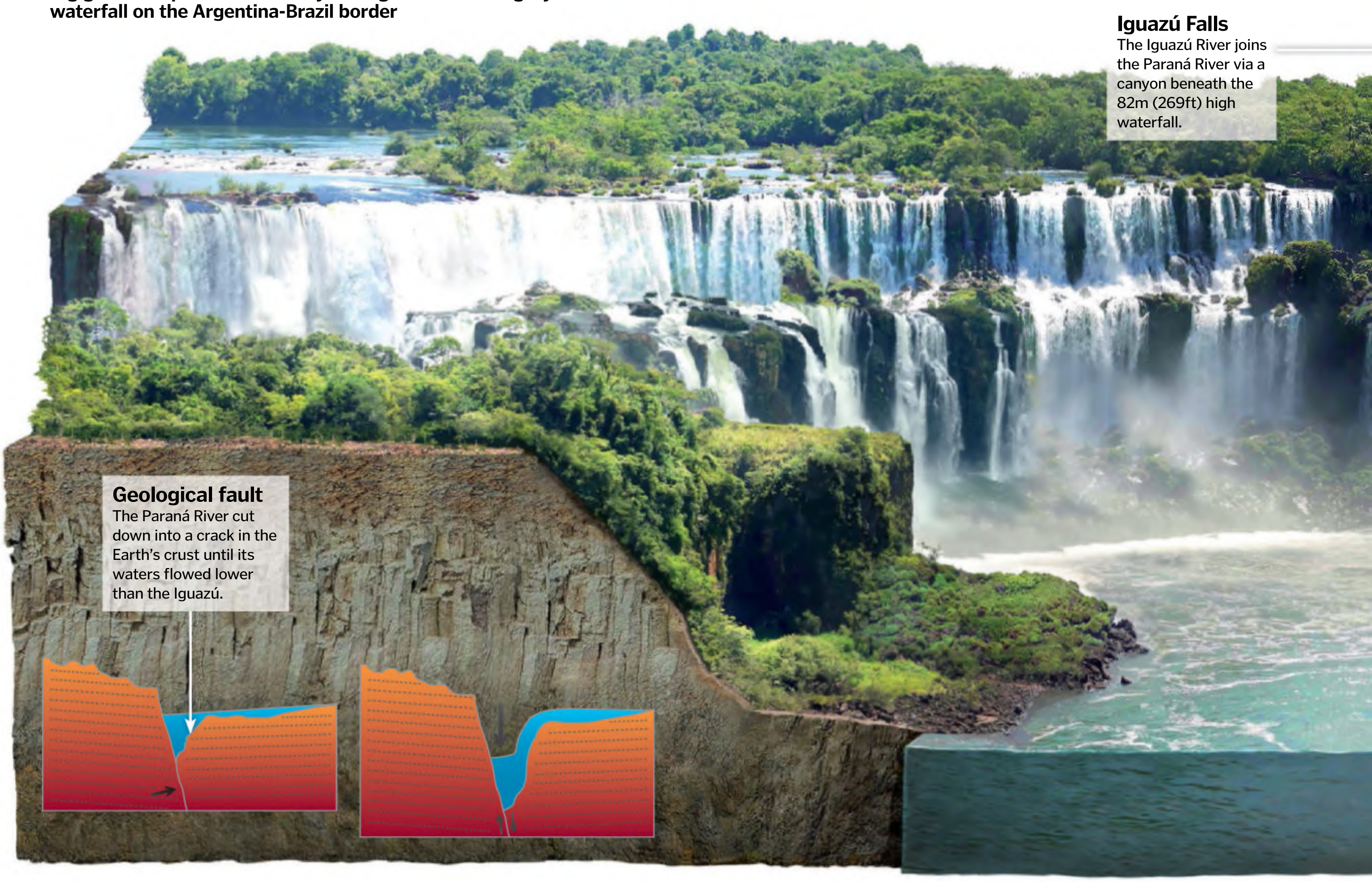
Yet these summer flow limits have a price. One study says the loss of potential electricity from the current treaty is 3.23 million megawatt hours each year – enough to run four million light bulbs.

Withdrawing more water could have benefits above hydropower generation. Samiha Tahseen is a civil engineering PhD student, studying Niagara flow at the University of Toronto. According to her, "you can reduce the erosion of the falls."

Another advantage to limiting the flow is that it minimises the mist that obstructs the view. Samiha adds: "There is no denying that the mist is dependent on the flow so if you decrease the flow of the falls a little bit, that helps."

The birth of Iguazú Falls

A gigantic eruption millions of years ago created a mighty waterfall on the Argentina-Brazil border



Iguazú Falls
The Iguazú River joins the Paraná River via a canyon beneath the 82m (269ft) high waterfall.

Geological fault
The Paraná River cut down into a crack in the Earth's crust until its waters flowed lower than the Iguazú.

THE STATS
IGUAZÚ FALLS

275 NUMBER OF DROPS

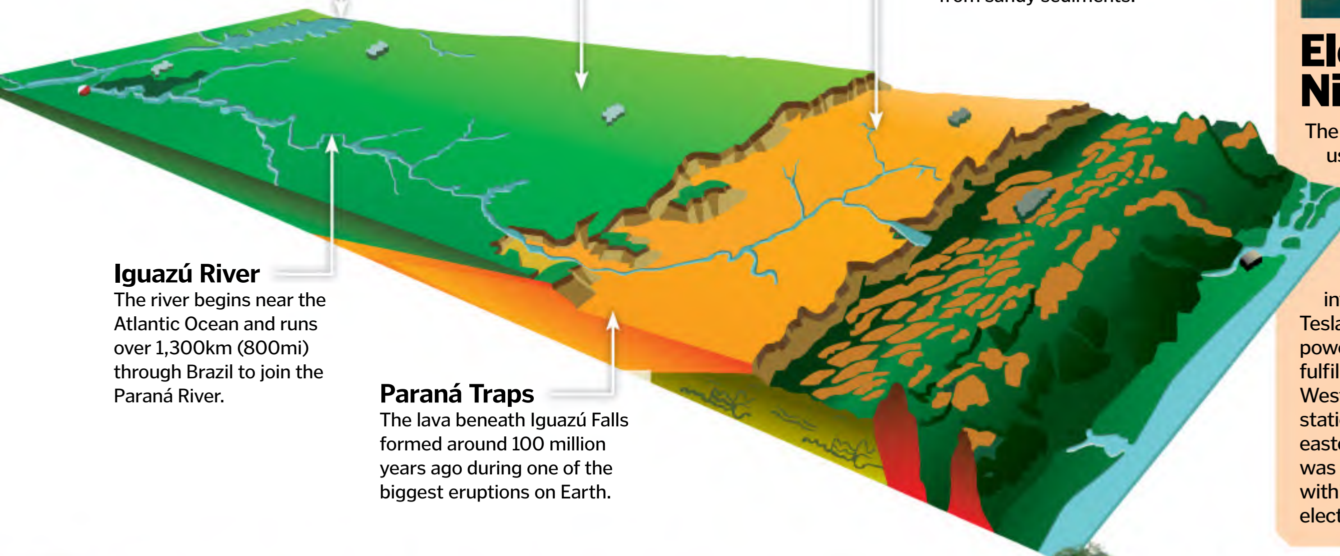
82m TOTAL HEIGHT

2.7km WIDTH

1,756m³/s FLOW RATE

12,750m³/s MAX FLOW

DID YOU KNOW? *The first person to go over Niagara Falls in a barrel was a 63-year-old teacher in 1901 – she survived*



Electrifying Niagara Falls

The first large power station to use alternating current was built at Niagara Falls in 1895. It was the first big supplier of AC, the form of electricity that supplies businesses and homes today, invented by genius Nikola Tesla. Tesla imagined harnessing the power of the falls. His dream was fulfilled when industrialist George Westinghouse built a Niagara station big enough to supply the eastern United States. The plant was the largest of its age and, within a few years, its power lines electrified New York City.

ON THE MAP

Where in the world
1. Niagara
2. Victoria
3. Iguazú
4. Angel
5. Reichenbach
6. Boyoma

The ever-changing Plitvice Lakes

How incredible geology has formed Croatia's waterfall paradise

The spectacular Plitvice Lakes are actually part of one large river flowing between the Mala Kapela and Licka Plješivica mountains in central Croatia. The river has divided into this series of interconnected lakes and waterfalls because of a geological phenomenon known as a karst landscape, where rock, water and organisms all work together to create new features.

The Plitvice river basin is made of limestone and dolomite, and as the water passes through it dissolves these rocks and becomes saturated with calcium carbonate. This chemical compound then sticks to the mucus secreted by the microscopic bacteria and algae that grow on moss plants in the water. The plants gradually become encrusted with the calcium carbonate and it slowly builds up at a rate of about one centimetre (0.4 inches) per year to form barriers of travertine rock. Some of these barriers, which have been growing since the Upper Triassic period, are around 4,000 meters (13,123 feet) thick and act as natural dams that split the river into lakes. As more water travels down from the mountains, it flows over these barriers to create waterfalls that cascade down the river basin.

Just as quickly as the flowing water erodes the travertine, more is formed when the calcium carbonate-saturated water pools at the base of the waterfalls. This means that the Plitvice Lakes are constantly changing size and shape as old waterfalls run dry and new ones are formed.

This clever geology is also responsible for giving the Plitvice Lakes their distinctive blue-green colour. When the white calcium carbonate coats the bottom of the lakes it reflects sunlight and the sky to create vivid colours that change depending on how the Sun's rays hit the water and how many organisms and minerals are present.

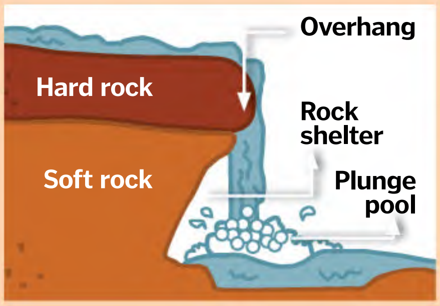
"The Plitvice Lakes are constantly changing size and shape"

DID YOU KNOW? *Plitvice Lakes National Park is a UNESCO World Heritage Site and is home to many endangered species*

On the map

How does a waterfall form?

Usually, waterfalls form when a river flows over areas of soft and hard rock. The flowing water erodes the soft rock more quickly than the hard rock, undercutting it to leave an overhang. This forms a basic waterfall, and as the water flows over this ledge, it often takes some rocks with it. These rocks crash into the riverbed below, so more erosion occurs to form a plunge pool. The soft rock behind the waterfall is also eroded as water splashes at the bottom, cutting into the rock to form a cave-like structure called a rock shelter. Eventually the water erodes the overhang of hard rock too, causing the waterfall to recede upstream. This process is slightly different to that which occurs at the Plitvice Lakes, as instead of carving existing rock into an overhang, the mineral-rich water there helps to create new ledges that the water can flow over.



The tallest Plitvice waterfall is over 70 metres (230 feet) high, the equivalent of almost 16 double-decker buses stacked on top of each other

Antarctica explored

What's large, hostile and used to trial missions to Mars? Antarctica – the world's coolest continent

Antarctica is the world's last great wilderness and Earth's coldest, windiest, highest and driest continent. Around 98% of the land area lies buried beneath kilometres of snow and ice, yet Antarctica is – paradoxically – a desert. In fact, it is so inhospitable that no one lives there permanently, despite it being 25% bigger than Europe. This frozen continent remained unexplored until the 19th century. Unveiling its mysteries claimed many lives.

Antarctica is definitely worth a visit from your armchair, however, because it may also be Earth's quirkiest and most remarkable continent. Among its marvels is a river that flows inland, Mars-like valleys where NASA scientists test equipment for space missions, and perpetually dark lakes where bacteria may have survived unchanged since Antarctica had lush forests like the Brazilian rainforest. Living in and around the Southern Ocean that encircles Antarctica are fish with antifreeze in their blood, the world's biggest animal, and a giant penguin that survives nine weeks without eating during the harsh Antarctic winter.

Antarctica is the chilliest place on Earth. At the Russian Vostok scientific research station in the cold, high continental interior, it can get cold enough for diesel fuel to freeze into icicles – even in summer. Vostok is the site of the coldest temperature ever recorded on Earth – an amazing -89.2°C (-128.6°F). The temperature in most freezers is only about -18°C (-0.4°F).

The continent is also Earth's windiest. Antarctica's ice cools the overlying air, which makes it sink. This cold, heavy air accelerates downhill, creating wind gusts of over 200 kilometres (124 miles) an hour. The sinking air at Vostok is so dry that some scientific researchers pack hospital IV (intravenous) drip bags to stop becoming dangerously dehydrated. Few clouds can form in the dry air, and most moisture falls as snow or ice crystals. Any snow that falls accumulates because it can't melt in the cold.

If the climate wasn't harsh enough, Antarctica never sees daylight for part of the winter because the sun barely rises over the horizon. Even in summer, the

Antarctic mountains, pack ice and ice floes

© Jason Auch

5 TOP FACTS
ANIMALS TO SPOT

Whales
1 Blue whales, Earth's largest animals, are among ten whale species found in Antarctic waters. Others include the killer whale and the sperm whale – the star of Moby Dick.

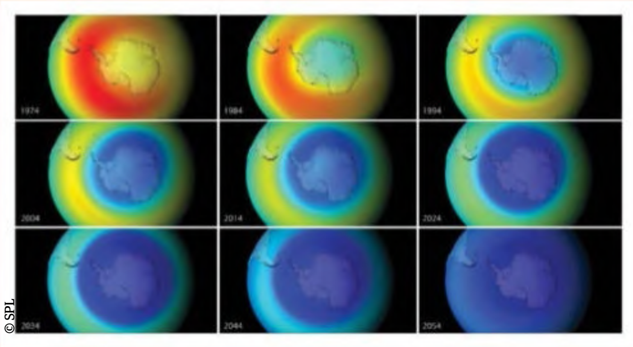
Penguins
2 There are 17 penguin species living in and around Antarctica. The emperor penguin – the world's tallest, largest penguin – is found nowhere else.

Seals
3 Most of Earth's seals live in Antarctic waters. These mammals hunt underwater for up to 30 mins and even sleep underwater, surfacing to breathe without waking.

Krill
4 Most Antarctic life wouldn't exist without these shrimp-like animals. Krill are about 6cm (2.4 inches) long, live up to five years and are food for most Antarctic predators.

Fish
5 Several fish species are adapted to Antarctica's oxygen-rich, icy waters, such as the Antarctic toothfish, whose blood contains antifreeze.

DID YOU KNOW? *Lake Chad in Antarctica was named by Robert Scott after Lake Chad in Africa*



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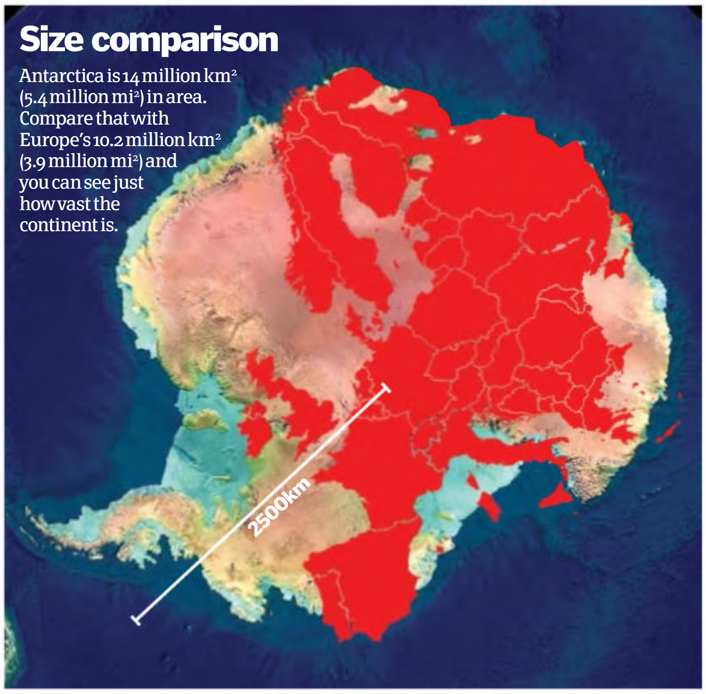
A world without ozone?
A 'hole' still exists over Antarctica

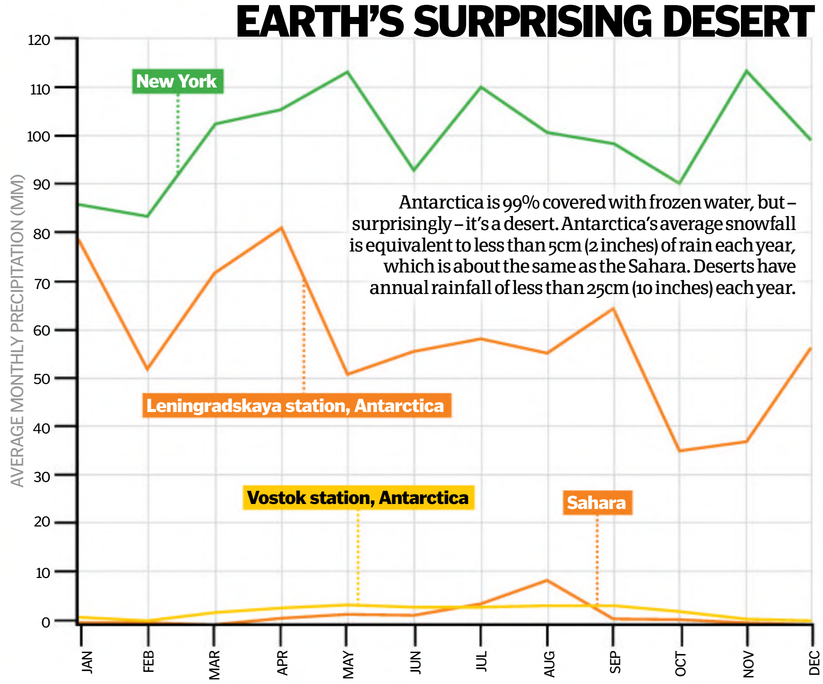
It's 2065, and skin cancer rates are soaring. Step outside in some cities and you'd be sunburned in ten minutes. That's the vision of NASA chemists, who predicted Earth's future if 193 countries hadn't agreed to stop producing CFCs in 1987. CFCs are man-made, chlorine-containing chemicals that destroy the Earth's ozone layer high in the atmosphere, which protects us from the sun's UV radiation. A 'hole' in this layer was discovered over Antarctica in the Eighties and persists today, because CFCs linger in the atmosphere for 50 to 100 years. The hole formed because the freezing winters allow unusual cold clouds to form. Chemical reactions on the cloud surface transform the chlorine in CFCs into an ozone-destroying form.

Size comparison

Antarctica is 14 million km² (5.4 million mi²) in area. Compare that with Europe's 10.2 million km² (3.9 million mi²) and you can see just how vast the continent is.



EARTH'S SURPRISING DESERT



Antarctica is 99% covered with frozen water, but – surprisingly – it's a desert. Antarctica's average snowfall is equivalent to less than 5cm (2 inches) of rain each year, which is about the same as the Sahara. Deserts have annual rainfall of less than 25cm (10 inches) each year.

"We're afraid if your name's not on the list, we can't let you in…"

Sun is feeble and low in the sky. The extreme cold partly explains why two huge ice sheets cloak Antarctica. The white ice cools it further by reflecting away about 80% of incoming sunlight. Together, these ice sheets contain around 70% of the world's fresh water. If they melted, global sea levels would rise by 70m (230ft) and swamp many of the world's major cities.

The East Antarctic ice sheet is the largest on Earth, with ice more than three kilometres (two miles) thick in places. Under the ice sheet are some of the oldest rocks on Earth – at least 3,000 million years old. The West Antarctic ice sheet is smaller, and drained by huge rivers of ice or glaciers. These move slowly in Antarctica's interior, but accelerate to up to 100m (328ft) per year towards the coast. The fastest is Pine Island glacier, which can flow at more than three kilometres (two miles) per year. When these glaciers hit the sea, they form huge, floating sheets of ice attached to the land called 'ice shelves'. The biggest is the Ross Ice Shelf, which covers approximately the area of France and is several hundred metres thick.

One of the world's biggest mountain ranges separates the two ice sheets. The Transantarctic Mountains are more than two kilometres (1.2 miles) high and 3,300 kilometres (2,051 miles) long – more than three times the length of the European Alps. The mountains were formed around 55 million years ago during a period of volcanic and geological activity. Volcanoes like Mount Erebus are still active today.

Antarctica's main ice-free area is the McMurdo Dry Valleys, a region with conditions like Mars through which runs the continent's longest, largest river. The Onyx River carries summer meltwater 40 kilometres (25 miles) inland from coastal glaciers to feed Lake Vanda, which is saltier at its bottom than the Dead Sea. The salinity of Dry Valley lakes like Lake Vanda allows their deep water to stay liquid at temperatures below the freezing point of fresh water. Other strange Antarctic lakes include Lake Untersee in the East Antarctic interior, which has water with the alkalinity of extra-strength laundry detergent.

Despite the harsh conditions and lack of soil, animals and plants survive on ice-free parts of Antarctica. In the windswept Dry Valleys, lichens, fungi and algae live in cracks in the rocks. Towards the coast, on islands and the peninsula, mosses are fed on by tiny insects, including microscopic worms, mites and midges. Some insects called springtails use their own natural antifreeze, so they can survive temperatures of less than -25°C (-13°F). There are even two species of flowering plants.

In contrast, the Southern Ocean surrounding Antarctica is among the richest oceans in the world. The annual growth and melting of sea ice dredges nutrients from the ocean depths, resulting in phytoplankton. A single litre of water can contain more than a million of these tiny plants. The phytoplankton are eaten by krill – tiny shrimp-like creatures that are the powerhouse of Antarctica's ecosystem and feed most of its predators, including seals, fish, whales and penguins. They form dense swarms, with more than 10,000 krill in each cubic metre of water. Some swarms extend for miles and can even be seen from space. Alarming recent studies show that krill stocks have fallen by 80% since the Seventies, probably due to global warming.

All of Antarctica's species are adapted to the extreme cold. Seals and whales have a thick layer of blubber for insulation and penguins have dense, waterproof plumage to protect them from salty, surface water at a frigid -1.8 °C (29°F). Some species of fish have antifreeze in their blood. Antarctic icefish have transparent blood and absorb oxygen through their skin.

The most common birds are penguins. Of the 17 species of Antarctic penguins, only two live on the continent itself. One is the world's largest penguin, the emperor penguin, which grows to 115cm (4ft) tall. Being large helps the penguin to keep warm. Emperor penguins breed on Antarctica's sea ice during the cold, dark winter, enduring blizzards and low temperatures. The male penguins keep their eggs warm by balancing them on their feet for up to nine weeks, while the female goes fishing at sea. During this fasting period, these super-dads huddle in groups of up to 5,000 penguins to keep warm, losing 45% of their body weight.

During the summer, around 4,400 scientists and support staff live on Antarctica, carrying out experiments. Some are drilling to extract cylinders of ice more than three kilometres (two miles) long, to provide a record of climate covering perhaps the last 740,000 years. The ice contains ancient air bubbles and compressed layers of snow. Scientists are also drilling into underground lakes like Lake Vostok, which may contain water and microbes isolated from the outside world for a million years.

Astrophysicists also benefit from Antarctica's clean, dry air. IceCube is an Antarctica-based experiment that tracks neutrinos, ghostly particles created by exploding stars. Another experiment is attempting to detect faint light from the Big Bang that created our universe. Scientists are also studying the feeding habits of Adélie penguins, using scales to check their weights on their favourite walking routes.

Antarctica's top sights

Larsen Ice Shelf

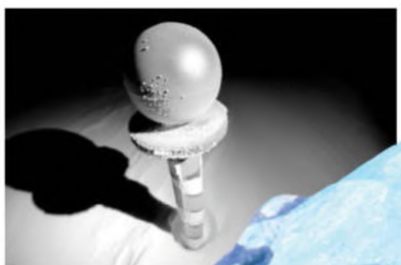
A Luxembourg-sized area of the Larsen Ice Shelf collapsed in only 35 days in 2002. Scientists said it was the first time the shelf had collapsed in 12,000 years.

Antarctic Peninsula

The Antarctic Peninsula is a mountain chain typically more than 2km (1.2mi) high that protrudes 1,334km (829mi) north towards South America. It's the warmest, wettest part of Antarctica.

South Pole

The geographic South Pole is where Earth's longitude lines converge. The striped ceremonial Pole where pictures are taken is about 90m (295ft) away from the real Pole, which is on a moving glacier.



West Antarctic ice sheet

The West Antarctic ice sheet is Antarctica's second largest ice sheet and is drained by huge ice rivers. Some scientists fear it could de-stabilise and collapse under climate change.

Ross Ice Shelf

The Ross Ice Shelf is the world's largest ice shelf and covers 510,680km (317,322mi) squared, roughly the area of France. It's about 1km (0.6mi) thick in places.

The ice-clogged waters of the McMurdo Sound, Antarctica

THE STATS ANTARCTICA

HIGHEST PEAK 4,892m | LOWEST TEMPERATURE –89.2°C | TOTAL AREA 14 million km^2

PERMANENT POPULATION Nil | SUMMER POPULATION ~4,400 people | LOWEST POINT –2,540m

DID YOU KNOW? *Antarctica's biggest purely terrestrial animal is a wingless midge, which grows to just 1.3cm (0.5 inches) long*

Lake Vanda has the clearest ice in the world (as transparent as distilled water), and it's possible to see straight down for many metres

Mount Erebus
Mount Erebus is among Earth's largest active volcanoes. Heat escaping the volcano melts the snow above into caves. The steam released freezes instantly into chimneys up to 18m (60ft) high.

East Antarctic ice sheet
The East Antarctic ice sheet is Earth's largest. It is more than 3km (2mi) thick in places and mainly flat, vast, featureless polar desert swept by icy winds.

Dry Valleys
The McMurdo Dry Valleys are Antarctica's largest ice-free area and resemble Martian landscapes. They contain mummified seal remains, salty lakes and a river that flows inland in the summer.

Lake Vostok
Lake Vostok is the biggest of 145 lakes buried beneath Antarctica's ice. Discovered in 1996, it's the largest geographic feature discovered on Earth in the last 100 years.

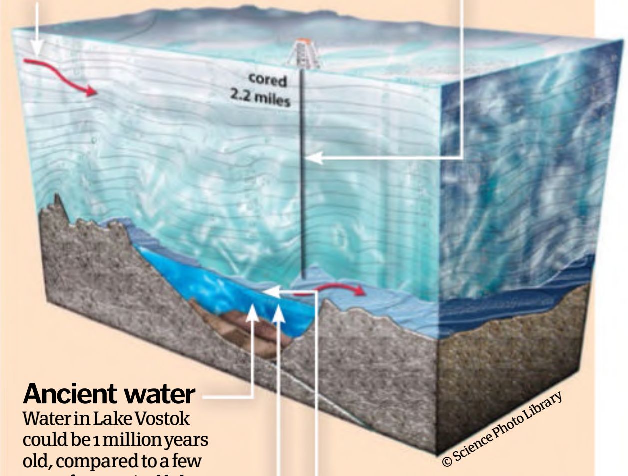
Transantarctic Mountains
The Transantarctic Mountains are among the world's biggest mountain ranges and divide Antarctica in two. They are 3,300km (2,051mi) long, with treeless peaks over 3km (2mi) high.

Lake Vostok – an alien world

Discover the largest lake beneath Antarctica's surface

Ice flow
The mass of ice on top of the lake takes thousands of years to creep from shore to shore.

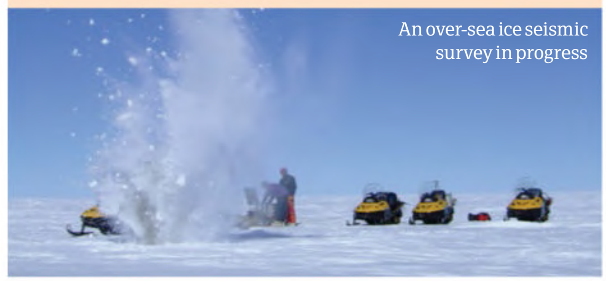
Life search
Russian researchers are drilling to the lake water through 4km (2.5mi) of ice to search for life.



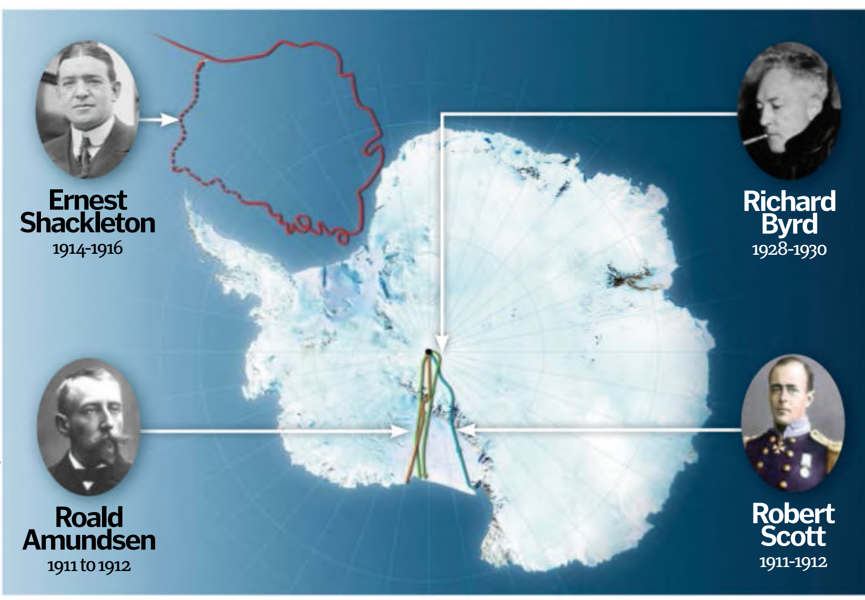
Ancient water
Water in Lake Vostok could be 1 million years old, compared to a few years for a typical lake.

Extreme living
Bacteria may live in Lake Vostok despite the perpetual darkness, icy water and enormous pressures.

Sloping lake surface
The lake surface slopes downwards because the ice is about 400m (1,312ft) thicker at one end than the other.

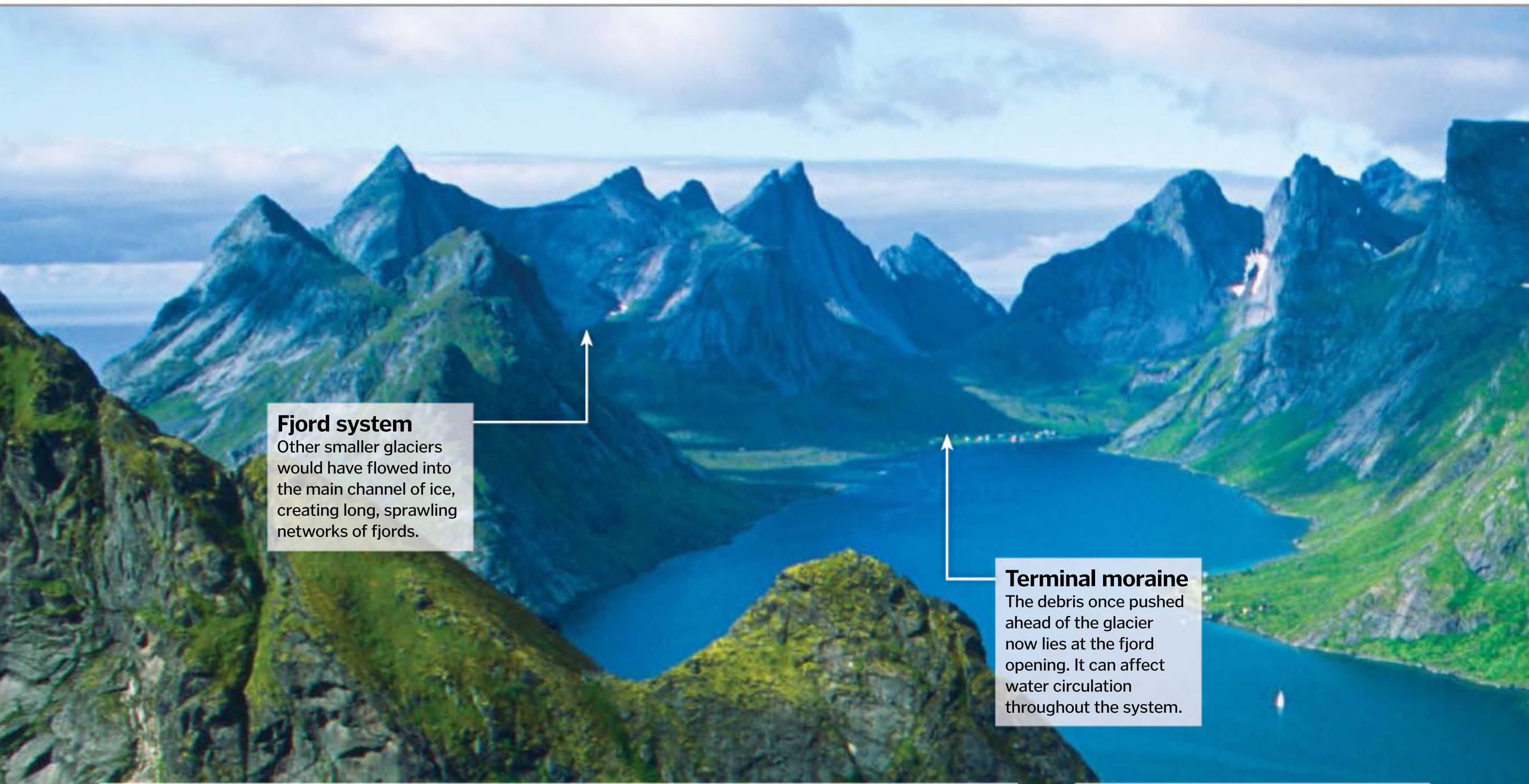


An over-sea ice seismic survey in progress



Early expeditions across Antarctica

By the late 19th century, Antarctica was Earth's last unexplored continent. The South Pole was the remotest place. The Pole was reached in December 1911 by Norwegian explorer Roald Amundsen who pioneered a new route. Amundsen's party raced the British expedition led by Robert Scott who arrived 33 days afterwards, having battled harsh weather and terrain. Scott's dispirited party died from starvation and exposure on the return journey. In 1914, Ernest Shackleton tried crossing Antarctica, but his ship 'Endurance' was crushed by winter ice. All his crew survived almost two years camping on the ice, until Shackleton led an epic 1,300 kilometres (808 miles) trip in a small boat to seek help. From 1928 onwards US explorer Richard Byrd led five expeditions to Antarctica, claiming vast territories for the USA. In November 1929, he flew over the South Pole. Today, the Pole is no longer uncharted territory – it even has its own post office!



How fjords form

As a product of the epic clash between ice and rock, find out how these amazing valleys are created

Fjords are long, steep-sided coastal valleys that are flooded by the sea. The majority of fjords developed during the last ice age, peaking approximately 20,000 years ago. Glaciers dominated the landscape, snaking their way to the ocean and tearing through anything that stood in their path. These massive valleys are typically found in mountainous, coastal areas of the Atlantic and Pacific oceans, and are common in Norway, Sweden, Greenland, Canada, Chile, New Zealand and Alaska.

As a glacier carved its way through the rock, it cut a distinctive U-shaped valley. The floor was flat and the sides were steep and high. As the massive river of ice – which could reach up to three kilometres (1.9 miles) thick – bore through the valley floor, it picked up rocky debris and carried it along for the ride, adding to the glacier's rock-shattering abrasive power. This rubble eventually made its way to the head of the glacier and was pushed in front of it as the glacier travelled – known as a terminal moraine. Such is the sheer power of the glacier to gouge out rock that the bottoms of fjords are often deeper than the ocean that they open into. For example, the deepest point of the Sognefjord in Norway is approximately 1,300 metres (4,265 feet) below sea level whereas the sill is just 100 metres (328 feet) below sea level. As the ice age came to a close, the oceans flooded into these extra-deep glaciated valleys, forming what we now know as fjords.

It's the rock formations of a glaciated landscape that are left for us to see today. The glacial moraine will still be present at the entrance of a fjord – a large sill acting as a barrier between fjord and open ocean. There are also other features such as skerries, which are rocky islands within a fjord that can be both large and mountainous or small and treacherous to navigate in a boat.

Life in a fjord

The water in a fjord is distinctly stratified, which affects the animals and plants that call it home. Dense seawater flows over the sill at the fjord's entrance and sinks to the bottom. Hardy deep-water animals such as sea cucumbers live down here in the thick mud, deposited over thousands of years. Deep-water coral reefs can also be found, providing valuable habitats for other species of algae, deep-water fish, crustaceans and molluscs.

Higher up in the water column, algae can thrive on the steep rocky sides of the fjords, providing food for hundreds of fish species. Oxygen-rich fresh water from rivers and meltwater streams runs into the fjord too, which combined with sunlit conditions can serve as the perfect environment for phytoplankton blooms.

The sheltered nature of a fjord can also offer a safe haven for larger marine-mammal visitors such as seals and whales, which often go there to mate.

HEAD 2 HEAD
RECORD FJORDS

LONGEST

1. Scoresby Sund
Located on the east coast of Greenland, the huge Scoresby Sund inlet is believed to be the longest fjord system found anywhere in the world.

NARROWEST

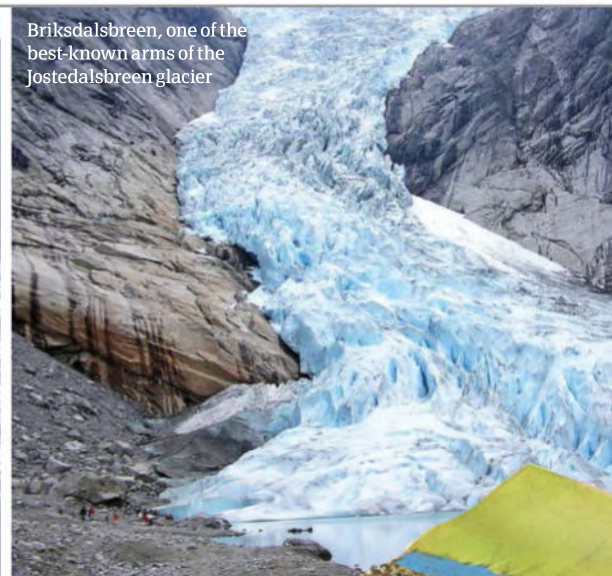
2. Nærøyfjord
Branching off Norway's larger and more famous Sognefjord near Bergen, the Nærøyfjord is just 250 metres (820 feet) wide at its narrowest point.

DEEPEST

3. Fiordo Baker
This fjord in Chile boasts the largest-known over-deepening of 1,344 metres (4,409 feet) – that equates to about three Empire State Buildings stacked together!

DID YOU KNOW? *The milky-turquoise colour of the glacier meltwater in a fjord is caused by super-fine debris called 'rock flour'*

Glaciers in Wrangell St Elias National Park, Alaska



Briksdalsbreen, one of the best-known arms of the Jostedalsbreen glacier

Glacier power

Discover the awesome Earth-shaping power of gigantic rivers of ice

Glaciers are huge rivers or sheets of ice, which have sculpted mountain ranges and carved iconic peaks like the pyramid-shaped Matterhorn in the Swiss Alps. The secret of this awesome landscape-shaping power is erosion, the process of wearing away and transporting solid rock. Glacial erosion involves two main mechanisms: abrasion and plucking. As glaciers flow downhill, they use debris that's frozen into the ice to 'sandpaper' exposed rock, leaving grooves called 'striations'. This is the process of abrasion. Plucking, however, is where glaciers freeze onto rock and tear away loose fragments as they pull away.

Today glaciers are confined to high altitudes and latitudes, but during the ice ages glaciers advanced into valleys that are now free of ice. Britain, for example, was covered by ice as far south as the Bristol Channel.

You can spot landforms created by ancient ice. Cirques are armchair-shaped hollows on mountainsides, which often contain lakes called 'tarns'. They're also the birthplaces of ancient glaciers. During cold periods, ice accumulated in shady rock hollows, deepening them to form cirques. When two cirques formed back-to-back, they left a knife-edge ridge called an 'arête'. Pyramidal peaks were created when three or more cirques formed. Eventually the cirque glacier spilled from the hollow and flowed downhill as a valley glacier. This glacier eroded the valley into a U-shape, with steep cliffs called 'truncated spurs'. When the glacier melted, tributary valleys were left hanging high above the main valley floor.

Hard rock outcrops in the valley were smoothed into mounds orientated in the direction of ice movement. Rock drumlins are shaped like whalebacks, adopting a smooth, convex shape. Roche moutonnée have a smooth upstream side, and a jagged downstream side formed by plucking. Where valley rocks varied in strength, the ice cut hollows into the softer rock, which filled with glacial lakes known as paternoster lakes.

8. Snout
The end of the glacier is called its snout, perhaps because it looks like a curved nose. The snout changes position as the glacier retreats and advances.

2. Medial moraine
A medial moraine is a debris ridge or mound found in the centre of a valley, formed when two tributary glaciers join and their lateral moraines merge.

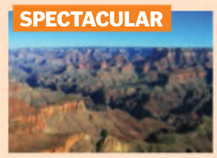
Modern-day glaciers are found where it's cold enough for ice to persist all year round

BEAUTIFUL

1. Landscape Arch, USA
This delicate natural arch – Earth's third largest – is only 2m (6.5ft) thick at its narrowest, but spans a whopping 90m (295ft).

LIVELY

2. Transgondwanan Supermountains, Gondwanaland
Nutrients eroded from a giant mountain range 600 million years ago may have helped Earth's first complex life to develop.

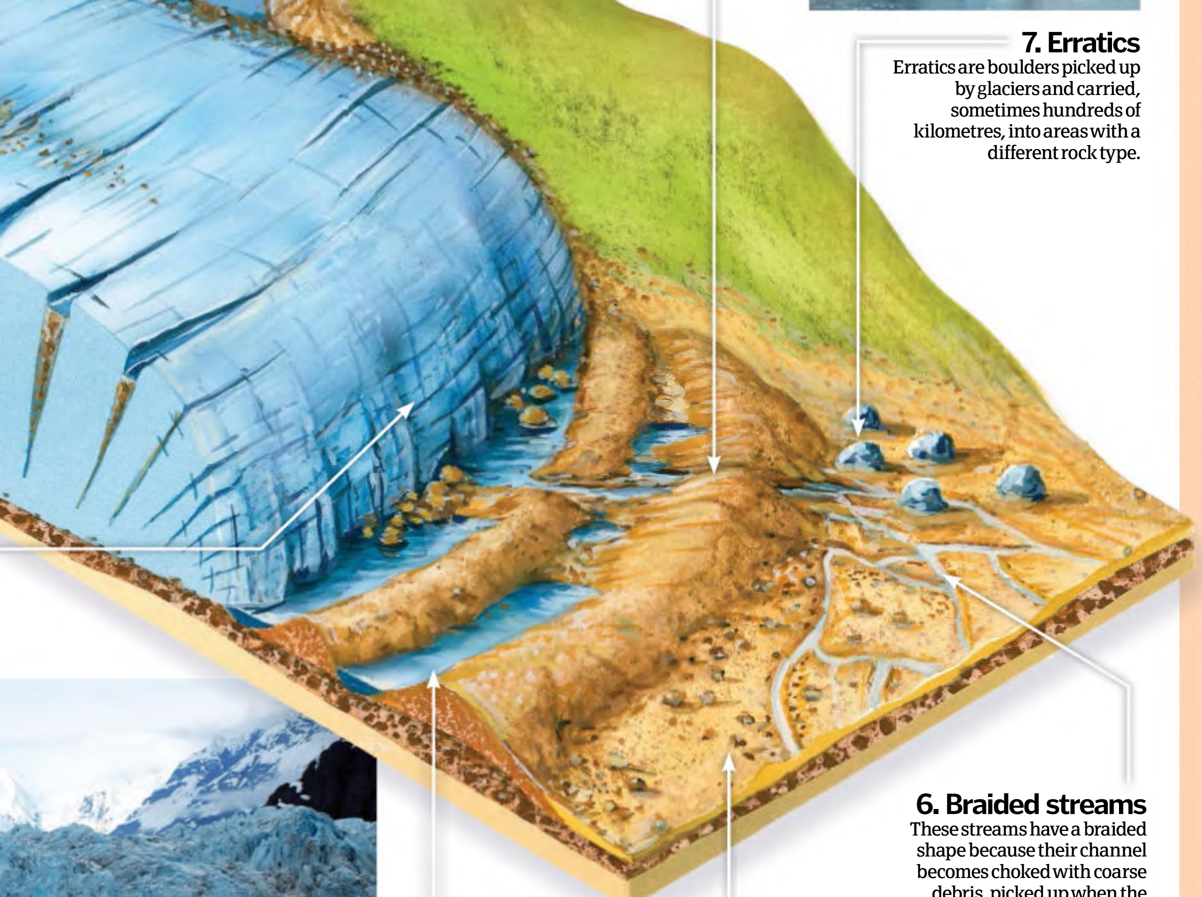
SPECTACULAR

3. Grand Canyon, USA
The Grand Canyon was eroded into the Colorado Plateau by the Colorado River, as mountain building uplifted the plateau.

DID YOU KNOW? *Ten per cent of the world's land is covered by ice, compared to about 30 per cent during the last ice age*

Spotter's guide to lowland glaciers

When you stand at the bottom – or snout – of a valley glacier, you can see landforms made of debris dumped by the ice. The debris was eroded further up the valley and transported downhill, as if on a conveyor belt. Meltwater rushing under the glacier sculpts the debris heaps.

The snout is the place in the valley where the glacier melts completely. This changes over time. If the glacier shrinks, it leaves a debris trail behind. Should it grow again, it collects and bulldozes this debris. To understand why the snout moves up and downhill, you need to see glaciers as systems controlled by temperature and snowfall. On cold mountain peaks, snow accumulates faster than the glacier melts. As ice flows into warmer lowlands, melting begins to exceed accumulation. The snout advances or retreats depending on whether inputs of snow exceed ice loss from the system by melting.



1. Lateral moraine
Lateral moraines are made from rocks that have fallen off the valley sides after being shattered by frost. When the glacier melts, the moraine forms a ridge along the valley side.

3. Terminal or end moraine
An end moraine is a debris ridge that extends across a valley or plain, and marks the furthest advance of the glacier and its maximum size.

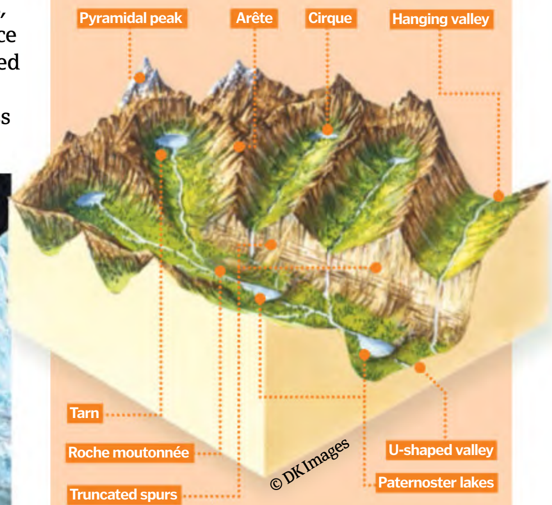
7. Erratics
Erratics are boulders picked up by glaciers and carried, sometimes hundreds of kilometres, into areas with a different rock type.

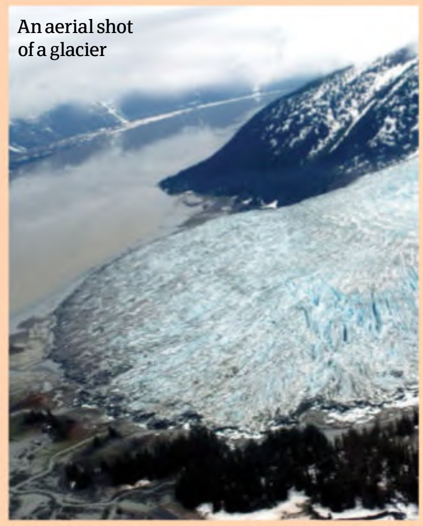
6. Braided streams
These streams have a braided shape because their channel becomes choked with coarse debris, picked up when the stream gained power during periods of fast glacier melt.

4. Recessional moraine
A recessional moraine is left when a glacier stops retreating long enough for a mound of debris to form at the snout.

5. Outwash plain
Outwash plains are made of gravel, sand and clay dropped by streams of meltwater that rush from the glacier during the summer, or when ice melts.

Inside an ice-carved valley




An aerial shot of a glacier

How does a glacier move?

Glaciers can only move, erode and transport debris if they have a wet bottom. Polar glaciers are frozen to the bedrock all year round and typically move around 1.5 metres (5 feet) per year, as ice crystals slide under gravity. In temperate climes like the European Alps, however, glaciers can slide downhill at 10-100 metres (30-330 feet) per year, due to the fact that meltwater forming under the glacier during mild summers acts as a lubricant.

If meltwater accumulates under a glacier, the ice can race forwards at up to 300 metres (990 feet) per day. During the fastest recorded surge, the Kutiah Glacier in Pakistan sped more than 12 kilometres (7.5 miles) in three months.

WONDERS OF THE NILE

It is one of Earth's most astounding waterways, but how does the Nile affect its arid surroundings?

Understandably considered to be the 'father of African rivers', the River Nile is quite simply awe-inspiring. Rising from south of the equator in Uganda and winding through north-east Africa all the way to the Mediterranean Sea, it is not just Earth's longest river (though some have contested it's beaten by the Amazon), but indisputably one of the most historic and diverse.

The Nile is formed from three principal sources: the White Nile, Blue Nile and Atbara. The White Nile begins at Lake Victoria, Uganda, and is the most southerly source. The Blue Nile begins at Lake Tana, Ethiopia, and is its secondary source, flowing into the White Nile near Khartoum. Lastly the Atbara River, which begins around 50 kilometres (30 miles) north of Lake Tana, is the third and smallest source, joining the other two bigger waterways at the eponymous Sudanese city of Atbara. Combined, these three primary sources create the River Nile, which today is naturally split into seven distinct regions ranging from the Lake Plateau of eastern Africa down to the vast Nile Delta that spans north of Cairo. These areas are home to diverse peoples and cultures, exotic flora and fauna, as well as a variety of notable features ranging from fierce rapids, to towering waterfalls and lush swamps.

While the Nile flows through many countries including Uganda, Sudan and Ethiopia, the country it is most affiliated with is Egypt, the most northerly and the last it passes on its course to the Mediterranean.

Origins
1 It has been suggested that the River Nile was created in its modern incarnation approximately 25,000 years ago when Lake Victoria developed a northern outlet.

Vast Victoria
2 The primary source of the Nile is Lake Victoria, which covers an area of more than 69,400km² (26,795mi²). Despite its size, it is very shallow and warm.

Dam pollution
3 While the construction of the Aswan Dam has prevented the Nile from flooding yearly in Egypt, it has also reduced its fresh water flow, in turn increasing pollution content.

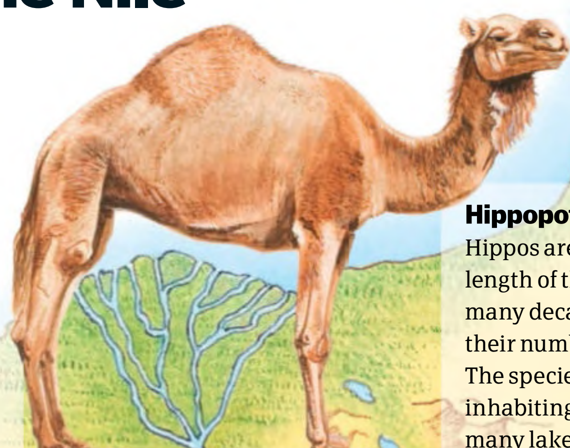
Back to black
4 In Ancient Egyptian times the River Nile was known as 'Ar', or 'Aur', which translates as 'black', referring to the dark, fertile sediment that was left behind after it flooded.

Delta
5 According to Greek geographer Strabo, the Nile Delta used to comprise seven delta distributaries. Today there are only two: the Rosetta and Damietta.

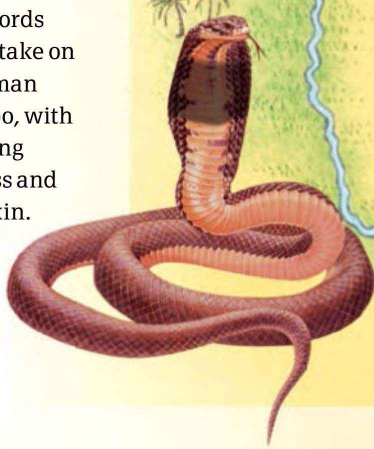
DID YOU KNOW? *The name 'Nile' is derived from the Greek 'Neilos', which means 'river valley'*

Beasts of the Nile

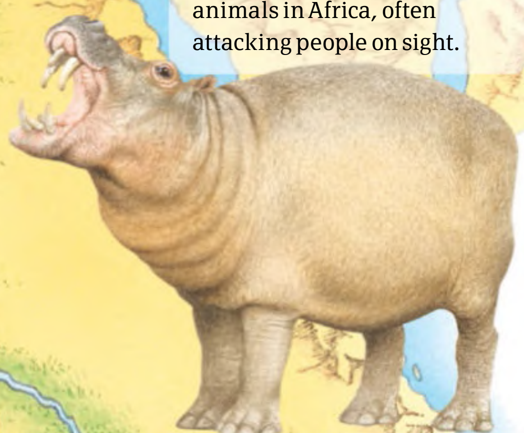
Dromedary camel
The second-largest species of camel, the dromedary has come to be a key image associated with Egypt. They are technically Arabian in origin but are now kept and used domestically throughout Egypt. They are commonly used to transport both goods and people, and are also a popular source of milk.



Red spitting cobra
This venomous snake is a native resident of Egypt's southern regions. It preys primarily on amphibians like frogs, however records indicate they will also take on birds and rodents. Human attacks are recorded too, with bite symptoms including muscle pain, numbness and disfigurement of the skin.



Hippopotamus
Hippos are found the entire length of the Nile, but due to many decades of poaching, their numbers are dwindling. The species is semi-aquatic, inhabiting the river itself, its many lakes and swamps as well as the fertile banks. They are one of the most aggressive animals in Africa, often attacking people on sight.



Grey heron
A large bird that frequents various parts of Africa, the grey heron is a common sight along the length of the river. Standing at approximately 100 centimetres (39 inches) tall and sporting a pinkish-yellow bill, the heron can typically be found on the Nile's banks and throughout the Egyptian Delta, where it feeds on fish, frogs and insects within the shallow waters. The bird appears in a lot of Ancient Egyptian artwork.

Nile crocodile
A dark bronze-coloured species of reptile, Nile crocodiles frequent the banks of the river throughout Egypt and other east African countries. These crocodiles are the largest found in the continent and are agile and rapid predators, feeding on a wide variety of mammals.

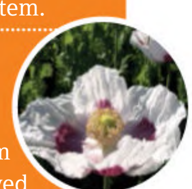
A desert oasis

1 Papyrus
This species of aquatic flowering plant belongs to the sedge family. The tall leafless grass has a greenish cluster of stems at its tip and has been used historically to produce papyrus paper.

2 Plume thistle
Found all over Egypt, but especially around the Nile, the plume thistle is a tall biennial plant that consists of a rosette of leaves, a taproot and a flowering stem. Traditionally, the stems were peeled and boiled for consumption.

3 Chamomile
This is a daisy-like plant from the family Asteraceae. There are many species of chamomile, however the one common to the Nile is Matricaria – a type commonly used in herbal remedies.

4 Blue Egyptian water lily
The 'blue lotus' is one of the most iconic plants on the Nile. With broad leaves and colourful blue blooms, this water lily stands out amid the sandy tones of Egypt. It had a spiritual link to the Ancient Egyptian deity Nefertem.



5 Opium poppy
As the name suggests this is the species of poppy from which opium is derived – the source of narcotics like morphine. The plant has blue-purple or white flowers and silver-green foliage.

It is here in Egypt that historically the Nile was at its most variable, with the river flooding annually. While the river still floods, thanks to the construction of the Aswan Dam and Lake Nasser, it only does so in southern Egypt, with the lower-lying north remaining relatively protected.

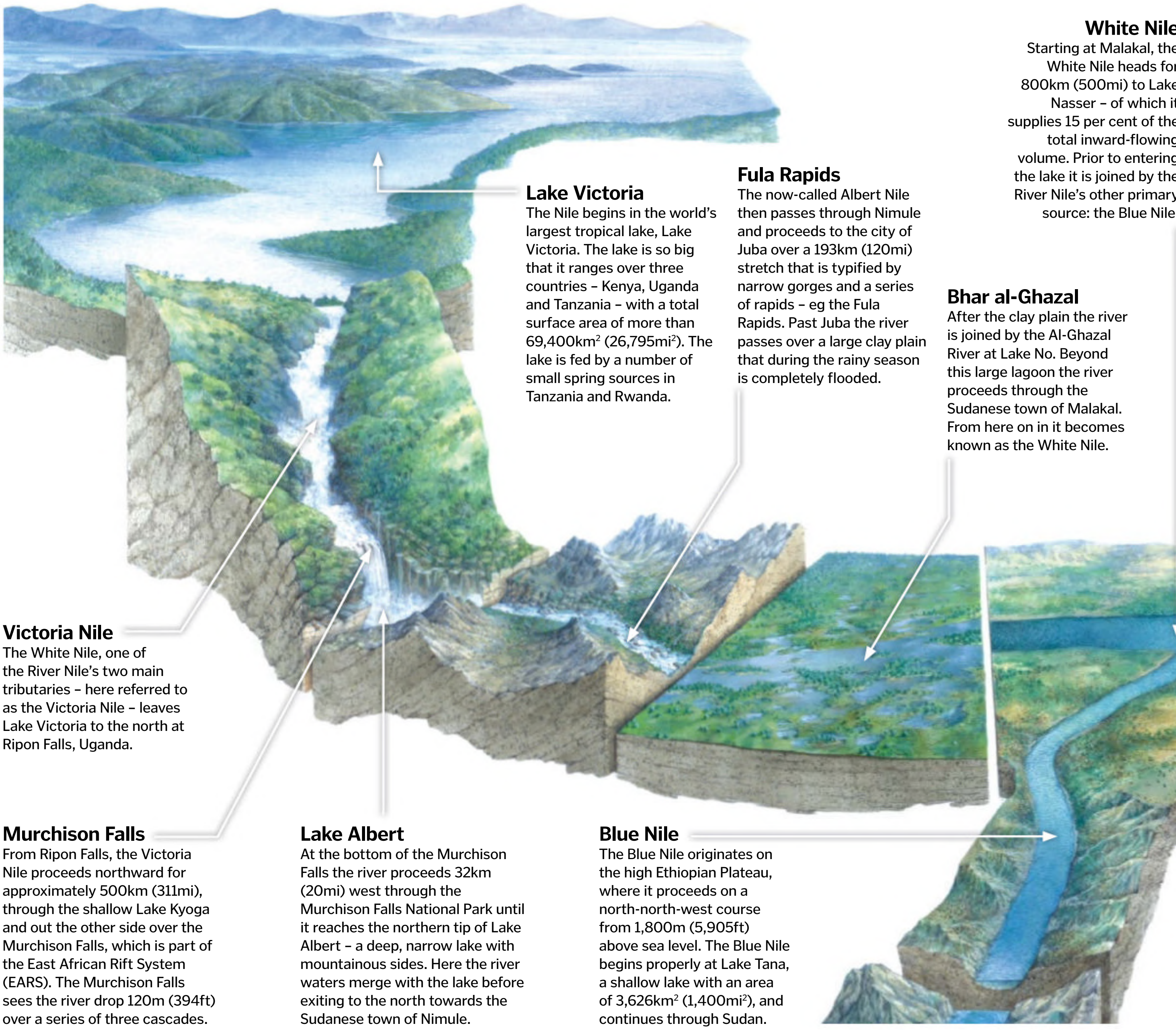
The flooding is largely caused by the rainy season in the Ethiopian Plateau, an area from which both the Blue Nile and Atbara draw their water. As such, when the floodwaters enter Lake Nasser in late-July, the Blue Nile accounts for 70 per cent of all water, the Atbara 20 per cent, with the White Nile only accounting for ten. This flooding sees the Nile's total inflow rise from 45.3 million cubic metres (1.6 billion cubic feet) per day up to a whopping 707.9 million cubic metres (25 billion cubic feet).

Crucially, while the dam at Aswan prevents annual flooding in Egypt, it does not stop its historical uses, which remain to this day incredibly wide ranging. The Nile is used as a source of irrigation for crops, water for industrial applications, transportation via boat and the cultivation of region-specific goods like papyrus. It's also an ecosystem for many unique plants and animals and a vital source of power, driving turbines that generate electricity.

Lake Nasser has become a haven for all kinds of wildlife, including migratory birds

Journey down the Nile

Take a grand tour down the River Nile from its main origin in Lake Victoria through to the Mediterranean



White Nile
Starting at Malakal, the White Nile heads for 800km (500mi) to Lake Nasser – of which it supplies 15 per cent of the total inward-flowing volume. Prior to entering the lake it is joined by the River Nile's other primary source: the Blue Nile.

Lake Victoria
The Nile begins in the world's largest tropical lake, Lake Victoria. The lake is so big that it ranges over three countries – Kenya, Uganda and Tanzania – with a total surface area of more than 69,400km² (26,795mi²). The lake is fed by a number of small spring sources in Tanzania and Rwanda.

Fula Rapids
The now-called Albert Nile then passes through Nimule and proceeds to the city of Juba over a 193km (120mi) stretch that is typified by narrow gorges and a series of rapids – eg the Fula Rapids. Past Juba the river passes over a large clay plain that during the rainy season is completely flooded.

Bhar al-Ghazal
After the clay plain the river is joined by the Al-Ghazal River at Lake No. Beyond this large lagoon the river proceeds through the Sudanese town of Malakal. From here on in it becomes known as the White Nile.

Victoria Nile
The White Nile, one of the River Nile's two main tributaries – here referred to as the Victoria Nile – leaves Lake Victoria to the north at Ripon Falls, Uganda.

Murchison Falls
From Ripon Falls, the Victoria Nile proceeds northward for approximately 500km (311mi), through the shallow Lake Kyoga and out the other side over the Murchison Falls, which is part of the East African Rift System (EARS). The Murchison Falls sees the river drop 120m (394ft) over a series of three cascades.

Lake Albert
At the bottom of the Murchison Falls the river proceeds 32km (20mi) west through the Murchison Falls National Park until it reaches the northern tip of Lake Albert – a deep, narrow lake with mountainous sides. Here the river waters merge with the lake before exiting to the north towards the Sudanese town of Nimule.

Blue Nile
The Blue Nile originates on the high Ethiopian Plateau, where it proceeds on a north-north-west course from 1,800m (5,905ft) above sea level. The Blue Nile begins properly at Lake Tana, a shallow lake with an area of 3,626km² (1,400mi²), and continues through Sudan.

THE STATS
NILE IN NUMBERS

LENGTH **6,650km** | AVERAGE DISCHARGE **2,830m³/s** | BASIN AREA **3.4mn km²**

WIDTH **2.8km** | PRIMARY SOURCE ELEVATION **2,700m** | SECONDARY SOURCE ELEVATION **1,800m**

DID YOU KNOW? *The White Nile has an almost constant volume, while the Blue Nile's is much more variable*

Egypt's ancient capital city, Cairo, is situated on the banks of the Nile

Search for the source

While today the sources of the Nile are well documented and clearly visible by satellite imagery, before the advent of such technology its source remained one of the planet's greatest mysteries, with various historians, geographers and philosophers speculating on its origin.

Arguably the earliest attempt to discern the source of the Nile was undertaken by Greek historian Herodotus (circa 484-425 BCE), who as part of his *Histories* recounts theories he gathered from several Egyptians. Unfortunately, while many of the tales are accurate to a point – with most describing the Nile to around modern-day Khartoum – none reveal its true origins, with Herodotus assuming it must begin in Libya.

This confusion and speculation continued with the Romans, with natural philosopher Pliny the Elder (23-79 CE) picking up from Herodotus stating the Nile's origin lay 'in a mountain of Lower Mauretania' – an area that correlates with modern-day Morocco. Indeed, this confusion remained right up until the 19th century, when a series of European-led expeditions slowly began to unearth the truth. These expeditions came to a head in 1875, when the Welsh-American journalist and explorer Henry Morton Stanley (1841-1904) confirmed that the White Nile, which was considered the one and true source, did indeed emanate from Lake Victoria in Uganda.

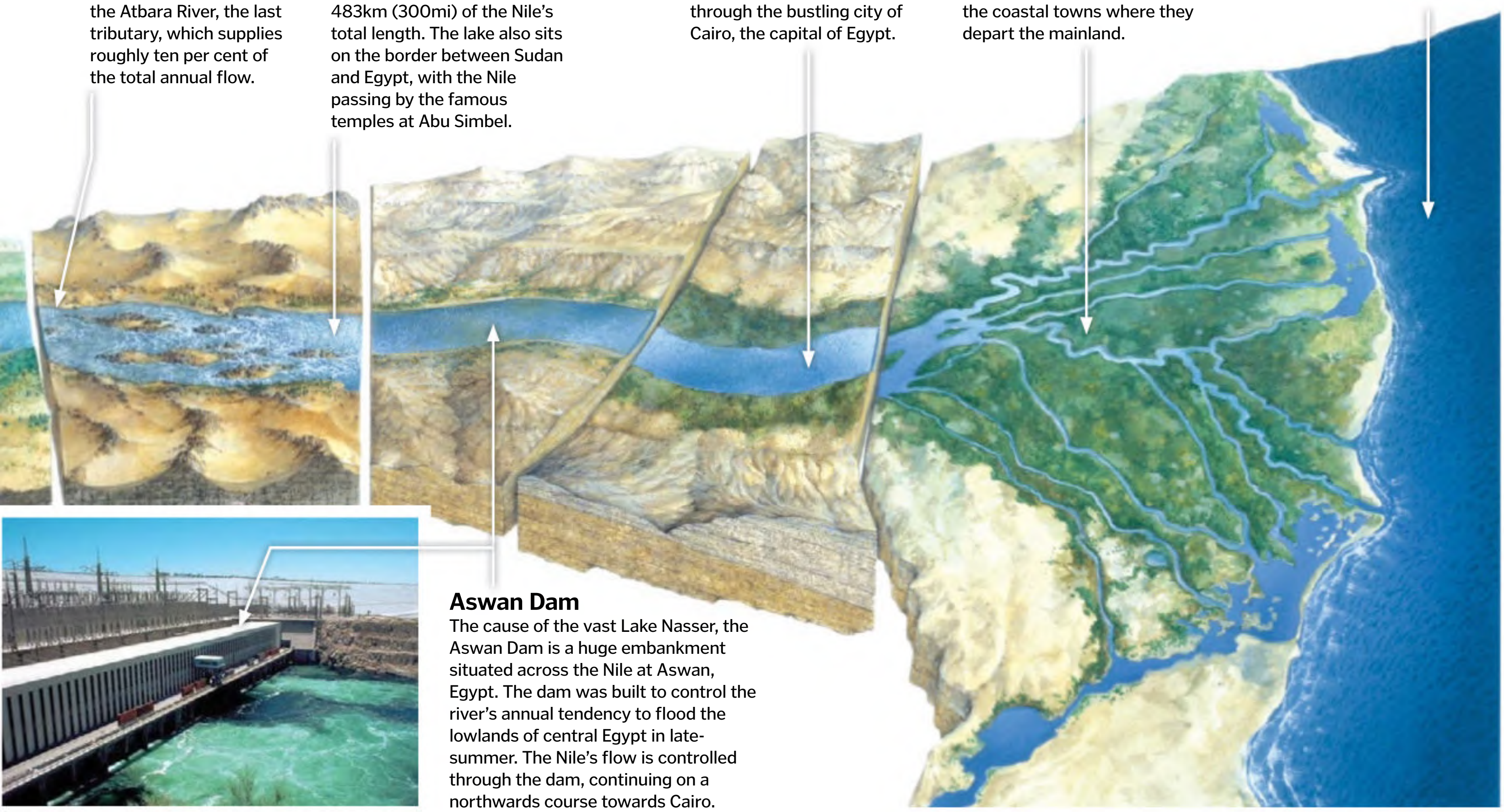
Khartoum
Near Khartoum the two primary rivers converge to create the River Nile proper, and proceed north for 322km (200mi). At this point the Nile is joined by the Atbara River, the last tributary, which supplies roughly ten per cent of the total annual flow.

Lake Nasser
The Nile then enters Lake Nasser, the second-largest man-made lake in the world. With a potential maximum area of 6,735km² (2,600mi²), it covers approximately 483km (300mi) of the Nile's total length. The lake also sits on the border between Sudan and Egypt, with the Nile passing by the famous temples at Abu Simbel.

Cairo
For 322km (200mi) after the Aswan Dam the River Nile passes through an underlying limestone plateau, which averages 19km (12mi) in width. After another 322km (200mi) the river flows through the bustling city of Cairo, the capital of Egypt.

Nile Delta
After flowing through Cairo the River Nile enters a delta region, a triangular-shaped lowland where the river fans out into two main distributaries: the Rosetta and the Damietta. These distributaries are named after the coastal towns where they depart the mainland.

Mediterranean
Finally, after around 6,650km (4,130mi), the Nile comes to an end in the Mediterranean Sea, a body of seawater that spans 2.5mn km² (965,000mi²).



Aswan Dam
The cause of the vast Lake Nasser, the Aswan Dam is a huge embankment situated across the Nile at Aswan, Egypt. The dam was built to control the river's annual tendency to flood the lowlands of central Egypt in late-summer. The Nile's flow is controlled through the dam, continuing on a northwards course towards Cairo.

Subterranean rivers

Discover how, over many millennia, water can create spectacular cave systems and secret waterfalls all hidden deep beneath the ground

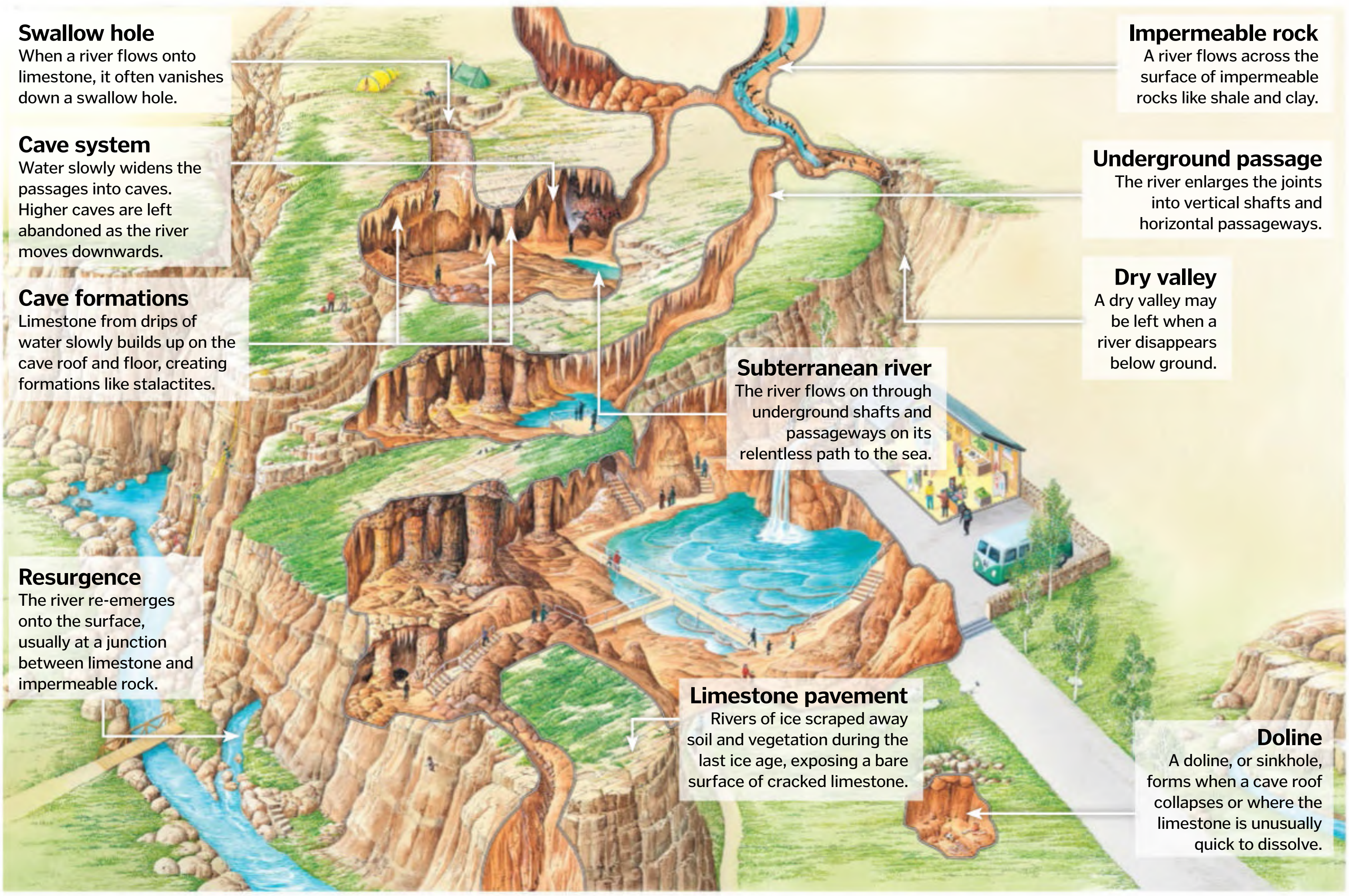
On the island of Palawan in the Philippines is a layer of limestone over 500 metres (1,640 feet) thick. The rock is honeycombed with a complex network of caves – some big enough to hold jumbo jets – that have formed due to running water from rain and streams. Deep inside the limestone is the Puerto Princesa Subterranean River, which flows 8.2 kilometres (five miles) through a warren of passages.

Underground rivers like the Puerto Princesa are found worldwide in a type of limestone terrain called karst. These dramatic landscapes are riddled with huge caves, pits and gorges. Famous examples include the South China Karst, which covers 500,000 square kilometres (193,000 square miles) of China's Yunnan, Guizhou and Guangxi provinces.

Karst forms when acid water seeps down tiny cracks, called joints, in the limestone. The acid slowly eats away the rock and enlarges the joints into vertical shafts and horizontal passages. Rivers flowing onto limestone often vanish from the surface down shafts called swallow holes and continue as underground waterways. Generally, dry valleys signal where the river once flowed on the surface.

Over millions of years, underground rivers can carve out huge cave networks – some that extend for hundreds of kilometres. Higher caves are left abandoned when gravity causes the river to drain into lower passages. The water seeps down through the limestone until it reaches impermeable rocks, then flows horizontally until it emerges near the base of the karst as a spring or waterfall.

During floods, or when the water table rises, the river can totally fill a cave and erode its roof. When the water retreats, the unsupported ceiling may crumble. The Reka Valley in Slovenia – a 100-metre (328-foot)-high gorge – formed when a cave collapsed centuries ago. This means the Reka River, which primarily runs underground through the Škocjan Caves, now sees daylight for part of its journey.

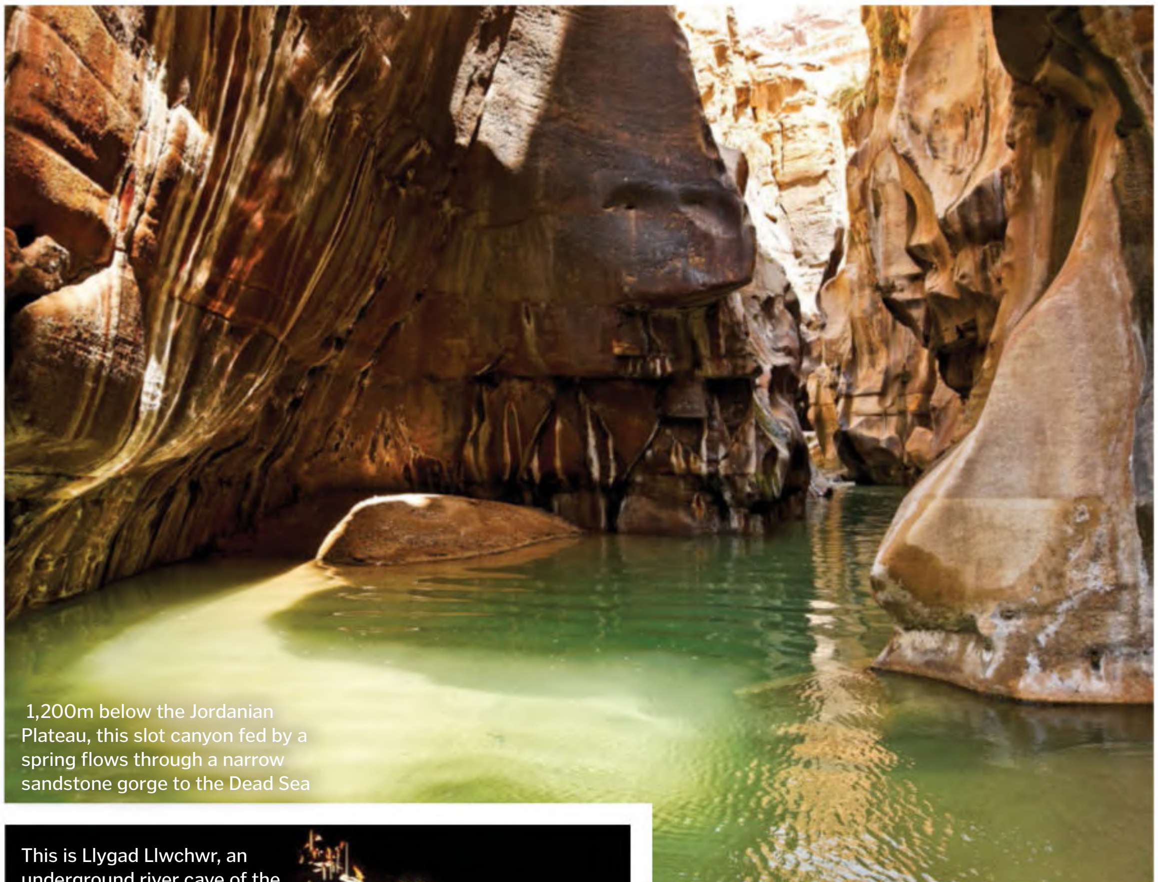


THE STATS
CLEARWATER CAVE, MALAYSIA

RIVER FLOW **150,000 tons/hr** LENGTH **189km** AVERAGE DIAMETER **16m**

FIRST DISCOVERED **1978** VERTICAL RANGE **350m** VOLUME **37mn m^3**

DID YOU KNOW? *A 20-million-year-old fossil of an aquatic mammal is embedded in the walls of the Puerto Princesa cave*


1,200m below the Jordanian Plateau, this slot canyon fed by a spring flows through a narrow sandstone gorge to the Dead Sea


This is Llygad Llwchwr, an underground river cave of the Black Mountain in Wales

How limestone dissolves

Limestone is made of the shells of tiny sea creatures that lived millions of years ago. Shells contain calcium, just like bones and teeth. Limestone is more than 80 per cent calcium carbonate and – like teeth – is decayed by acid.

Rain and stream water absorb carbonic acid from the atmosphere and humic acid from decaying vegetation in the soil. When water seeps down limestone joints, the acid dissolves the calcium carbonate. Calcium bicarbonate is formed and washed away – sometimes in huge quantities. An estimated 600 tons of calcium bicarbonate are removed daily by the waters of Silver Springs in Florida, USA, for instance.

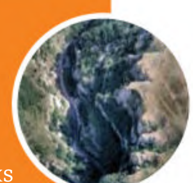
Limestone landforms

1 Swallow hole
Rivers can disappear underground down openings called swallow holes. Swallow holes like Gaping Gill in Yorkshire, UK, form where limestone is heavily fractured and jointed. Gaping Gill is also the site of Britain's highest unbroken waterfall.

2 Caves

Earth's largest underground chamber is in a karst formation. Borneo's Sarawak Chamber is 100 metres (328 feet) high and 700 metres (2,297 feet) long. It's so wide it could fit in eight jumbo jets!

3 Limestone pavement
A famous example of a limestone pavement lies above Malham Cove, a cliff in the Yorkshire Dales. This bare rock surface formed during the last ice age when glaciers scraped away soil to expose the limestone. It consists of slabs called clints, separated by cracks known as grikes.

4 Dry valley

Cheddar Gorge in Somerset is Britain's biggest dry valley. It too formed during the last ice age when cracks in the limestone filled with ice. Water couldn't penetrate the rock so it flowed across the surface, gouging out a gorge.

5 Stalactites and stalagmites
Caves contain many stunning formations like stalactites and stalagmites. These spikes of rock form when water drips from the ceiling, leaving traces of limestone on the roof and floor over many centuries.

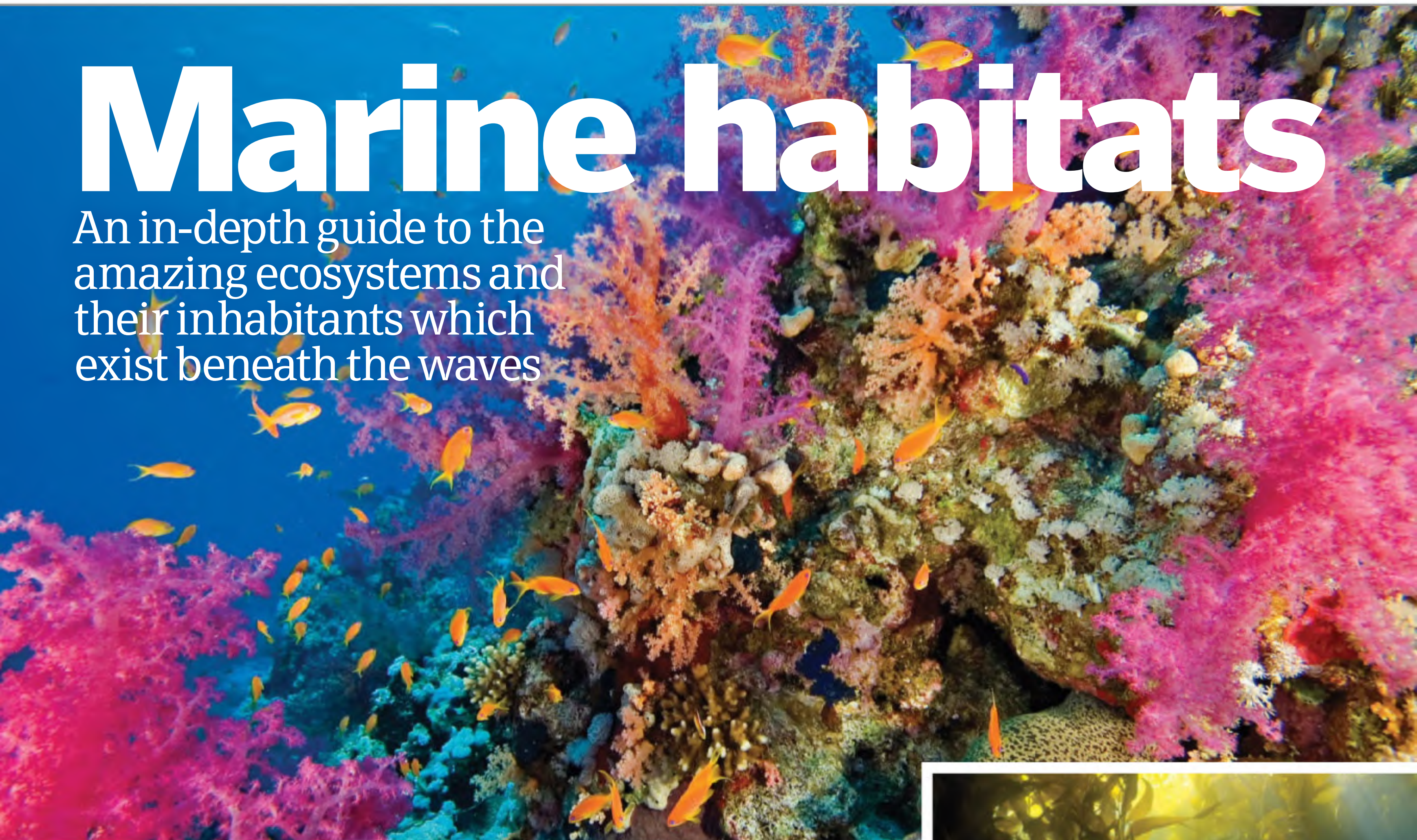
ON THE MAP

Underground river caves around the planet

1. Puerto Princesa River, Philippines
2. Phong Nha, Vietnam
3. Križna Jama Cave, Slovenia
4. Rio Secreto, Mexico
5. Santa Fe River, FL, USA
6. Sof Omar, Ethiopia

Marine habitats

An in-depth guide to the amazing ecosystems and their inhabitants which exist beneath the waves



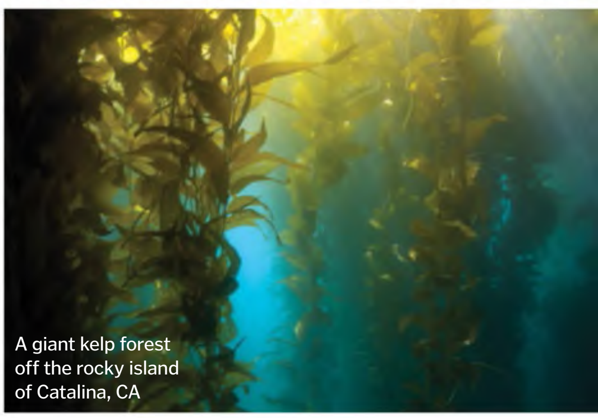
Earth's oceans support thousands of unique habitats. Each species has a niche and is adapted for the physical and chemical properties of its home in the water column (a pelagic habitat) or on the seabed (a benthic habitat). Sunlight is a major governing factor and most species-rich areas are in shallow waters where light is plentiful. Likewise temperature is another key regulator of life in the sea. This is due to its strong influence over the rate of chemical reactions, which affects the growth, reproductive success and general activity of any creatures whose body temperature is the same as the water around them. Each ocean habitat is also affected by many other factors such as salinity, pressure and nutrients to name but a few.

The rocky shore is the first frontier between land and sea. It's known as the littoral zone and is a high-energy environment, battered by waves. Organisms living here have to be hardy, as the waves take their toll and the tide floods in and out twice a day, leaving rockpools to bake in the Sun. Yet despite these hard conditions, the littoral zone is full of life.

The upper tidal reaches are favoured by tough species such as barnacles, limpets and periwinkles. These shell-dwellers hunker down when the tide goes out and re-emerge as the water returns. The middle and lower-shore habitats support the species that are a little less adapted for the absence of water. Algae grow in cracks and crevices with plenty of available light for photosynthesis. Mussels, sea snails and chitons make the middle shore their home, whereas crabs, oysters, anemones, urchins, starfish, kelp and even young fish can be found on the lower shore and in the shallows beyond.

On the sandy beaches that often accompany rocky coastal habitats, the power of crashing waves erodes the shoreline and deposits fine gravel and silt. This creates a porous habitat that is perfectly suited to species of worms that live within the sandy material, as well as flatfish that have evolved to blend in.

Estuaries also shoulder the boundary between land and sea. Characterised by tidal water that fluctuates in salinity, estuaries play host to species that are perfectly adapted to these rapid chemical transitions. Animals like oysters and some crabs can regulate their osmotic properties (the way that their bodies handle saltwater and freshwater) to deal with the daily salinity changes, whereas other creatures prefer to head out with the tides to stay in the salty realm. Other animals such as glass eels actually live in estuarine environments and change their salinity preferences throughout their life cycle.



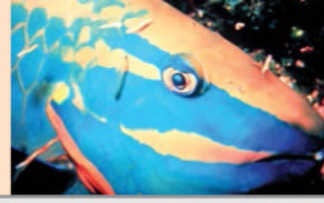
A giant kelp forest off the rocky island of Catalina, CA

In warmer climates, estuarine water is often colonised by mangrove swamps, which are ecosystems with another unique set of salinity adaptations. Mangrove trees, of which there are many types, have long, twisting roots that can filter seawater. The leaves can also excrete salt,

STRANGE BUT TRUE
GRAINS OF TRUTH

How is the fine sand near coral reefs produced?

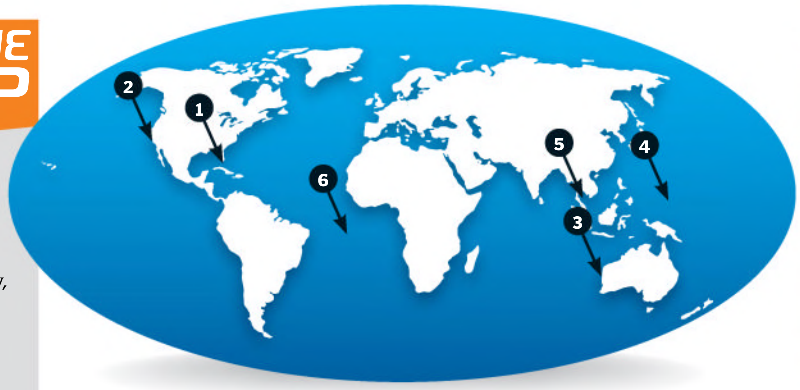
A Waves **B** Fish eating coral **C** Old sandcastles



Answer:
The reef-dwelling parrotfish mainly eat the algae within coral polyps. The fish rip off coral chunks and grind it up. Excess coral is then excreted as fine sand – it's fish poo!

DID YOU KNOW? At Earth's deepest point, the pressure is 11,318 tons/m² – about the same as trying to hold up 48 jumbo jets!

ON THE MAP



Ocean ecosystems

1. Mangrove swamps: southern Florida
2. Kelp forests: Monterey Peninsula, California
3. Seagrass beds: Shark Bay, Western Australia
4. Lowest point on Earth: Challenger Deep
5. Artificial reef (made of 25 tanks): Gulf of Thailand
6. Hydrothermal vent fields: Mid-Atlantic Ridge

making them ideally adapted for living in brackish water. The large mangrove roots hold the shoreline together and resist erosion as well as protecting the shore from wind and wave energy. This provides shelter for animals and other plants, and mangroves are important nursery grounds and essential food sources for birds, crustaceans and fish, along with large marine mammals such as manatees.

Seagrass beds are often found growing near mangrove ecosystems in estuaries, bays, inlets or lagoons. Seagrasses are one of the few groups of flowering plants in the sea and they need clear, shallow water to grow. These underwater lawns are home to animals such as seahorses and pipefish that rely on the shelter and nutrients from the grass, but as fragile ecosystems, seagrass beds are under threat. Pollution, competition from invasive species and increased sediment in the water are endangering the longevity of these habitats.

Moving farther out from the coast, the shallow offshore waters of the continental shelf are known as the sublittoral zone. Light is still plentiful in the water column here, which means that productivity is high. Conditions are ideal for plant and algal growth, and so can support some of the ocean's most diverse yet delicate ecosystems: coral reefs.

Reefs form when coral larvae in the water column attach to rocks and other substrates and start to grow. The coral is made up of calcium-carbonate skeletons that house coral polyps. These polyps in turn contain tiny photosynthetic plant cells called zooxanthellae, which lend coral its vibrant colour. The coral needs a specific set of physical and chemical parameters to survive, which is why reefs are so fragile. Lots of light and a relatively constant temperature of around 20 degrees Celsius (68 degrees Fahrenheit) are essential. Because of this, increasing global temperatures are threatening the existence of reefs across the planet. If the temperature of the water gets too high, bleaching can occur which is when the coral ejects the zooxanthellae algae. This causes the coral to turn white, and without the zooxanthellae to photosynthesise, the coral

Man-made reefs

Man-made reefs are areas of the seafloor that are colonised by marine species as a result of the reef's placement by humans. Reefs can be created in order to promote biodiversity in an area, or to compensate for overuse of a habitat. Other artificial reefs are less deliberate, as organisms colonise things such as shipwrecks or oil platforms. The reefs can bring life to otherwise barren areas, providing a substrate for many species to flourish. The ocean floor can be a very challenging place to live, and so once lifted into the water column, organisms are exposed to ocean currents big and small, which bring with them food (plankton) as well as other essential nutrients that enable life to thrive.

Once the reef is in place, the colonisation process will begin almost instantly. The first arrivals will be encrusting species such as barnacles and tubeworms. The larvae of these critters land on the reef by chance; after being spawned, they hitch a ride on the currents and are swept away to find a new home. Then come the hydroids, closely followed by sea urchins and scallops. As diversity increases, so does the deliciousness of the reef for other predators, which are then drawn to the area for food. After a few years, the reef will be bursting at the seams with life, which in turn attracts more new arrivals. Examples of man-made reefs include sunken aircraft carriers, art sculptures, tanks and even memorial gardens where a person's ashes can be encased in a 'reef ball' and laid to rest.

Life in the mudflats

Coastal mudflats are large intertidal expanses of silt and sediment, usually found at the mouth of an estuary or in other sheltered environments. Mudflats are highly productive and are teeming with important biological species and processes. The top layer of mud, which gives the flats their characteristic brown colour is rich in oxygen, but the lower layers are black and anoxic, and these support a different type of microbial ecosystem based on chemical reactions. Species diversity is usually low, but numbers of these animals are very high and the oxygenated mud generally harbours lugworms, cockles, mussels and some types of algae, among many others. Intertidal mudflats also provide a nursery ground for many creatures, eg salmon, which take advantage of the sheltered waters to feed and mature before leaving for the open ocean. Similarly migratory birds and coast-based mammals also depend on the mudflats for their calorie-rich food stores.

Seamount ecology

Seamounts are underwater mountains that rise from the ocean floor. They appear near tectonic boundaries or hotspots and are formed as lava seeps out of the Earth and cools in the water to form a conical structure. When the mountain gets large enough it will breach the surface – the Hawaiian islands formed this way, for example.

Seamounts are oases of life in the open ocean as their conical shape provides a safe haven for deep-sea corals, sponges, worms, crustaceans and fish. The mountain soars high off the seabed, so strong currents run over it, providing plankton for filter-feeding species and promoting the upwelling of nutrients to support thousands of animals – many unique to these habitats. Fish are drawn to this bounty of food, and themselves attract larger predators like sharks and tuna. Seamounts are also thought to be navigational aids for migrating ocean dwellers like whales.

will die. Without the coral, the ecosystem it once supported will eventually decline and the thousands of species living there will need to find a new home.

In the clear, near-shore habitats that have cooler temperatures, giant kelp forests make the most of the sublittoral light. Instead of roots, kelp has finger-like holdfasts that grip on to rocks on the ocean floor. The cool, oxygen- and nutrient-laden water provides an environment where the kelp can thrive. And, in turn, the expansive forests provide food and shelter for fish, seals, jellyfish and sea otters, among others.

As the continental slope begins to increase, the ever-deeper water provides new niches to fill. The epipelagic zone is the upper sunlit layer of the open ocean and this habitat bears a stark contrast to the species-rich environments of the littoral and sublittoral zones. Many large, ocean-going species are found here, such as cetaceans like whales and dolphins, invertebrates such as jellyfish and large fish such as bluefin tuna and marlin, but they are few and far between. These animals are specially adapted to living in this vast expanse of water, with streamlined bodies, powerful muscles and clever camouflage.

Deeper still, the seabed continues to drop through the bathyal and bathypelagic zones and then levels off at the abyssal plain and abyssopelagic zone. Marine biologists know very little about the life that survives at and below these depths. What we do know is it's icy cold, pitch black and the staggering pressure would crush any air in the swim bladders of regular fish.

But deep-sea varieties have bodies that are made mostly of water. Muscles are more gelatinous with less protein, meaning a slower pace of life is essential. Helpfully this saves energy in a deep-sea organism, as food is often scarce. Another strange yet beautiful adaptation of animals in deeper habitats is bioluminescence. In the case of the anglerfish it is used to lure prey; others use their flashing lights to attract a mate or confuse predators. However animals also have to rely on the heightening of other senses, such as smell or vibration to find a meal – or not become one.

The abyssal plains and their alien-like inhabitants are interrupted by mountainous scores through the seabed in the form of oceanic ridges. Ridges are hotspots of tectonic activity, and also boast one of the most interesting marine habitats: hydrothermal vents.

Hundreds of clam, mussel, shrimp, tubeworm and snail species populate the large chimneys that spew out magma-heated, mineral-rich waters from the Earth's crust. Chemicals dissolved in the vent waters form the basis of the food chain in lieu of sunlight.

These environments are totally different to those found in shallower waters hundreds of metres above. They are a prime example of how marine life is capable of flourishing under some of the most extreme conditions, and proof that the creatures which live in the ocean truly are masters of adaptation.

From surface to seabed

Explore the types of ocean ecosystem and see how their inhabitants have adapted to them

5 TOP FACTS
MARINE GROUPS

Plankton

1 Phytoplankton (algae) and zooplankton (tiny animals) provide food for many animals. Larvae drift in zooplankton to distribute species, phytoplankton is the base of all marine food webs.

Carnivores

2 Carnivores keep the food web in check and regulate the populations of their prey. Without top predators, an opportunistic species could take over an ecosystem.

Bacteria

3 These microscopic decomposers are as vital as any bigger animal. They convert dead organic matter back into nutrients that are then made available to plants.

Plants

4 As well as microscopic algae, larger algal species as well as marine plants are crucial. They get energy from the Sun and photosynthesise to provide an entire ecosystem with food.

Herbivores

5 Usually animals such as small fish graze on plants and algae. They are prey for carnivores that then feed the apex predators. A few mammals like manatees are herbivores too.

DID YOU KNOW? *Giant kelp that forms huge forests in shallow, sunlit waters can grow up to 30cm (12in) per day*

Hydrothermal vents

Find out how these oceanic hot springs form and why sealife depends on them

The deep ocean is one of the harshest places to live on our planet – cold, dark and with pressures up to 250 times greater than on land. When scientists discovered the first hydrothermal vent in 1977, they were amazed to see heaps of clamshells clinging to it and large colonies of shrimp.

Volcanic, or hydrothermal, vents (also called smokers) are similar to hot springs on land, but sit around 2,100 metres (7,000 feet) beneath the ocean surface. Superheated water spews out of cracks in the seabed forming plumes of mineral particles that look like smoke. Fragile chimneys of minerals up to ten metres (33 feet) high form around the plumes and can grow upwards at 30 centimetres (12 inches) a day.

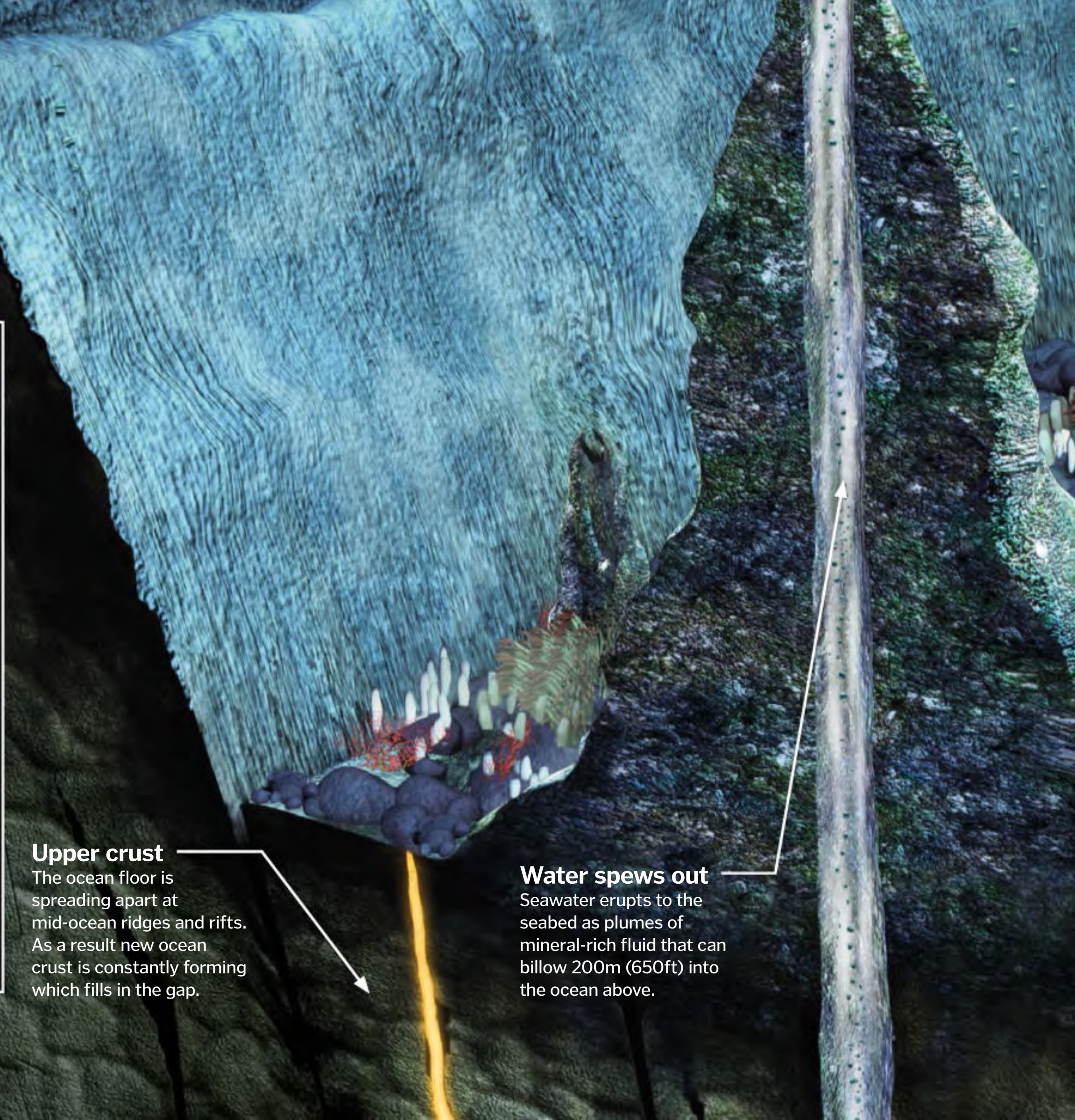
Temperatures vary between two degrees Celsius (35.6 degrees Fahrenheit) in the deep ocean to above boiling point around the vents. The water is heated by molten rock close to the seabed. Cracks and hot rocks are found at rifts where vast tectonic plates that make up Earth's crust are slowly moving apart. New ocean crust is created in the gaps between plates.

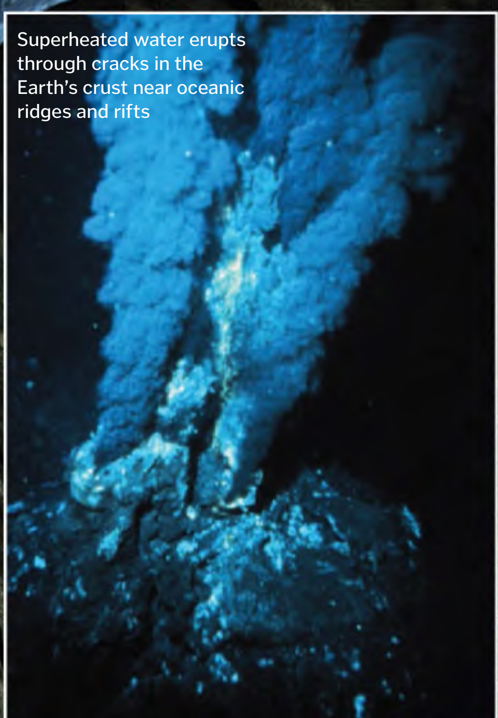
No one knows how many vents exist. The deep ocean is largely unexplored by humans – the first vents were photographed by unmanned research submersibles. The vents cool after a few years or decades as new ocean crust moves outwards from the mid-ocean ridges by 6-18 centimetres (2.4-7 inches) per year. New vents are quickly colonised by bacteria, which live in deep-sea rocks and water in small numbers.

Since vents were discovered, they've been found in the Pacific and Indian Oceans, in the mid-Atlantic and the Arctic. Species vary between vents. In the Atlantic Ocean, for example, there are no worms, clams nor mussels, but many white shrimp.

How smokers work

Learn why volcanic vents create chimneys and colourful smoke in the ocean depths




Superheated water erupts through cracks in the Earth's crust near oceanic ridges and rifts

5 TOP FACTS
VENT LIFE

Vent tube worm
1 These bizarre red-and-white worms can be two metres (six feet) tall and have no mouth or stomach. They rely on bacteria living inside them to convert chemicals into food.

Pompeii worm
2 These bristle-covered worms can survive in hotter conditions than any other animal. They live inside vent chimneys, where it's over 80 degrees Celsius (176 degrees Fahrenheit)!

Vent crab
3 Adult vent crabs have eyesight similar to military night-vision goggles to help them see at ocean depths of 2.7 kilometres (1.7 miles). They are the top predators around vents.

Vent shrimp
4 These blind invertebrates have simple light detectors on their backs instead of eyes, which may work like infrared heat vision to help them spot glowing vents in the gloom.

Scaly-foot gastropod
5 The metal scales protecting these snails from crab attack are unique – other snails have soft, slimy feet. Their body armour could inspire designs of motorcycles or flak jackets.

DID YOU KNOW? *There may be hydrothermal vents that could support alien life beneath an ocean on Jupiter's moon Europa*

Living without sunlight

The first life able to exist without energy from sunlight was discovered around a black smoker vent. Before then, scientists believed life in the dark deep ocean survived by eating food scraps that had fallen from shallower waters.

More than 300 species of shrimp, clams, predatory anemones and others live around vents – many unique – with around 35 new species discovered each year. All rely for food on mats of white bacteria, which use poisonous hydrogen sulphide from vent water as fuel to convert carbon dioxide and water into edible carbohydrates. Some species, such as vent worms, have bacteria living in their bodies. These bacteria take the place of plants on the Earth's surface. When the vent cools, tiny organisms can also eat the iron and sulphur inside the chimneys.

Superheating explained

Water gushing from volcanic vents can be four times hotter than 100 degrees Celsius (212 degrees Fahrenheit) – the approximate boiling point of water in your kettle. Yet it doesn't turn into steam…

The reason for this is the immense pressure in the deep ocean. Imagine you're standing on the seabed with a huge column of water above. The ocean weighs down on you with a pressure 250 times greater than on land; it's similar to having an elephant stand on your big toe!

These high pressures squeeze water in volcanic vents, stopping it expanding when heated. When liquid water boils into steam, molecules that were close together absorb enough heat energy to fly off in different directions. But these huge pressures prevent water molecules flying around as steam – they can't get far enough before hitting another moving molecule.

Superheated water can enter rock cracks like steam, but is as effective as water at dissolving minerals.

The phosphorus cycle

Why is this element so important to life and how is it processed by nature?

Phosphorus is a crucial element to life, whether an organism is a member of the plant or animal kingdom. It forms a fundamental component of genes – the DNA and RNA structure that determines what we are – and it also plays a major role in the ATP (adenosine triphosphate) energy cycle, without which we wouldn't be able to contract our muscles. In vertebrates like us mammals, around 85 per cent of the phosphorus in our bodies can be found in our teeth and bones.

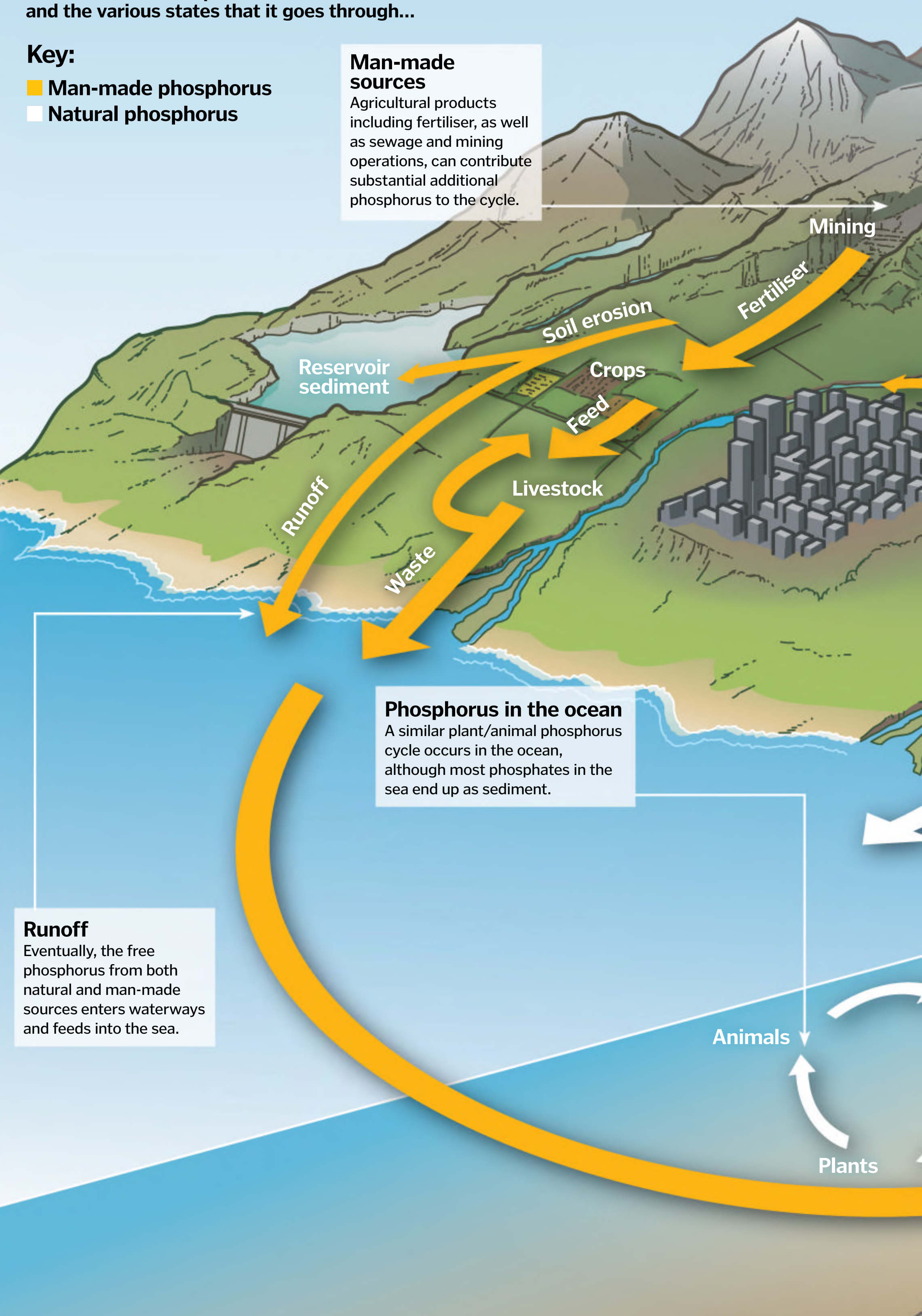
Phosphorus goes through a cycle similar to that of carbon, nitrogen and sulphur. However, unlike these important systems, because of the Earth's normal range of temperatures and pressures, hardly any of the phosphorus on our planet exists as a gas. Instead, most of it is bound up in sedimentary rock and a small proportion in water, although phosphorus isn't very soluble in H_2O and tends to bond more readily to molecules in the soil, entering watery ecosystems as part of runoff particles.

Phosphorous minerals (phosphates) enter the food chain from rocks via weathering. Plants absorb the phosphorus ions in the soil, herbivores ingest phosphorus by eating the plants and in turn, carnivores absorb it from herbivores. It's returned to the cycle via excretion and decomposition. Fertilisers and sewage can create an excess of phosphorus in the cycle, which can cause 'blooms' of suffocating algae in the sea.

How phosphorus is recycled

Discover where this prolific element comes from and the various states that it goes through...

Key:
- Man-made phosphorus
- Natural phosphorus



A dangerous gas

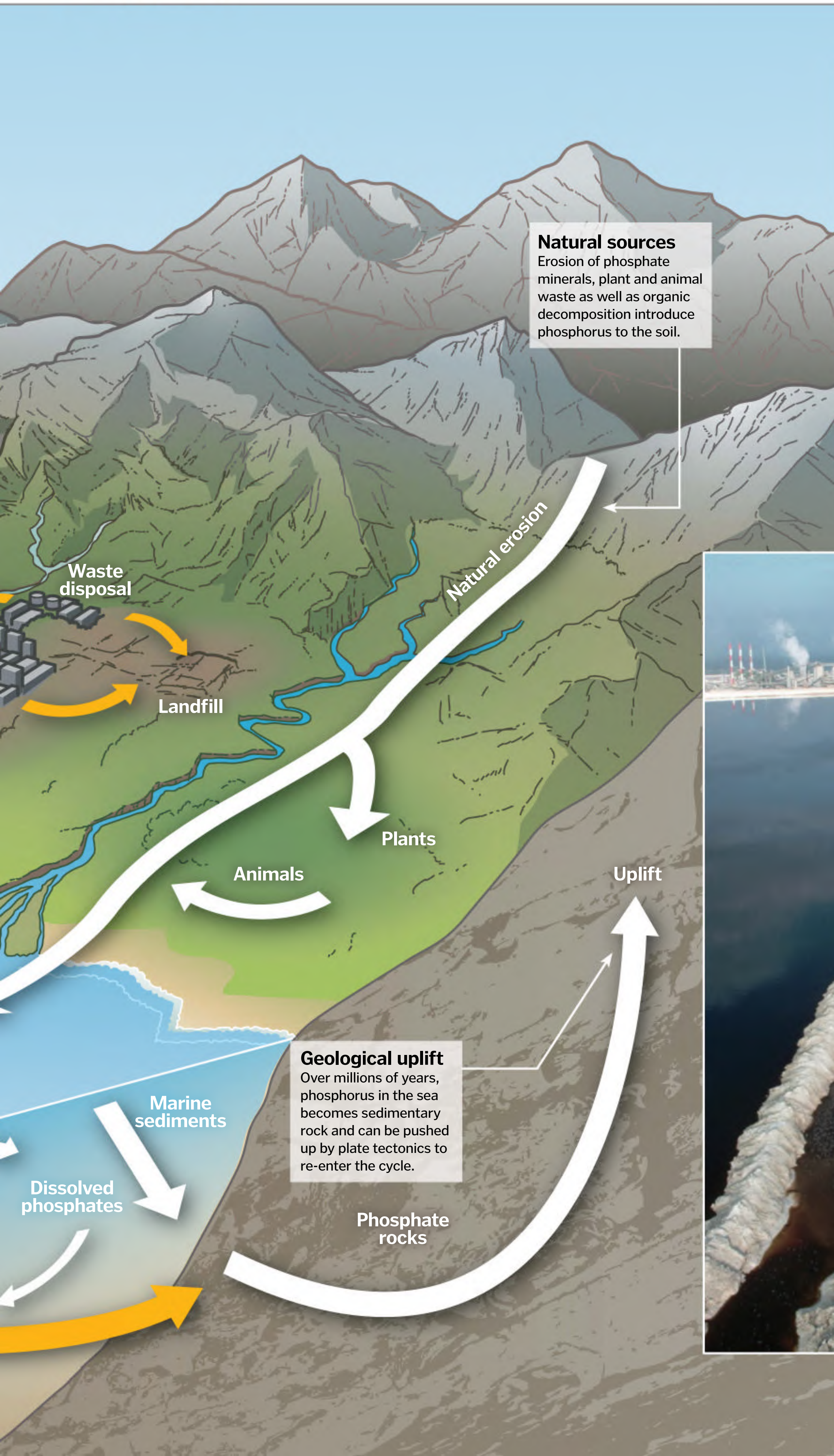
The gaseous form of phosphorus – phosphine – is usually only found under lab conditions as hydrogen phosphide (PH_3) and is completely odourless in its pure form, although it has a strong rancid fish or garlic smell in its impure diphosphane form. Phosphine is also extremely flammable and toxic; concentrations as low as one part per million can quickly cause a number of short-term symptoms, including vomiting and breathing difficulties. Higher concentrations can cause permanent damage and even death. It does have a use in industry, however, playing a role in the manufacture of semiconductors (components vital to the electronics field) and also in pest control. In the latter it's found as a gaseous fumigant or as phosphide pellets, treated to prevent the gas from exploding, which kill pests like rodents when inhaled/consumed.

Which avian product is a rich source of phosphorus?

A Bird feathers B Bird poo C Bird eggs

Answer: In 1840, guano (bird droppings) was identified as a ready source of phosphorus and saltpetre, or nitre, which is used for making gunpowder.

DID YOU KNOW? Early match industry workers were subject to 'phossy jaw', a disease that made the jaw glow and decay

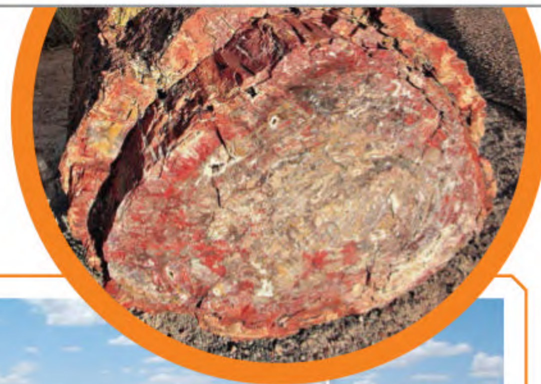


Discovery of phosphorus

Phosphorus was first discovered as an element in the 17th century. It was the 13th element to be found but the first since bismuth was discovered in ancient times. In 1669, German alchemist Hennig Brand came upon phosphorus when experimenting with urine in pursuit of creating the fabled philosopher's stone – the substance that was widely thought to facilitate the transmutation of metals like lead into gold or silver. Brand boiled litres of urine down into a paste that he heated through water, allowing its vapours to condense. Instead of gold, he got a waxy white substance that glowed in the dark: a phosphorous compound called ammonium sodium hydrogen phosphate. The glow that comes from white phosphorus is a slow reaction with oxygen that takes place at the surface of the element, which creates molecules that emit a visible wavelength of light. White phosphorus was used in matches for a time before it was removed because of its toxicity.

Strip-mining for phosphate near Tampa, FL. Florida provides about 25 per cent of global phosphorus production

Petrified forests



Perfectly preserved 225-million-year-old trees

All over the world you can find strange-looking slabs of wood, strewn across a barren landscape. However, these haven't actually been wooden for millions of years.

Around 225 million years ago, prehistoric trees fell into rivers, where they were quickly covered with a layer of sediment, silt and mud. This rapidly formed a tight wrap around the trunk, cutting off any oxygen that would have rotted the wood. Over time, minerals were absorbed into the wood, including silica. This material is known for its crystallising properties and as the log slowly rotted away over a period of many centuries, the silica replaced it, forming stunning crystal representations of the original material's shape and turning the wooden logs into quartz slabs.

As the floods washed or evaporated away, they left these quartz slabs scattered around the plains. Wind and sand erosion continued to batter these slabs until the last few pieces of organic material was stripped away, leaving stunning quartz blocks dotted around barren, arid landscapes around the world.

Petrified wood tends to be found in areas near volcanoes. This is because the silica, which is key to the production of the stunning crystals, usually comes from ash spewed out by an erupting volcano. Most petrified forests are protected areas, so you are allowed to go and view these incredible natural phenomena, but unfortunately you can't take any of it home for your mantelpiece.

Why do plants rot?

Once a plant dies, it will start to rot (decompose). They decay because microorganisms release enzymes that break down compounds for digestion. Bacteria and fungi – the main decomposers – depend on moisture and oxygen for their respiration. When both are absent from the process, the microorganisms work much slower and, in the case of petrified wood, rotting can take millions of years.

Notable petrified forests

The Petrified Forest National Park near Holbrook, Arizona, is one of the biggest and most impressive petrified forests in the world. It houses nearly a dozen different types of petrified wood, ranging from conifers to ferns. It grew to today's impressive size due to the large river network upstream of the site.

Argentina's Petrified Forest National Monument is a jaw-dropping demonstration of the changes the planet has undergone in its lifetime. Before the vast Andes mountain range even existed, vegetation was everywhere, some trees reaching 100m (328ft) high. Then, geological shift created the Andes and accompanying volcanoes, burying the plant life in ash, creating an amazing petrified forest.

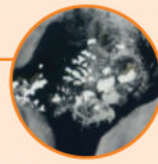
The petrified forest near Maadi, around 30 kilometres (19 miles) from Cairo in Egypt is quite young, the logs appearing around 35 million years ago. This was a time of geological upheaval as the Red Sea formed from the separation of tectonic plates. The forest spans about six kilometres (four miles) and was declared a protectorate in 1989 so it could be officially preserved by the Egyptian government.

KEY DATES
DEVELOPMENT OF THE LITHOSPHERE

3.8bya The lithosphere begins to break up, forming tectonic plates, allowing volcanoes and mountains to form.

1914 Joseph Barrell is the first to present the theory that the Earth's crust is made up of two layers.

1912 Alfred Wegener proposes the theory of continental drift, but his findings are met with disdain by many scientists.



1940 Dr Reginald Daly realises the asthenosphere has to be nearly liquid to explain its reaction to melting ice caps.

1960s Scientists finally agree that movement under the sea is caused by tectonic plates shifting.

DID YOU KNOW? Movement along the San Andreas fault line is pushing Los Angeles 4.6cm (1.8in) closer to San Francisco every year

The lithosphere

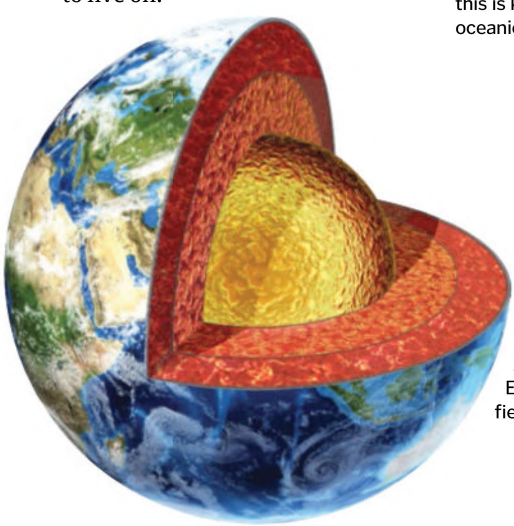
A closer look at the land on which we stand

The Earth is made up of four main layers: the inner core, outer core, mantle and the crust. The lithosphere includes the crust and the top portion of the mantle. It can be as thick as 100 kilometres (62 miles) and covers the entire planet, either as land or as ocean.

The lithosphere is constantly moving, but very slowly. It is broken up into huge sections known as tectonic plates. When two plates collide, the impact creates huge shock waves that cause earthquakes and tsunamis on the surface. They move around because material from the lower mantle rises and sinks in swirling convection currents, dragging the plates along with them.

The lithosphere can be broken down into two main layers. The deepest layer of the lithosphere is the solid upper mantle which floats on the softer mantle called the asthenosphere below. The upper layer, effectively Earth's surface, is known as the pedosphere and reacts with the atmosphere above.

The lithosphere's strength is crucial to life existing on Earth as it protects us from the incredible heat of the Earth's core, while providing a stable landmass for us to live on.



A cross-section of the Earth, showing its fiery-hot inner layers

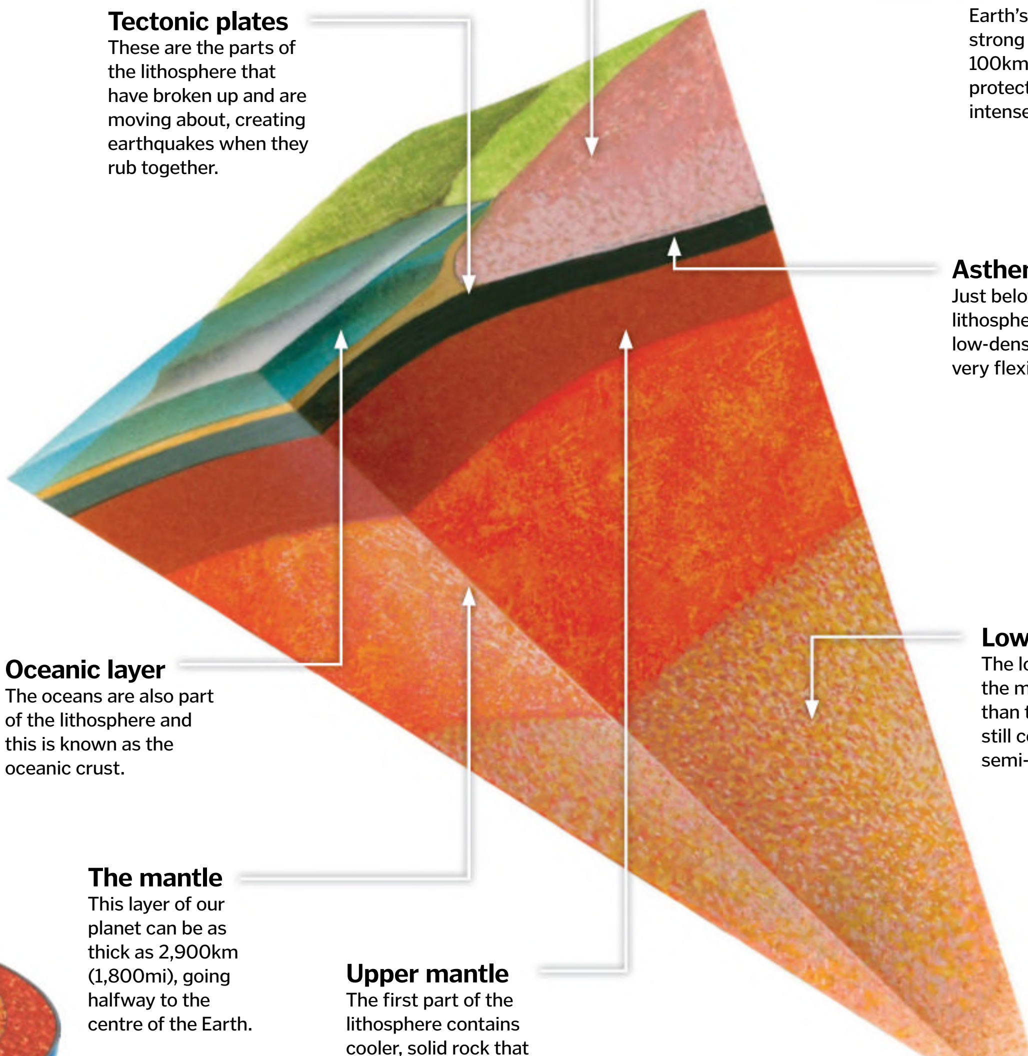
How did continents form?

The lithosphere has been around since the formation of the Earth, but it has been hypothesised that all land was once joined together. This supercontinent is called Pangaea, Greek for 'all lands.' The theory goes that as the tectonic plates split apart, they pulled the various landmasses with them, forming the continents we know today.

If you look closely, South America and Africa fit together well, with North America slotting neatly into the middle. Further evidence for Pangaea comes in the form of fossils found in both Africa and South America. The animals that formed the fossils are unlikely to have lived in both continents unless they were once conjoined.

Cutting through the Earth

What would the Earth would look like if you sliced a 100km (62mi) section out of it?



Tectonic plates
These are the parts of the lithosphere that have broken up and are moving about, creating earthquakes when they rub together.

Pedosphere
Earth's crust is strong and up to 100km (62mi) thick, protecting us from intense heat.

Asthenosphere
Just below the lithosphere, this low-density layer is very flexible.

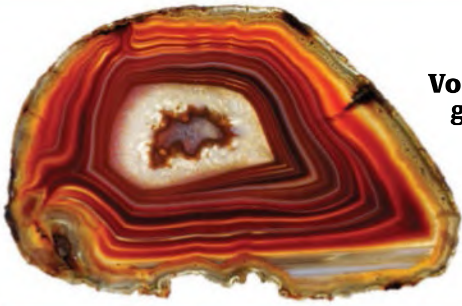
Oceanic layer
The oceans are also part of the lithosphere and this is known as the oceanic crust.

Lower mantle
The lower half of the mantle is cooler than the core, but still contains semi-molten rock.

The mantle
This layer of our planet can be as thick as 2,900km (1,800mi), going halfway to the centre of the Earth.

Upper mantle
The first part of the lithosphere contains cooler, solid rock that provides the base for the tectonic plates.

ROCKS, GEMS & FOSSILS



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Volcanic geodes

130 **Crater lakes**

128 **Burning gas crater**

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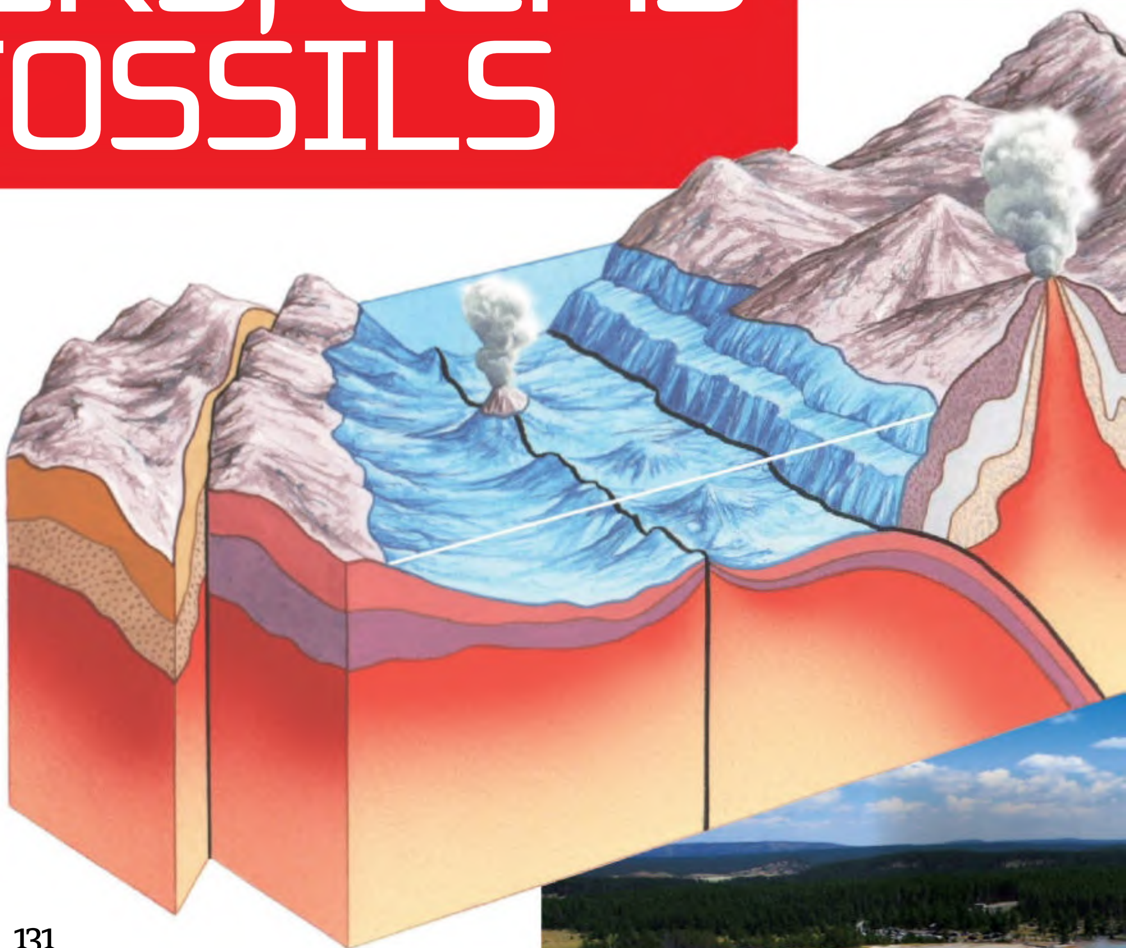
How amber develops



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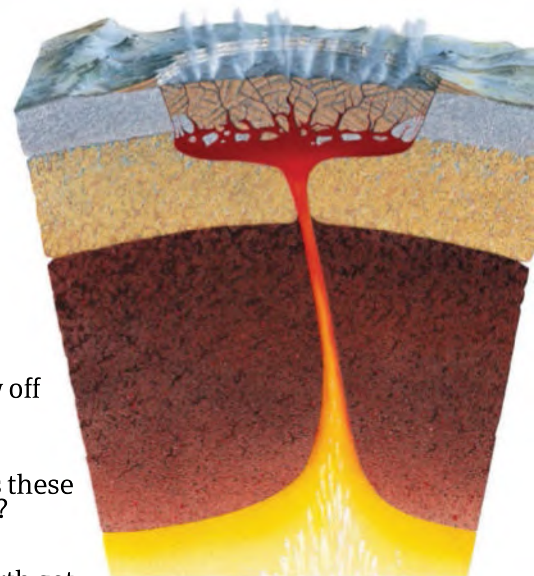
What are fossils?



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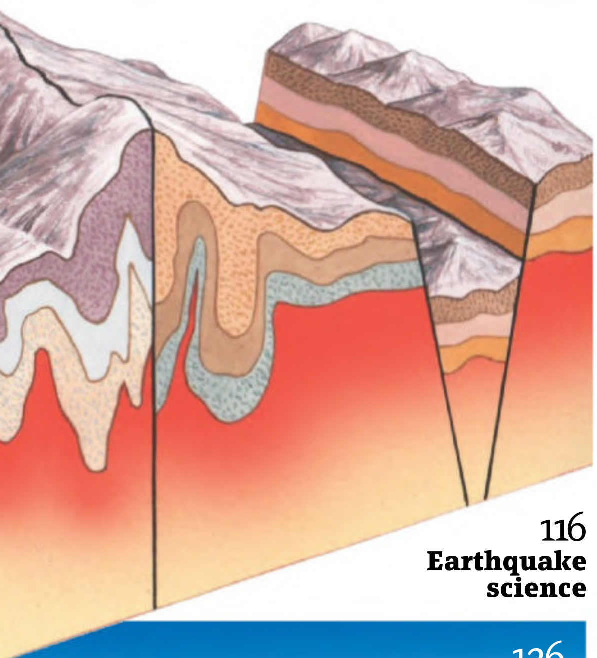
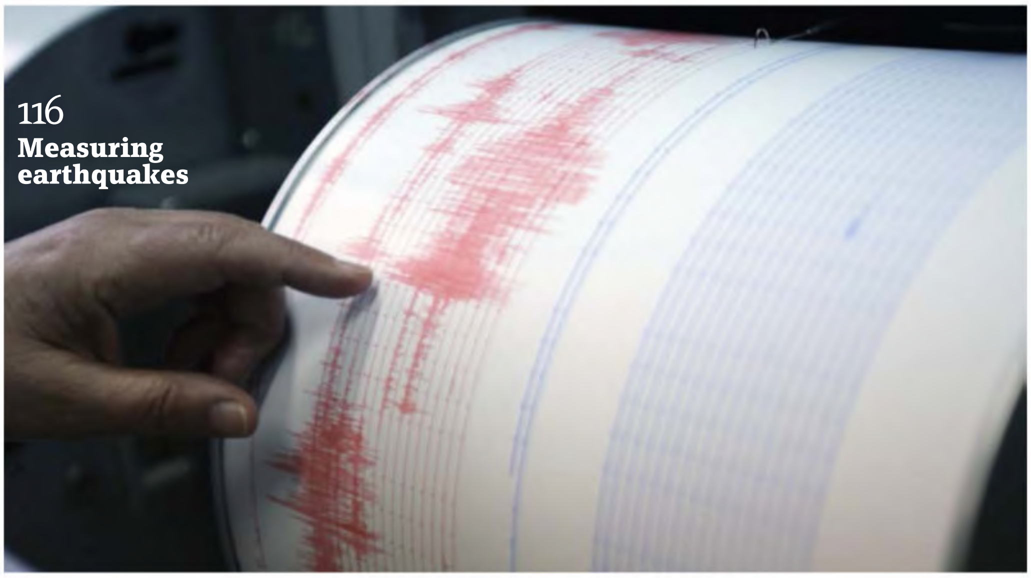
Get inside a massive supervolcano





Deadlier than an asteroid strike, these massive formations have the potential to destroy civilisation

SUPER VOLCANOES

Many people will remember the airport chaos of spring 2010 when Eyjafjallajökull, one of Iceland's largest volcanoes, erupted after almost two centuries of slumber.

But though it might be hard to believe, considering the mammoth amount of disruption that it caused, the Icelandic eruption was tiny compared to a super-eruption's devastating power. The Eyjafjallajökull event measured a mere 4 on the Volcanic Explosivity Index (VEI), which rates the power of eruptions on an eight-point scale. A massive VEI 8 blast, on the other hand, would threaten human civilisation. Such a super-eruption would spew out more than 1,000 cubic kilometres (240 cubic miles) of ejecta – ash, gas and pumice – within days, destroying food crops, and changing the world climate for years.

A super-eruption hasn't happened in recorded history, but they occur about every 10,000-100,000 years. That's five times more often than an asteroid collision big enough to threaten humanity. Scientists say there's no evidence that a super-eruption is imminent, but humans will face nature's ultimate geological catastrophe one day.

A supervolcano is simply a volcano that's had one or more super-eruptions in its lifetime. Supervolcanoes are typically active for millions of years,but wait tens of thousands of years between major eruptions. The longer that they remain dormant, the bigger the super-eruption. They typically erupt from a wide, cauldron-shaped hollow called a caldera, although not every caldera houses a future supervolcano.

5 TOP FACTS SUPERSIZED VOLCANOES

Mysterious
1 Some of Earth's supervolcanoes remain undiscovered. A mystery eruption in Ethiopia, for example, dumped 4,150km^3 (996mi^3) of debris in eastern Africa and the Red Sea.

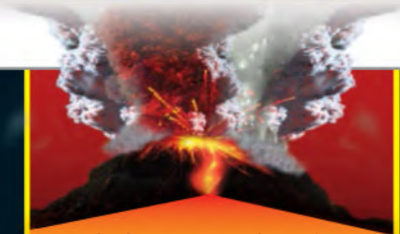
Mass murderers
2 Some claim the Lake Toba eruption about 74,000 years ago almost drove humans extinct by plunging Earth into a volcanic winter. Only 3,000-10,000 people survived it, they believe.

Made in 2000
3 The word 'supervolcano' was coined in 2000 by BBC science documentary *Horizon*. The word is now used to describe volcanoes that produce gigantic, but rare, eruptions.

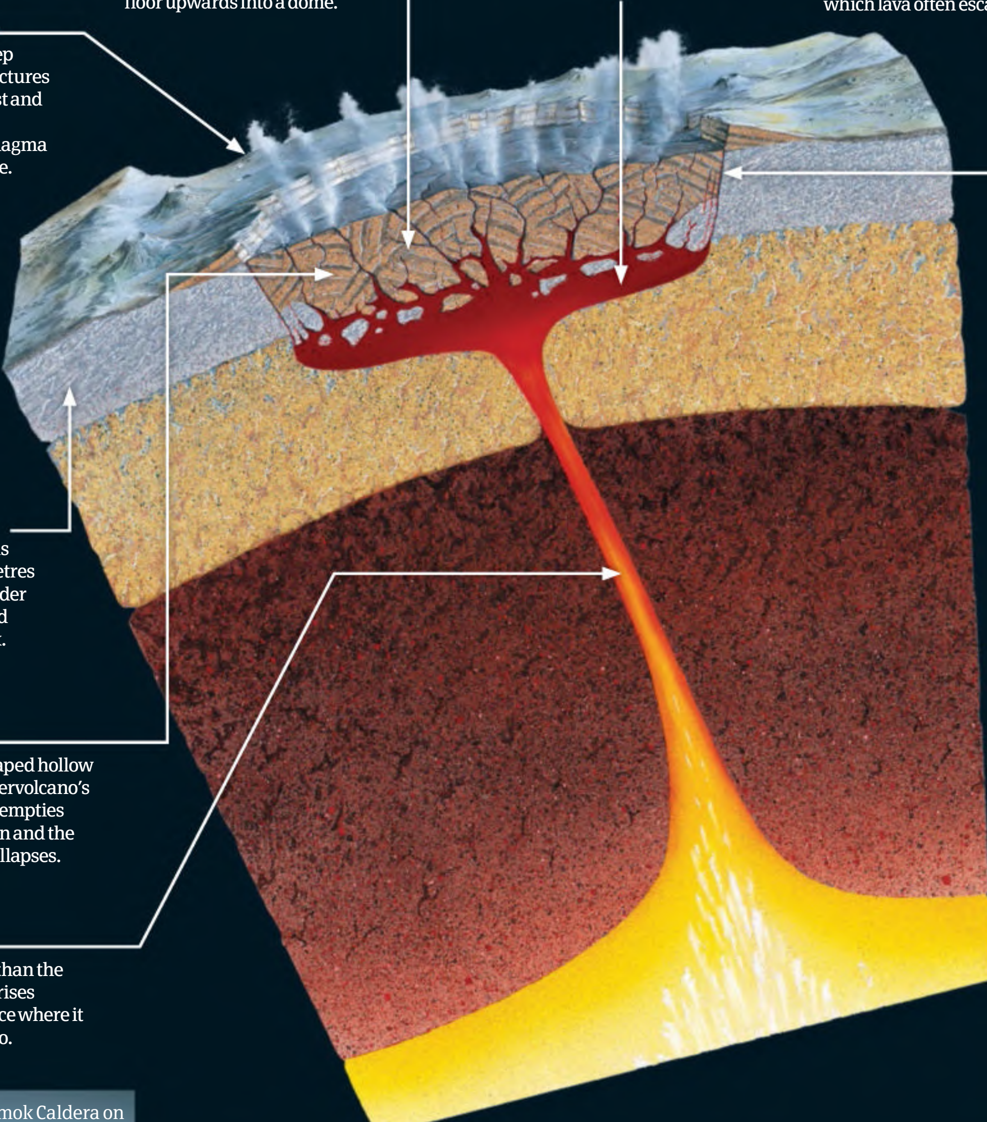
Maybe not
4 The odds of a Lake Taupo-sized super-eruption – that is, more than 1,000km^3 (240mi^3) of ash – this century are less than lightning striking your friends and family.

Massive
5 Supervolcano eruptions are dwarfed by Earth's largest lava flow, the Siberian Traps, which flooded an area the size of Australia. Lava erupted here for more than a million years.

DID YOU KNOW? Water heated under Yellowstone causes the park's many geysers



Inside a supervolcano



Resurgent dome
Molten rock rising in the underground magma chamber pushes the overlying caldera floor upwards into a dome.

Shallow magma chamber
An underground pool of molten rock called magma, which vents to the surface as a volcanic eruption.

Ring fractures
A circular fracture running around the collapsed edge of the magma chamber through which lava often escapes.

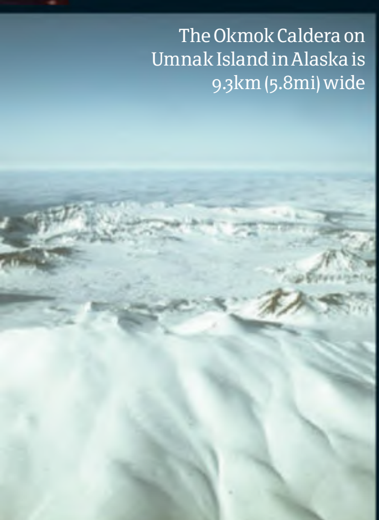
Hot springs
Snow and rain seep down through fractures in the Earth's crust and are subsequently superheated by magma close to the surface.

Earth's crust
The Earth's crust is perhaps 56 kilometres (35 miles) thick under the continents and made of solid rock.

Caldera
This cauldron-shaped hollow forms when a supervolcano's magma chamber empties during an eruption and the rock roof above collapses.

Magma
Magma is lighter than the Earth's crust and rises towards the surface where it erupts as a volcano.

© Science Photo Library



The Okmok Caldera on Umnak Island in Alaska is 9.3km (5.8mi) wide

Predicting the next super-eruption

Volcanologists at the Yellowstone Volcanic Observatory are among those studying supervolcanoes. They hope to have decades or centuries to prepare for a super-eruption. Warning signs could include the ground bulging and cracking as hot rock muscles to the surface, an increase in small eruptions and earthquakes, and changes in the gases escaping the ground.

Scientists analyse earthquakes by measuring ground vibration with seismometers. Earthquakes often increase before eruptions as magma and gas force through underground fractures, causing rocks to break. The ground historically rises before eruptions due to upwelling magma. For example, the north flank of US volcano Mount St Helens rose by a staggering 80 metres (262 feet) in 1980.

Scientists constantly keep track of Earth movements using networks of satellite GPS receivers. Like GPS in cars, these monitor the receiver's location on the ground. Another satellite technology, InSAR, measures ground movement over large areas once or twice annually.

COUNTDOWN TO ERUPTION

8. CALDERA FORMS
DAYS
The rock cylinder inside the ring fractures and plunges into the emptied magma chamber. Gas and lava spurt from the fractures.

7. DEADLY CLOUDS
DAYS
The fractures join into a ring of erupting vents. Toxic ash and fragment clouds race downhill at snow avalanche speed.

6. SUPER-ERUPTION
HOURS TO DAYS
The expanding gases act like bubbles of pop in a shaken bottle, flinging lava and rock high into the atmosphere.

5. MAGMA CHAMBER RUPTURES
HOURS TO DAYS
Vertical fractures in the swollen crust breach the magma chamber, allowing pressurised, gas-filled magma to escape to the surface as lava.

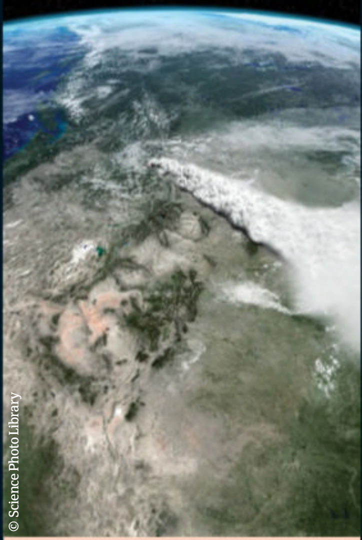
4. WARNING SIGNS INCREASE
WEEKS TO CENTURIES
Warning signs of a super-eruption may include swarms of earthquakes and the ground rapidly swelling up like baking bread.

3. MAGMA CHAMBER EXPANDS
TENS OF THOUSANDS OF YEARS
Supervolcano magma chambers can grow for tens of thousands of years because they are surrounded by flexible hot rock.

2. PRESSURE BUILDS
TENS OF THOUSANDS OF YEARS
As magma accumulates in a chamber, the pressure builds and the cavity expands. Fractures begin to form in the chamber roof.

1. MAGMA RISES
TIME: MILLIONS OF YEARS
Magma forms when rock deep in the Earth liquefies and pushes through the solid crust towards the surface.

This artist's illustration reveals the smoke and ash that could result from a supervolcanic eruption at Yellowstone



The fallout following a super-eruption

A supervolcano erupting today could threaten human civilisation. Clouds of molten rock and iridescent gas travelling three times faster than motorway cars would obliterate everything within 100 kilometres (60 miles) of the blast. Dust would spread thousands of kilometres, blotting out the Sun. People's unprotected eyes, ears and noses would fill with needle-like ash, which can pop blood vessels in the lungs and kill by suffocation.

Up to 0.5 metres (1.6 feet) of ash could rain down each hour, collapsing roofs, poisoning water supplies and halting transport by clogging car and aircraft engines; just a few centimetres of ash can disrupt agriculture. The 1815 eruption of Indonesia's Mount Tambora caused the 'year without a summer' when European harvests failed, bringing famine and economic collapse. Financial markets could be disrupted and countries swamped by refugees. Some scientists say a Yellowstone super-eruption could render one-third of the United States uninhabitable for up to two years.

The supervolcano simmering under Yellowstone National Park in the USA is probably the world's most studied, but super-eruptions occur so rarely that they remain a mystery. We know of 42 VEI 7 and VEI 8 eruptions in the last 36 million years, but much of the debris from these ancient super-eruptions has worn away. Eruptions like these take place at irregular intervals and scientists are unsure what triggers them.

Supervolcanoes, like all volcanoes, occur where molten or partly molten rock called magma forms and erupts to the Earth's surface. All supervolcanoes break through the thick crust that forms the continents. The Yellowstone caldera sits on a hot spot, a plume of unusually hot rock in the solid layer called the mantle that lies below the Earth's crust. Blobs of molten mantle rise from the hot spot towards the surface and melt the crustal rocks.

Other supervolcanoes like Lake Toba in Sumatra, Indonesia, lie on the edges of the jigsaw of plates that make up the Earth's crust. Near Sumatra, the plate carrying the Indian Ocean is being pushed underneath the crustal plate carrying Europe. As it descends, the ocean plate melts to form magma.

Vast quantities of magma are needed to fuel a super-eruption. Some scientists believe that supervolcanoes are 'super' because they have gigantic, shallow magma chambers that can hold volumes of up to 15,000 cubic kilometres (3,600 cubic miles) and grow for thousands of years. Magma chambers are underground pools of accumulated magma that erupt through cracks to the surface. Volcanoes with smaller chambers expel magma before enough pressure builds for a supersized event.

Some scientists speculate that hot, flexible rocks surround supervolcano magma chambers, allowing them to swell to accommodate more magma. The rocks are kept malleable by blobs of magma repeatedly welling up from below.

A super-eruption starts when the pressurised magma explodes through fractures in the chamber roof. The eruption is violent because supervolcano magma is rich in trapped gas bubbles, which expand and burst as it abruptly depressurises; the eruption is akin to uncorking a champagne bottle. The magma is also sticky and unable to flow easily because it's made partly from melted continental crust. This is in contrast to a volcano such as Mauna Loa in Hawaii, which gently pours out lava because its magma is fluid and contains little gas.

Hot fragments and gas soar to heights of more than 35 kilometres (22 miles) and spread in the atmosphere. Some of the fragments drift down and blanket the ground like snow. Other hot fragments rush downhill for hundreds of square kilometres at speeds exceeding 100 kilometres per hour (62 miles per hour) as toxic, ground-hugging pyroclastic flows. The magma chamber rapidly drains during the super-eruption, causing the roof above to sink into the empty space to (re-)form a caldera.

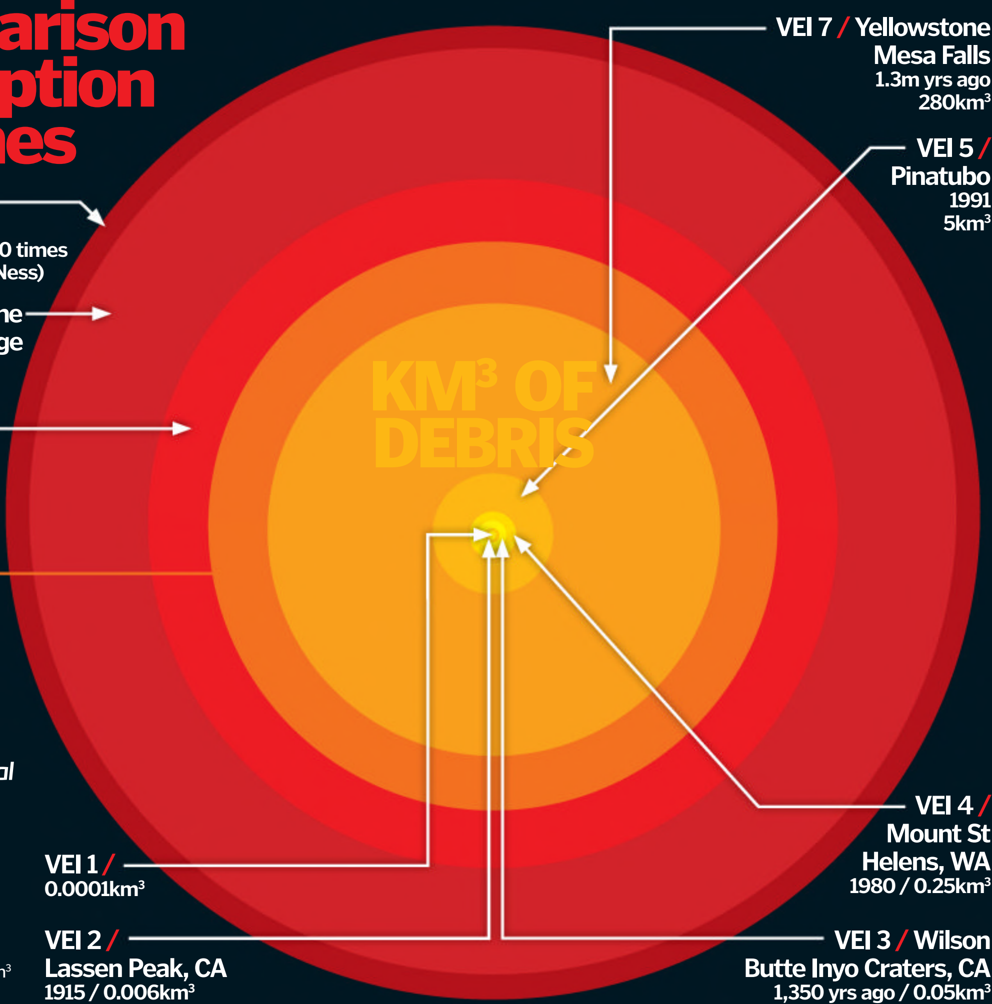
Comparison of eruption volumes

VEI 8 / Toba
74,000 yrs ago
2,800km³ (that's 380 times the volume of Loch Ness)

VEI 8 / Yellowstone Huckleberry Ridge
2.1m yrs ago
2,450km³

VEI 8 / Yellowstone Lava Creek
640,000 yrs ago
1,000km³

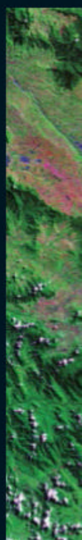
VEI 7 / Long Valley Caldera
760,000 yrs ago
580km³



Volcanic Explosivity Index (VEI)

Volume of material in eruption

VEI 8: >1,000km³
VEI 7: 100-1,000km³
VEI 6: 10-100km³
VEI 5: 1-10km³
VEI 4: 0.1-1km³
VEI 3: 0.01-0.1km³
VEI 2: 0.001-0.01km³
VEI 1: 0.00001-0.001km³
VEI 0: <0.00001km³



HEAD 2 HEAD
SUPERVOLCANO SHOWDOWN

© USGS

BIG

1. Huckleberry Ridge Caldera
Yellowstone National Park, USA
Yellowstone's biggest eruption 2.1 million years ago blasted a hole in the ground around three times wider than Greater London.

BIGGER

2. Lake Toba
Sumatra, Indonesia
This eruption 74,000 years ago smothered south-east Asia in 15cm (5.9in) of ash and excavated the planet's largest volcanic lake.

BIGGEST

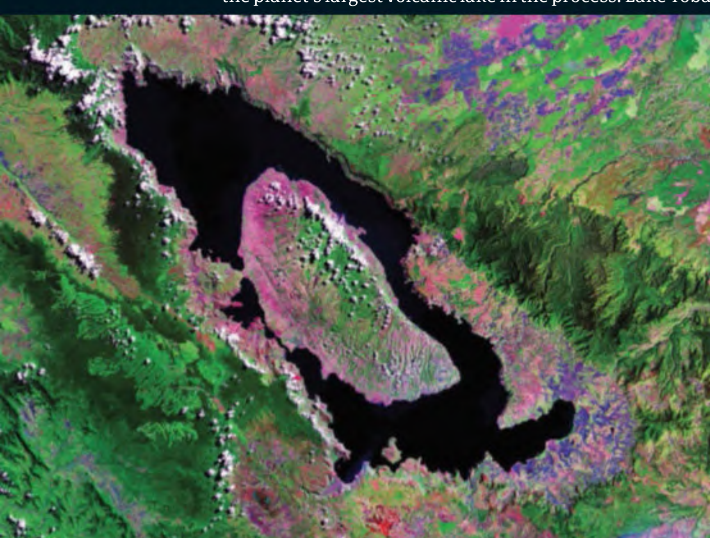
3. La Garita Caldera
Colorado, USA
Earth's biggest known super-eruption, which occurred approximately 28 million years ago, would have buried surrounding states in debris 12m (39ft) deep.

DID YOU KNOW? *Our Solar System's most powerful volcano is Loki, which is located on Jupiter's moon Io*

VOLCANOES VS SUPERVOLCANOES
The explosive battle

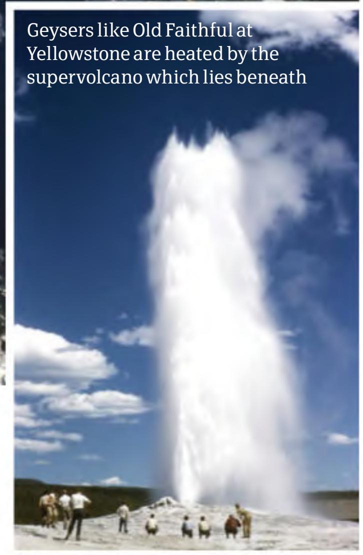
TYPICAL VOLCANO	TYPICAL SUPERVOLCANO
FOOTPRINT	
Volcanoes vary, but a typical shield volcano might be 5.6km (3.5mi) across. The crater – equivalent to a caldera – of Mount St Helens, USA, is about 3.2km (2mi) wide.	Bigger calderas produce larger eruptions, meaning most supervolcanoes cover vast areas. Lake Toba is 90km (56mi) long and lies in such a caldera.
HEIGHT	
Normal volcanoes are cone-shaped mountains perhaps 1km (3,280ft) high. Mount St Helens, for example, stands 635m (2,084ft) above its crater floor.	Supervolcanoes have 'negative' topography: they erupt from smouldering pits. Lake Toba, which lies in a supervolcano caldera, is over 0.5km (0.3mi) deep.
VOLUME	
Typical volcanoes have smaller magma chambers. The magma chamber of Mount St Helens, for example, has a volume of just 10-20km³ (2.4-4.8mi³).	Yellowstone's magma chamber and caldera are similar in width. The chamber is 60 x 40km (37 x 25mi) wide, and 5-16km (3-10mi) below the surface.
EJECTA	
Even huge volcanoes produce comparatively little debris; eg Yellowstone's super-eruptions were up to 2,500 times bigger than the 1980 St Helens blast.	Super-eruptions eject more than 1,000km³ (240mi³) of debris. They also spew at least 10^{12} tons of magma: more than the mass of 50 billion cars.
DAMAGE	
A few eruptions, like Mt Tambora in 1815, changed global climate, but most of the 20 volcanoes erupting as you read this affect only their immediate vicinity.	A Yellowstone eruption could lower Earth's average temperature by 10°C (18°F) for ten years. Within 1,000km (621mi) of the blast, 90 per cent of people could die.

A super-eruption took place in Sumatra 74,000 years ago, forming the planet's largest volcanic lake in the process: Lake Toba



©NASA

A satellite view of Yellowstone National Park, which is positioned above a hot spot in the Earth's crust



Geysers like Old Faithful at Yellowstone are heated by the supervolcano which lies beneath

Yellowstone's restless giant

Beneath Yellowstone National Park bubbles an active supervolcano. A magma chamber, lying as close as eight kilometres (five miles) to the surface in places, fuels the park's 10,000 jewel-coloured hot springs, gurgling mud pools, hissing steam vents and famous geysers like Old Faithful. The 8,897-square-kilometre (3,435-square-mile) park includes the volcano's caldera, which spans 4,400 square kilometres (1,750 square miles); that's big enough to cover the emirate of Dubai.

The supervolcano is fuelled by a 'hot spot', a plume of hot rock rising from hundreds of kilometres below the Earth's surface. Hot spots act like gigantic Bunsen burners, driving catastrophic eruptions by melting the rocks above them. Scientists remain uncertain why hot spots form; they're not found at the edge of Earth's crustal plates and most volcanic activity happens where these plates jostle against one another. Since the hot spot formed around 17 million years ago, it has produced perhaps 140 eruptions. The North American crustal plate has slid southwest over the stationary hot spot like a belt on a conveyor leaving a 560-kilometre (350-mile) string of dead calderas and ancient lava flows trailing behind.

There have been three super-eruptions since Yellowstone moved over the hot spot: 2.1 million, 1.3 million and 640,000 years ago. Each eruption vented enough magma from the volcano's storage reservoir to collapse the ground above into a caldera. The first and largest eruption created the Huckleberry Ridge Tuff, more than 2,450 cubic kilometres (588 cubic miles) of volcanic rock made of compacted ash. The eruption blasted a huge caldera perhaps 80 x 65 kilometres (50 x 40 miles) in area and hundreds of metres deep across the boundary of today's national park. The most recent caldera-forming eruption blanketed much of North America in ash and created today's Yellowstone Caldera. Hot gas and ash swept across an area of 7,770 square kilometres (3,000 square miles).

ON THE MAP

Six known supervolcanoes

1. Lake Toba, Sumatra, Indonesia
2. Long Valley, California
3. Lake Taupo, New Zealand
4. Valles Caldera, New Mexico
5. Aira Caldera, southern Japan
6. Yellowstone National Park, United States

What is lava?

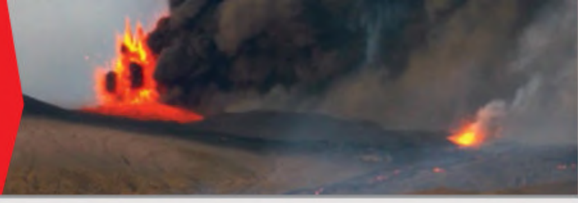
Take a closer look at the molten material ejected by volcanoes

Beneath the Earth flows molten rock known as magma. When a volcano erupts, the resulting explosion shoots this magma out into the atmosphere. At this point the magma becomes known as lava. There is no major difference between magma and lava; the terms merely distinguish whether the molten rock is beneath or above the surface. Caused by gas pressure under the surface of the Earth, a giant volcanic eruption can be incredibly powerful with lava shooting up to 600 metres (2,000 feet) into the air.

Lava can reach temperatures of 700-1,200°C (1,300-2,200°F) and varies in colour from bright orange to brownish red, hottest to coldest, respectively. This viscous liquid can range from the consistency of syrup to extremely stiff, with little or no flow apparent. This is regulated by the amount of silica in the lava, with higher levels of the mineral resulting in a higher viscosity. When lava eventually cools and solidifies it forms igneous rock.

Inside lava are volcanic gases in the form of bubbles, which develop underground inside the magma. When the lava erupts from inside the volcano, it is full of a slush of crystalline minerals (such as olivine). Upon exposure to air the liquid freezes and forms volcanic glass. Different types of lava have different chemical compositions, but most have a high percentage of silicon and oxygen in addition to smaller amounts of elements such as magnesium, calcium and iron.

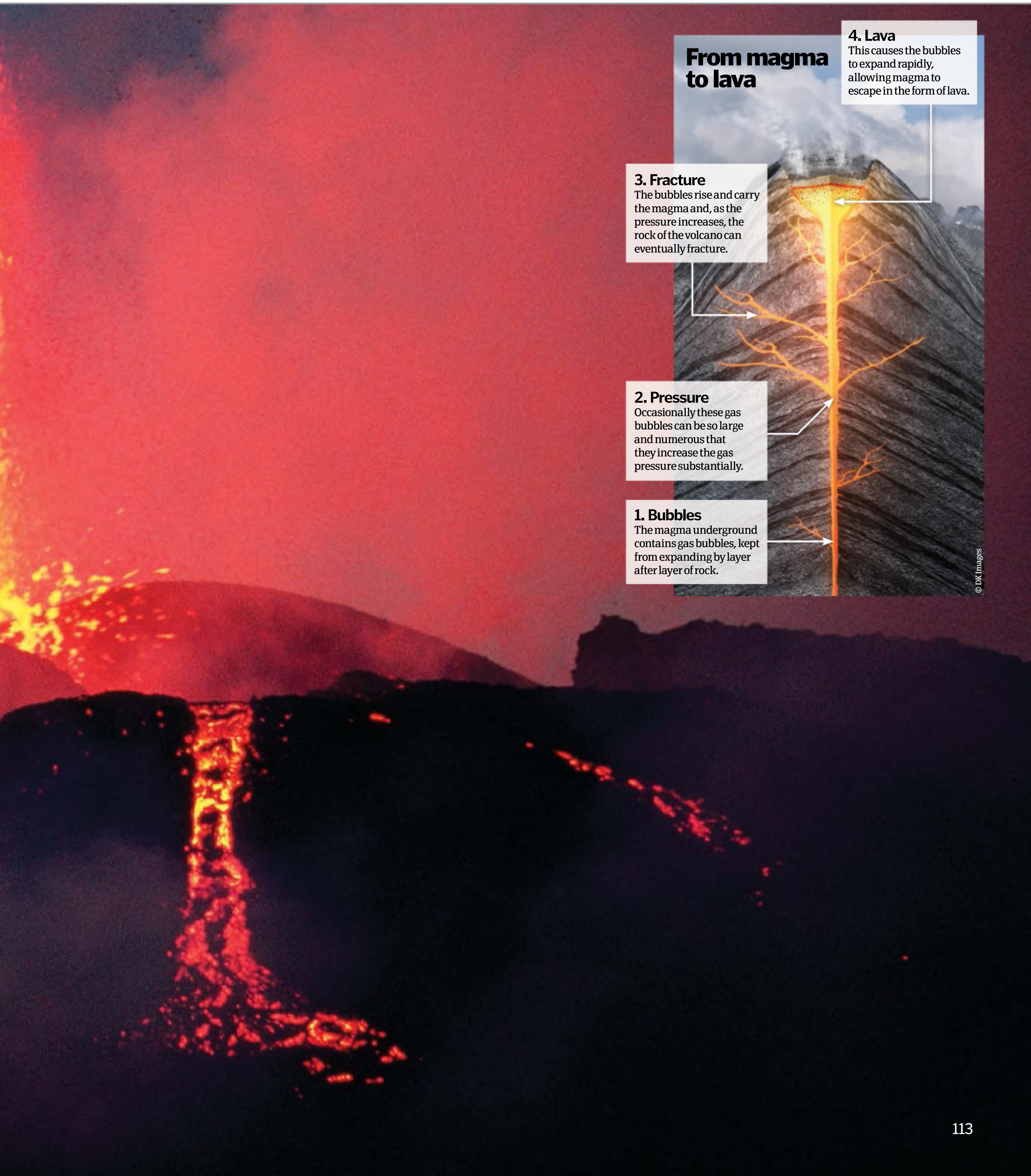
DID YOU KNOW?



Fighting fire with fire

Explosives have been suggested as a means of stopping lava flows since 1881 and have had varying degrees of success. In 1935 and 1942 the US Air Force was unsuccessful in stopping a lava flow in Hawaii by dropping bombs on it, but the tactic was partially successful in 1975 and 1976.

DID YOU KNOW? *The fastest recorded lava flow is 60km/h (40mph) at a stratovolcano that erupted in DR Congo in 1977*



The eruption of Mount St Helens

Discover how a mountain lost its top in America's most economically destructive volcanic eruption

Mount St Helens blew off its summit in May 1980 with the energy of 20,000 Hiroshima-size atomic bombs. The resulting rock blast and mudslides killed 57 people and around 7,000 large animals, engulfed 200 houses, choked rivers, buried highways and flattened trees like matchsticks. Ash closed nearby airports for up to two weeks, grounding thousands of flights. The damage cost $1.1 billion to repair.

The volcano remains active and America's second-most dangerous. It sits on the Ring of Fire – a 40,000-kilometre (25,000-mile) horseshoe of volcanoes circling the Pacific Ocean. Beneath Mount St Helens, two of the massive rock plates that form the Earth's crust are colliding; the oceanic Juan de Fuca Plate is sliding beneath the continental North American Plate. As the ocean plate grinds down into the Earth's crust, water is released. The water helps to melt the overlying hot rock into magma, which erupts through the brittle crust. The old North American crust contains lots of silica, which makes the magma sticky.

Gas builds up in this thick magma until it violently erupts with gas, rock and steam. This debris piles up into steep-sided volcanoes. Before the 1980 eruption, Mount St Helens was 3,000 metres (1,000 feet) tall and had been dormant since 1857. The volcano reawakened in March 1980 with a series of tremors and a growing bulge on its north side. A week before the eruption, the bulge grew two metres (6.6 feet) daily. After the eruption, Mount St Helens had shrunk by about 400 metres (1,300 feet).

Inside the eruption

Learn how 2.8 billion cubic metres of mountain was blown away

Ash eruption
Erupted ash blanketed a 57,000km^2 (22,000mi^2) area – enough to bury one football pitch 240km (150mi) deep!

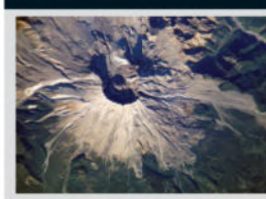
Summit lowered
The summit of Mount St Helens was reduced by about 400m (1,312ft) due to the eruption.

Uncorking
The debris avalanche allowed high-pressure steam in rocks and fissures, plus gas dissolved in the cryptodome, to expand and explode.

Cryptodome
A dome of sticky magma built up beneath the mountain, making the surface bulge and destabilising the rocks above.

Rotational slide
The volcano's north flank collapsed in 15 seconds as three blocks of rock slumped downhill as a huge debris avalanche.

The statistics…



Mount St Helens

Location: Washington, USA
Height: 2,600m (8,530ft)
Years of activity: 40,000
Last major eruption: May 1980
Type of formation: Subduction-related
Last eruption: January 2008

The 1980 eruption

Find out how this Washington mountain exploded over a day

March-May 1980
Bulge
Up to 30 mini-earthquakes shake the mountain daily and the volcano's north slope begins to bulge.

18 May 8.32am
Mega-quake strikes
20 seconds after 8.32am, a 5.1-magnitude earthquake rumbles 1.6km (a mile) beneath the volcano.

8.32am
Summit collapses
Ten seconds later the volcano's bulging north flank slides downhill as a gigantic rock avalanche that moves at up to 69m (226ft) per second.

8.35am
Sideways blast
Pressurised superheated gas and steam explode sideways, like champagne from an uncorked bottle, after the heavy overlying rock slides away.

STRANGE BUT TRUE

HELEN WHO?

Who is Mount St Helens named after?

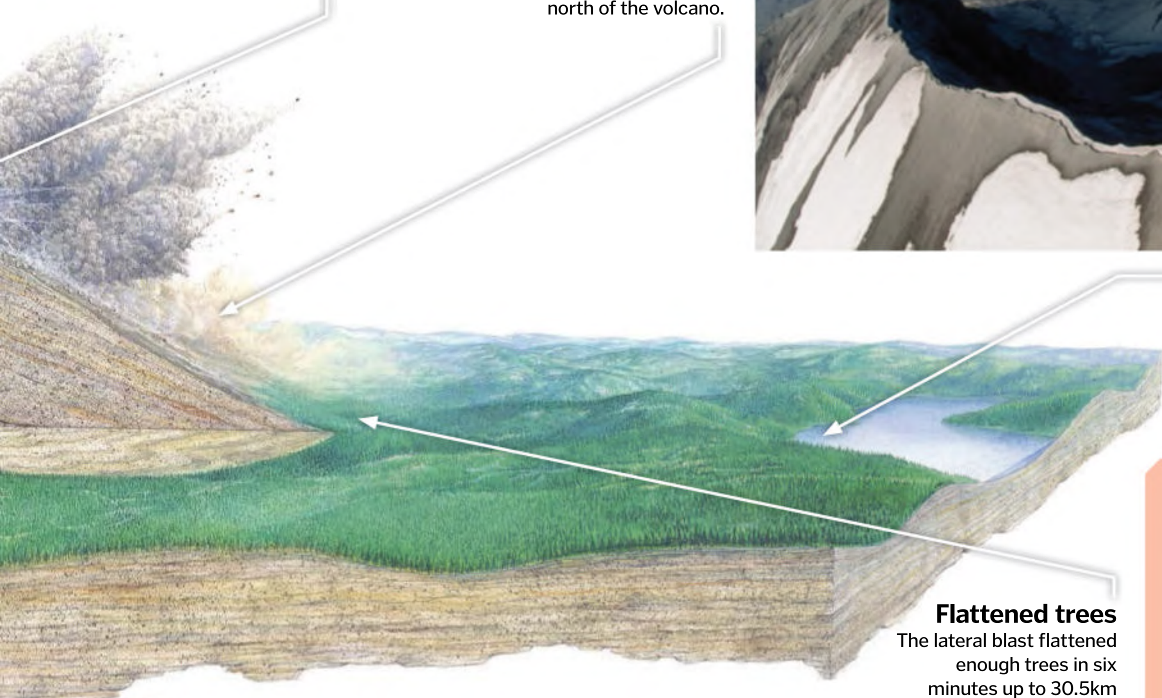
A Lord Helen **B** Baron St Helens **C** Mr Mount

Answer:

Explorer Captain George Vancouver named Mount St Helens during a surveying expedition from 1791-95 after his close friend, Alleyne Fitzherbert (Baron St Helens) – a British ambassador to Spain.

DID YOU KNOW? *An eruption four times larger than the 1980 blast caused Native Americans to flee 3,600 years ago*

The majority of Mount St Helens is less than 3,000 years old



Crater
The eruption and sliding blocks created an amphitheatre-shaped crater 1.5 x 3.2km (1 x 2mi) wide, open to the north.

Lateral blast
A hot blast of rock, ash and gas obliterated the landscape in a 600km^2 (230mi^2), fan-shaped zone north of the volcano.

Lahars
Pyroclastic mudflows called lahars filled local rivers, killing 12 million salmon, damaging 27 bridges and forcing 31 ships to remain in river ports.

Flattened trees
The lateral blast flattened enough trees in six minutes up to 30.5km (19mi) from the volcano to build 300,000 houses!

ON THE MAP

Six major active volcanoes around the world today

1. Citlaltépetl, Veracruz-Puebla, Mexico
2. Mauna Loa, Hawaii, USA
3. Fuji, Honshu, Japan
4. Nyamulagira, DR Congo
5. Vesuvius, Campania, Italy
6. Tambor, Sumbawa, Indonesia

What are lava tubes?

Lava tube
A lava tube forms when treacle-like basaltic lava flows downhill from a volcano along a channel like a river. Over time, a solid rock crust forms on the channel's surface as the 1,000-degree-Celsius (1,832-degree-Fahrenheit) lava cools when it's exposed to air. The lava within can remain hot and runny for tens of kilometres even when the tube is completely crusted over.

Pahoehoe
The ropey-looking lava emerging from the tube is called pahoehoe – a Hawaiian word for flows that form bizarre shapes. The tube is only partly filled by lava: the lava's heat downcuts through the channel bed. Superheated air and gas fill the space above the lava and re-melt the ceiling to create soda straw stalagmites – formations which are only found in lava tubes.

8.42am
Ash eruption
A huge mushroom cloud made up of ash and steam shoots more than 19km (12mi) into the atmosphere from the volcano's crater.

8.50am
Mudflows
The rock avalanche mixes with water to form mudflows in the nearby Toutle River, filling the valley up to 180m (600ft) deep with debris.

12.00pm
Pyroclastic flows
Glowing clouds of deadly volcanic rock, ash and explosive gases froth over the crater rim and descend down the volcano like a pot of oatmeal boiling over.

1.00pm
Aftermath
Streetlights turn on automatically during the afternoon in parts of eastern Washington as the dense ash cloud turns daylight into darkness.

Earthquakes

What causes these devastating natural hazards and what are we doing to predict and prepare for them?

Earthquakes are one of our planet's most destructive natural hazards, with the ability to flatten entire cities, trigger enormous tsunamis that wash away everything in their path, and cause a devastating loss of life.

Part of an earthquake's immense power lies in its unpredictability, as a huge quake can strike with very little warning, giving those nearby no time to get to safety. Though we don't know when they will occur, we can predict where, thanks to our knowledge of plate tectonics.

The thin top layer of the Earth, known as the crust, is divided into several plates that are constantly moving. This is caused by heat from the core of the Earth creating convection currents in the mantle just below the crust, which shifts the plates in different directions.

As the plates move, they collide, split apart or slide past each other along the plate boundaries, creating faults where the majority of earthquakes occur. At divergent or constructive plate boundaries the plates are moving apart, causing normal faults that form rift valleys and ocean ridges. When plates move toward each other along convergent or destructive plate boundaries, they create a reverse or thrust fault, either colliding to form mountains or sliding below the other in a process known as subduction. The third type is a conservative or transform plate boundary, and involves the two parallel plates sliding past each other to create a strike-slip fault.

Being able to identify these fault lines tells us where earthquakes are most likely to occur, giving the nearby towns and cities the opportunity to prepare. Although the secondary effects of an earthquake, such as landslides and fires from burst gas lines, can be fatal, the main cause of death and destruction during earthquakes is usually the collapse of buildings. Therefore, particularly in developed parts of the world, structures near to fault lines are built or

5 TOP FACTS
QUAKE-PROOFING

Animal inspiration
1 Scientists are trying to mimic the threads that mussels use to stay attached to their shells in order to develop construction materials that are rigid but flexible for absorbing shock.

Invisibility cloak
2 Dubbed the 'seismic invisibility cloak', 100 concentric plastic rings would be buried beneath the foundation of a building and deflect the surface waves around the structure.

Cardboard constructions
3 Architect Shigeru Ban has designed a church made of 98 giant cardboard tubes reinforced with wooden beams. The cardboard is sturdy but lightweight, so would cause little damage if it collapsed.

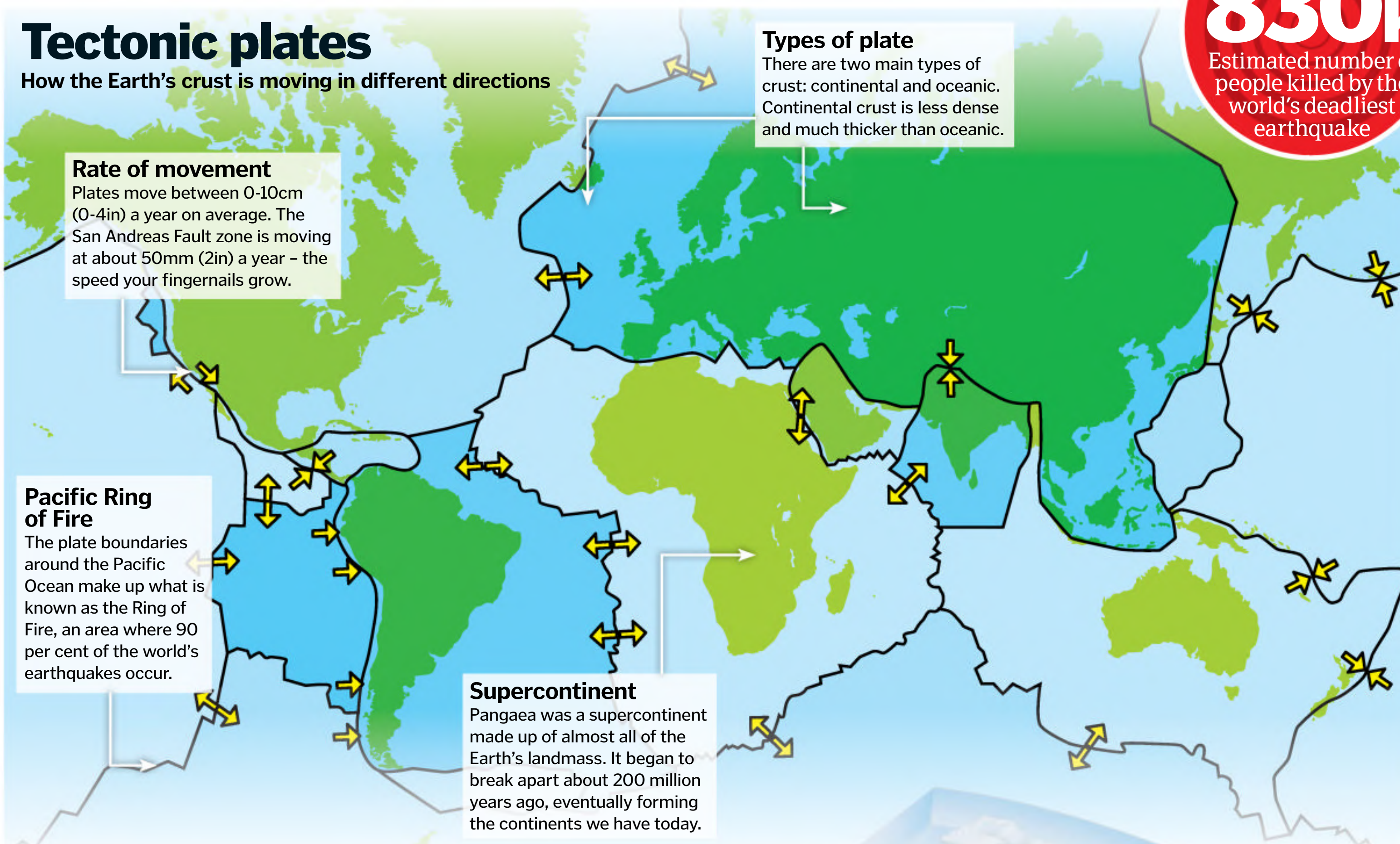
Plastic wrap
4 Fiber-reinforced plastic wrap could go around supporting columns in existing buildings. A pressurised adhesive would then be pumped between the column and the wrap.

Smart materials
5 Shape-memory alloys (SMAs) can return to their original shape after experiencing strong forces, so could be used in place of steel and concrete for more resilient buildings.

DID YOU KNOW? *There are ca 500,000 earthquakes in the world each year, but only 100,000 can be felt – 100 of them cause damage*

830k
Estimated number of people killed by the world's deadliest earthquake

Tectonic plates
How the Earth's crust is moving in different directions



Types of plate
There are two main types of crust: continental and oceanic. Continental crust is less dense and much thicker than oceanic.

Rate of movement
Plates move between 0-10cm (0-4in) a year on average. The San Andreas Fault zone is moving at about 50mm (2in) a year – the speed your fingernails grow.

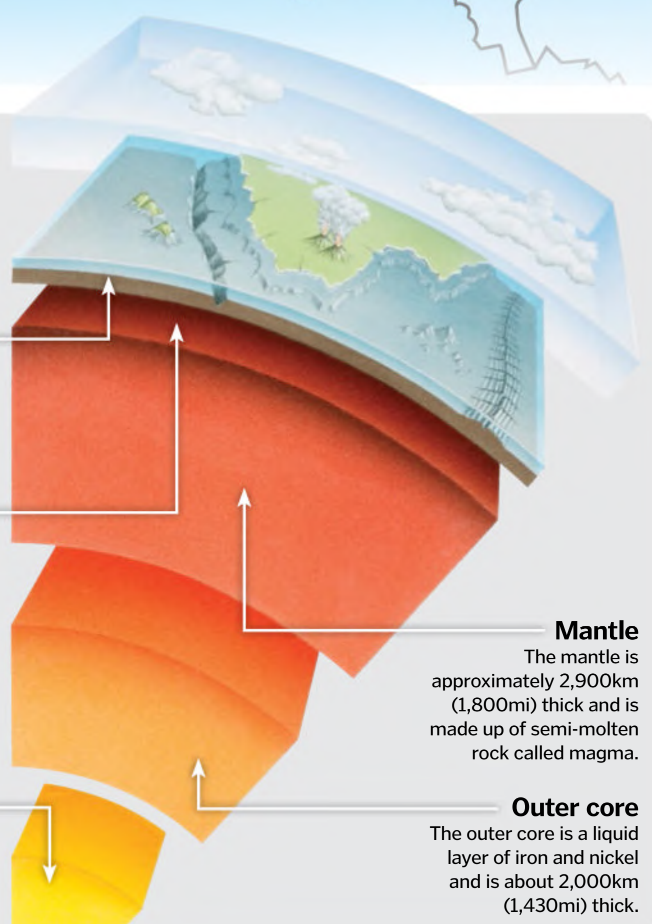
Pacific Ring of Fire
The plate boundaries around the Pacific Ocean make up what is known as the Ring of Fire, an area where 90 per cent of the world's earthquakes occur.

Supercontinent
Pangaea was a supercontinent made up of almost all of the Earth's landmass. It began to break apart about 200 million years ago, eventually forming the continents we have today.

adapted to withstand violent shock waves. The surrounding population will usually carry out regular earthquake drills, such as The Great California ShakeOut, that gives people a chance to practise finding cover when a quake hits. Unfortunately, many poorer areas cannot afford to be so well prepared, and so when an earthquake strikes, the resulting destruction is often even more devastating and the death toll is usually much higher.

However, our knowledge of how earthquakes work and the development of new technologies are helping us to find potential methods for predicting when the next one will strike. Scientists can currently make general guesses about when an earthquake may occur by studying the history of seismic activity in the region and detecting where pressure is building along fault lines, but this only provides very vague results so far. The ultimate goal is to be able to reliably warn people of an imminent earthquake early enough for them to prepare and minimise the loss of life and property. Until then, being under the constant threat of an impending earthquake is unfortunately part of everyday life for those living along the Earth's constantly active fault lines.

The Earth's structure
Cut through the different layers of our planet



Crust
The crust is the rocky outer layer of the Earth and is 40km (25mi) thick on average.

Lithosphere
The lithosphere, which is about 100km (62mi) deep in most places, includes the harder upper portion of the mantle and the crust.

Mantle
The mantle is approximately 2,900km (1,800mi) thick and is made up of semi-molten rock called magma.

Inner core
The inner core is made of solid nickel and iron, with temperatures of up to 5,500°C (9,930°F).

Outer core
The outer core is a liquid layer of iron and nickel and is about 2,000km (1,430mi) thick.

Anatomy of an earthquake

How earthquakes are caused and shake the ground beneath our feet

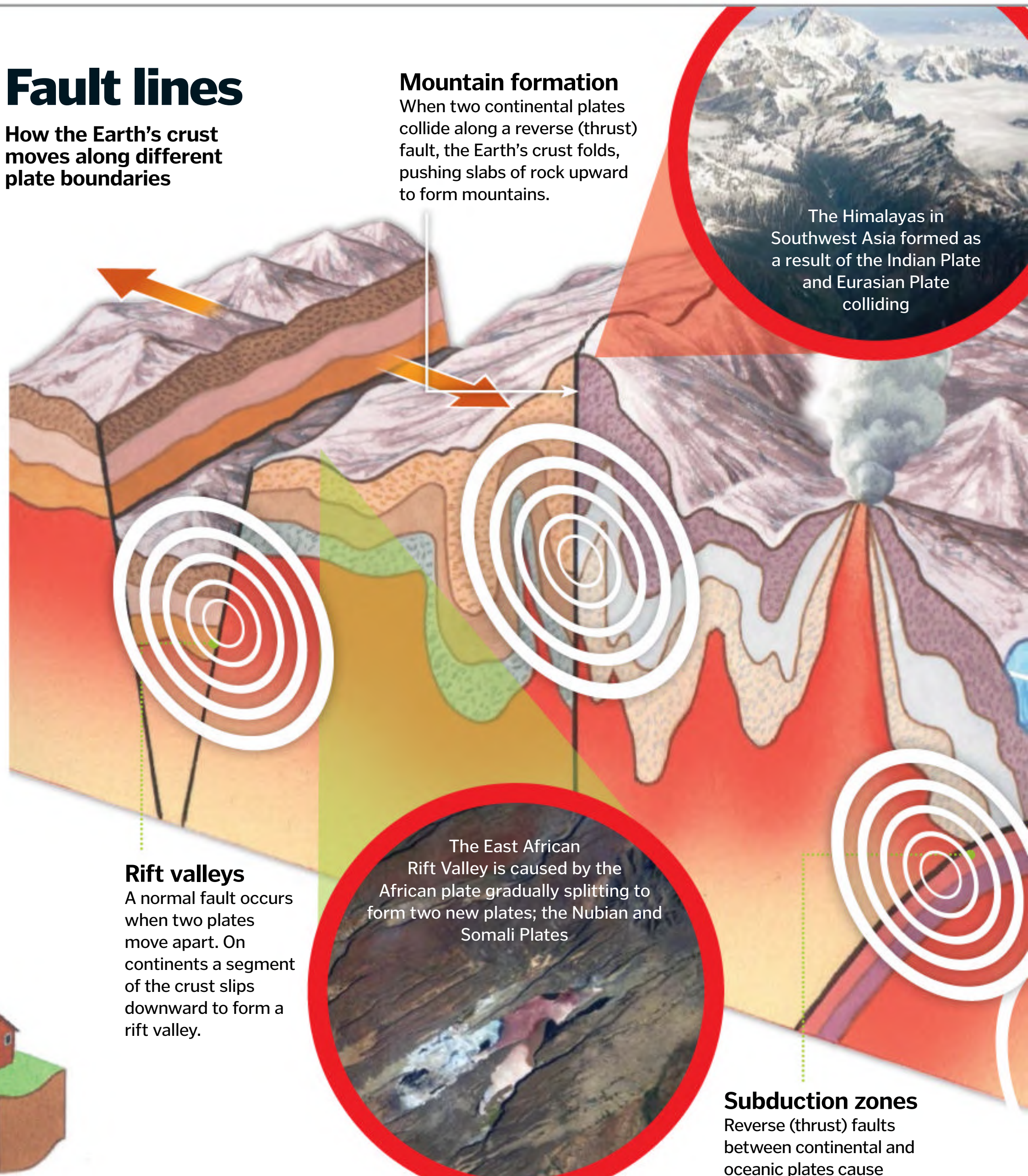
Earthquakes are caused by the build-up of pressure that is created when tectonic plates collide. Eventually the plates slip past each other and a huge amount of energy is released, sending seismic waves through the ground. The point at which the fracture occurs is often several kilometres underground and is known as the focus or hypocentre. The point directly above it on the surface is the epicentre, and this is where most of the damage is caused. Earthquakes have different characteristics depending on their type of fault line, but when they occur underwater, they can sometimes trigger enormous destructive waves called tsunamis.

Fault lines

How the Earth's crust moves along different plate boundaries

Mountain formation

When two continental plates collide along a reverse (thrust) fault, the Earth's crust folds, pushing slabs of rock upward to form mountains.



The Himalayas in Southwest Asia formed as a result of the Indian Plate and Eurasian Plate colliding

Rift valleys

A normal fault occurs when two plates move apart. On continents a segment of the crust slips downward to form a rift valley.

The East African Rift Valley is caused by the African plate gradually splitting to form two new plates; the Nubian and Somali Plates

Subduction zones

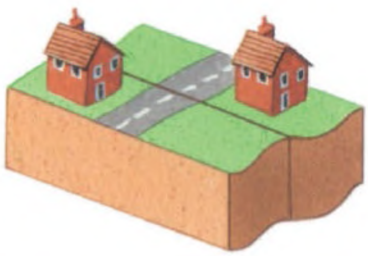
Reverse (thrust) faults between continental and oceanic plates cause subduction, causing the higher-density oceanic plate to sink below the continental plate.

How earthquakes occur

The build-up of pressure that causes the ground to move and shake

Friction causes pressure

As the tectonic plates are pushed past or into each other, friction prevents them from moving and causes a build-up of immense pressure.

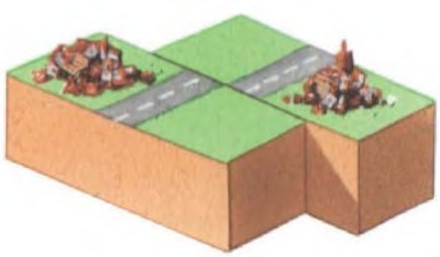


Energy is released

When the pressure finally overcomes the friction, the plates will suddenly fracture and slip past each other, releasing energy and causing seismic waves.

The process starts again

Once the energy has been released, the plates will assume their new position and the process will begin all over again.



Tsunamis

How underwater earthquakes trigger enormous and devastating waves

Water displacement

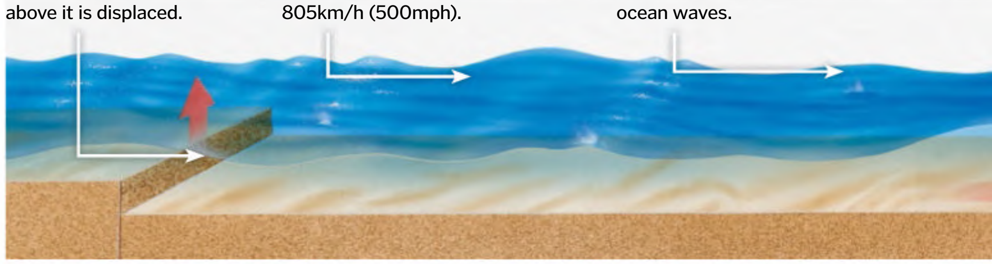
As two oceanic plates slip past each other and cause an earthquake, a huge amount of water above it is displaced.

Small beginnings

Small, rolling waves begin to spread outward from the earthquake's epicentre at speeds of up to 805km/h (500mph).

Tsunami in disguise

The tsunami's long wavelength and small wave height – usually less than 1m (3.3ft) – means that it blends in with regular ocean waves.



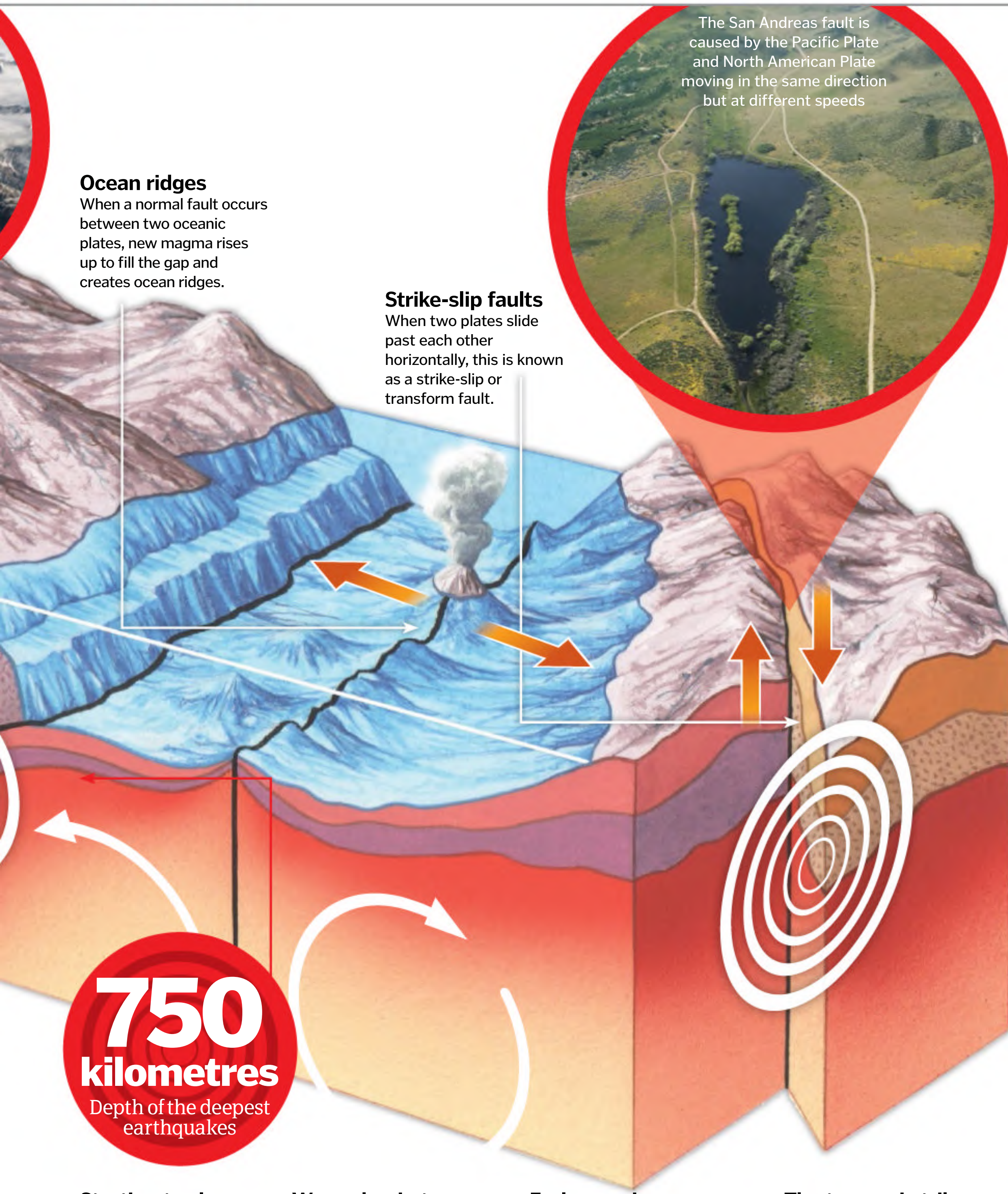
RECORD BREAKERS
BIG TREMOR

9.5

MOST POWERFUL EARTHQUAKE

The largest earthquake ever recorded happened on 22 May 1960 in southern Chile. It was caused by the subduction of the Nazca Plate under the South American Plate.

DID YOU KNOW? *Tsunamis and tidal waves are different things as the latter is caused by gravitational activity, not earthquakes*



The San Andreas fault is caused by the Pacific Plate and North American Plate moving in the same direction but at different speeds

Ocean ridges
When a normal fault occurs between two oceanic plates, new magma rises up to fill the gap and creates ocean ridges.

Strike-slip faults
When two plates slide past each other horizontally, this is known as a strike-slip or transform fault.

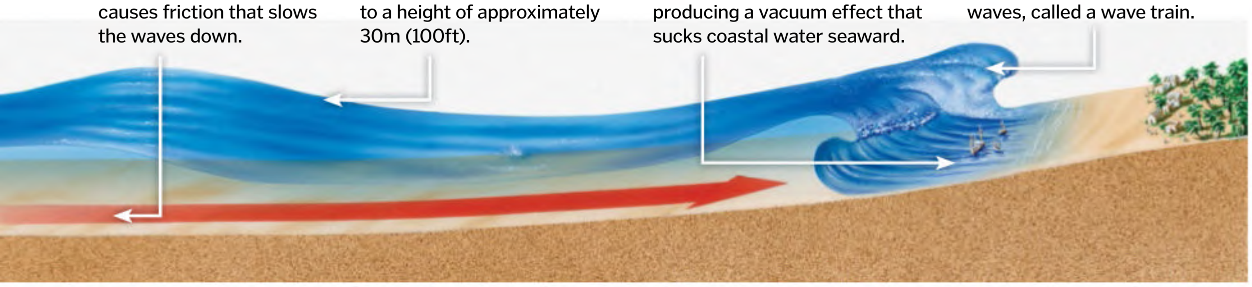
750 kilometres
Depth of the deepest earthquakes

Starting to slow
As they reach the shallower waters of the coast, the rising sea floor causes friction that slows the waves down.

Waves begin to grow
As they slow down, the wavelengths begin to shorten, causing the tsunami to grow to a height of approximately 30m (100ft).

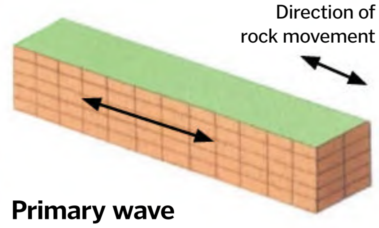
Early warning
A tsunami's trough, the low point beneath the wave's crest, often reaches shore first, producing a vacuum effect that sucks coastal water seaward.

The tsunami strikes
A few minutes later, the tsunami's crest will hit the shore followed by a series of more waves, called a wave train.

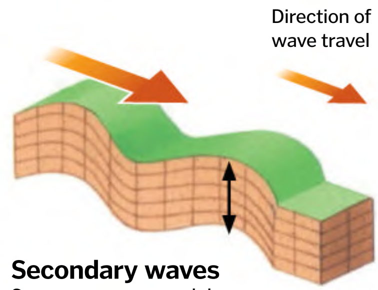


Earthquake waves

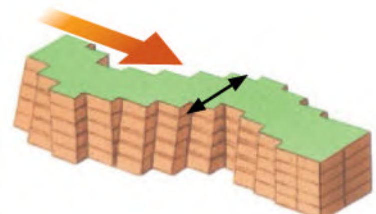
How seismic waves travel through the Earth's crust



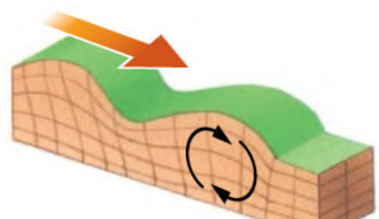
Primary wave
P waves travel back and forth through the Earth's crust, moving the ground in line with the wave. They are the fastest moving of the waves, travelling at about 6-11km/s (3.7-6.8mi/s) , and so typically arrive first with a sudden thud.



Secondary waves
S waves move up and down, perpendicular to the direction of the wave, causing a rolling motion in the Earth's crust. They are slower than P waves, travelling at about 3.4-7.2km/s (2.1-4.5mi/s), and can only move through solid material, not liquid.



Love waves
Unlike P and S waves, surface waves only move along the surface of the Earth and are much slower. Love waves, named after the British seismologist AEH Love, are the faster of the two types and shake the ground side to side, perpendicular to direction of the wave.



Rayleigh waves
Rayleigh waves, named after the British physicist Lord Rayleigh, are surface waves that cause the ground to shake in an elliptical motion. Surface waves arrive last during an earthquake but often cause the most damage to infrastructure due to the intense shaking they cause.

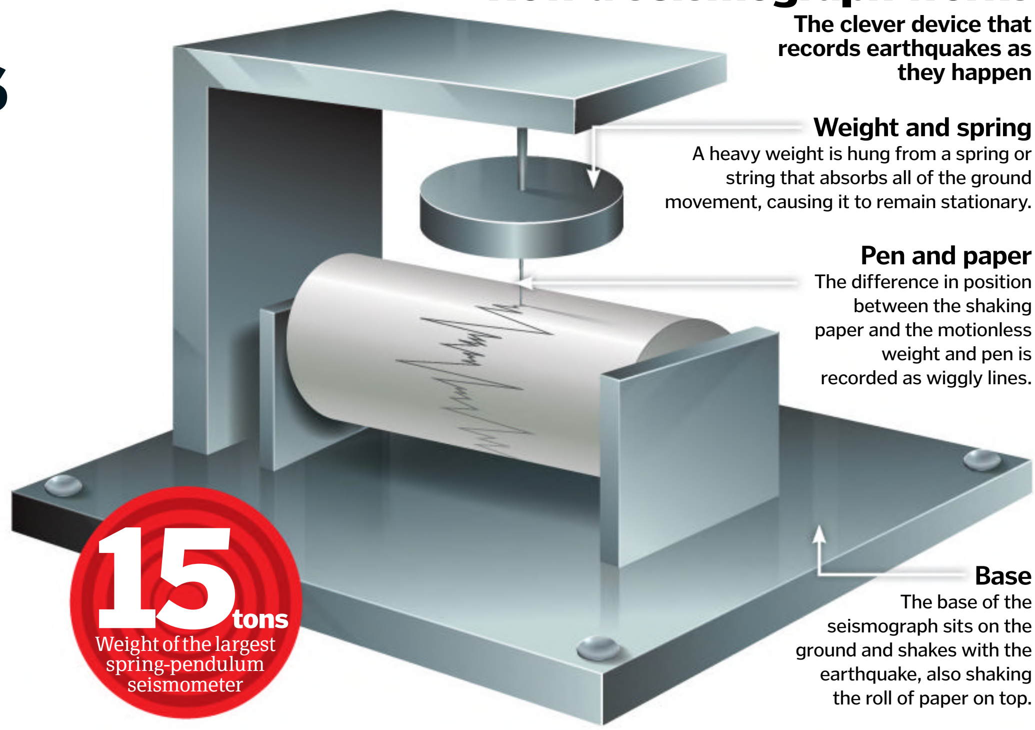
Monitoring earthquakes

Earthquake-recording methods of the past and present

Earthquakes are measured using an instrument called a seismograph, which produces a visual record of tremors in the Earth's crust. This shows the seismic waves of the earthquake as a wiggly line, allowing you to plot the different waves types. The small but fast P waves appear first, followed by the larger but slower S waves and surface waves. The amount of time between the arrival of the P and S waves shows how far away the earthquake was, allowing scientists to work out the exact location of the epicentre. The size of the waves also helps them determine the magnitude or size of the earthquake, which is measured using the Richter Scale.

How a seismograph works

The clever device that records earthquakes as they happen

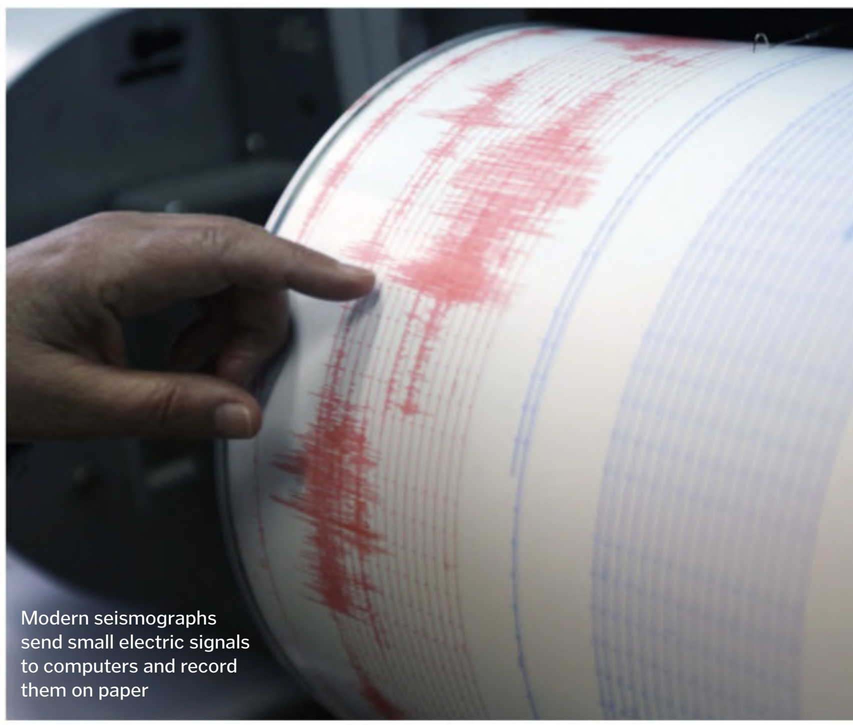


15 tons
Weight of the largest spring-pendulum seismometer

The earliest known seismograph resembled a wine jar and had a diameter of 1.8m (6ft)

The first seismograph

The earliest known seismoscope was invented by Chinese philosopher Chang Hêng in 132. It didn't actually record ground movements, but simply indicated that an earthquake had hit. The cylindrical vessel had eight dragon heads around the top, facing the eight principal directions of the compass, each with an open-mouthed toad underneath it. Inside the mouth of each dragon was a ball that would drop into the mouth of the toad below when an earthquake occurred. The direction of the shaking could be determined by which dragon released its ball. It is not known what was inside the vessel, but it is thought that some kind of pendulum was used to sense the earthquake and activate the ball in the dragon's mouth. The instrument reportedly detected a 650-kilometre (373-mile)-distant earthquake which was not felt by people at the location of the seismoscope.



Modern seismographs send small electric signals to computers and record them on paper

The Richter Scale

Measuring the magnitude of earthquakes using US seismologist Charles F Richter's system

0-2.9
There are more than 1 million micro earthquakes a year but they are not felt by people.

3.0-3.9
Minor earthquakes are felt by many people but cause no damage – there are as many as 100,000 of these a year.

4.0-4.9
Felt by all, light earthquakes occur up to 15,000 times a year and cause minor breakages.

5.0-5.9
A moderate earthquake causes some damage to weak structures. There are around 1,000 of them a year.

Laser beams are used to detect small movements of the ground in Parkfield, California

With a little bit of warning, people can hide under tables and desks to protect them from falling debris in an earthquake

Predicting earthquakes

Modern methods that could help us plot future seismic activity

Currently, earthquakes cannot be predicted far enough in advance to give people much notice, but there are some early warning systems in place to give people a few seconds or minutes to prepare before the serious shaking starts. When seismometers detect the initial P waves, which don't usually cause much damage, they can estimate the epicentre and magnitude of the earthquake and alert the local population before the more destructive S waves arrive. Depending on their distance from the epicentre, people should then have just enough time to take cover, stop transport and shut down industrial systems in order to reduce the number of casualties.

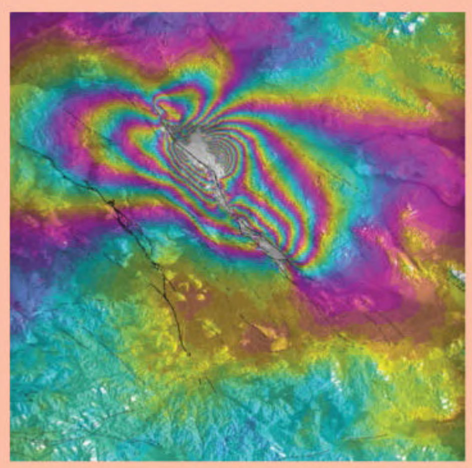
Scientists are also enlisting the help of the general public to help them develop early warning systems. The Quake-Catcher Network (QCN) is a worldwide initiative supplying people with low-cost motion sensors that they can fasten to the floor in their home or workplace. These sensors are then connected to their computer and send real-time data about seismic activity to the QCN's servers, with the hope that earthquake warnings can be issued when strong motions are detected in any of these.

To be able to predict earthquake further in advance, a characteristic pattern or change that precedes each earthquake needs to be identified. One suggestion is that increased levels of radon gas escape from the Earth's crust before a quake, however this can also occur without being followed by seismic activity, so does not provide conclusive evidence of a earthquake.

Scientists are even trying to determine whether animals can predict earthquakes better than we can, but no widespread unusual behaviour has been linked to earthquakes. Other potential earthquake-predicting methods are being tested in Parkfield, California along the San Andreas fault. Among other things, scientists are using lasers to detect the movement of the Earth's crust, sensors to monitor groundwater levels in wells, and a magnetometer to measure changes in the Earth's magnetic field, all with the hope that this will allow them to predict the next big quake.

Radar mapping

One of the more recent developments in earthquake monitoring is interferometric synthetic aperture radar (InSAR). Satellites, or specially adapted planes, send and receive radar waves to gather information about the features of the Earth. The reflected radar signal of a fault line is recorded multiple times to produce radar images, which are then combined to produce a colourful interferogram (below). Each colour shows the amount of ground displacement that has occurred between the capturing of each image, mapping the slow warping of the ground surface that leads to earthquakes. This technique is sensitive enough to detect even tiny ground movements, allowing scientists to monitor fault lines in more detail and detect points where immense pressure is building up. It is hoped that this data will eventually enable scientists to tell when this pressure has reached a hazardous level, leading to more reliable earthquake predictions that give the public days or even weeks to prepare.



6.0-6.9

Over 100 strong earthquakes happen each year, causing moderate damage in populated areas.

7.0-7.9

A loss of life and serious damage over large areas are the result of major earthquakes that happen around ten times a year.

8.0 & higher

There are fewer than three earthquakes classed as 'great' each year, but they cause severe destruction and loss of life over large areas.

Cave creation

How do huge parts of the Earth get hollowed out?

Caves can form anywhere, from in the surface of the Earth, to inside mountains, or even underwater. In fact, any rock has the potential to turn into a cave because they're created by erosion, which can happen in multiple ways.

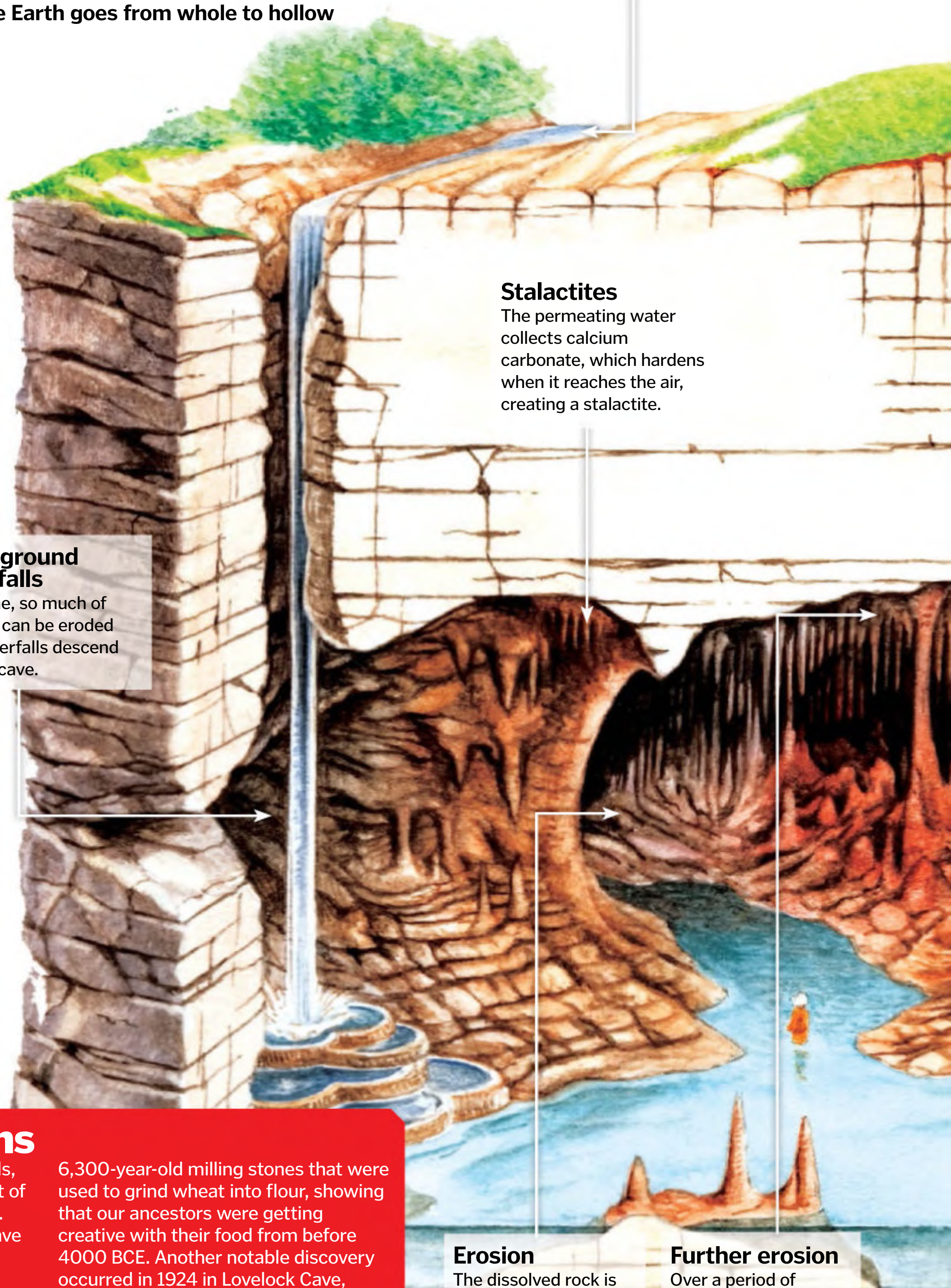
The most common kind of cave is called a solution cave. These tend to be made of rocks such as limestone or gypsum, as they dissolve faster in water than other kinds of rock. Water falling as rain collects carbon dioxide from the atmosphere before descending through the ground. The carbon dioxide mixed with rainwater can form carbonic acid, which is a key ingredient in dissolving the rock, especially in places where there is an existing fissure. Further erosion and collapse transforms these cracks into networks of tunnels and caves. The water will either stay in the base of the cave once it reaches rock that it can't dissolve, or flows out through a hole to begin the whole process again.

Some of the most incredible formations in cave structures are stalactites and stalagmites. Stalactites are the pointy shards that descend from the roof of a cave. These are created when the dripping rainwater collects calcium carbonate on its way through the rock. Once it reaches the open space the calcium carbonate solidifies. This builds up as water drips along the stalactite before hardening. Stalagmites are made of calcium carbonate too, but build from the base of the cave upward if the water has dripped down before becoming solid.

Underwater and overground caves are formed in similar ways. Rock is repeatedly attacked by a force of nature, such as ocean tides, winds or sand. This bombardment wears away at the rock, creating a dent that gets steadily bigger until a cave is formed.

Inside a cave

How the Earth goes from whole to hollow



Cave revelations

As well as being natural marvels, caves can tell us a whole host of things about life in the past. Archaeologists in China have unearthed evidence of humans making fire in caves as far back as 400,000 years ago. Meanwhile, the Cowboy Caves of Utah revealed 6,300-year-old milling stones that were used to grind wheat into flour, showing that our ancestors were getting creative with their food from before 4000 BCE. Another notable discovery occurred in 1924 in Lovelock Cave, Nevada. Among the 10,000 items found were 'duck decoys' – devices used to lure ducks toward hunters who would catch them for food!

STRANGE BUT TRUE
MODERN CAVEMAN

What is inside a Lanzarote lava cave?

A House B Restaurant C Bouncy castle

Answer:
César Manrique, Lanzarote's most famous artist, lived inside a system of volcanic bubbles that were formed by a 1730 volcanic eruption. It was his studio for 24 years before housing the César Manrique Foundation, an organisation that aims to promote the arts.

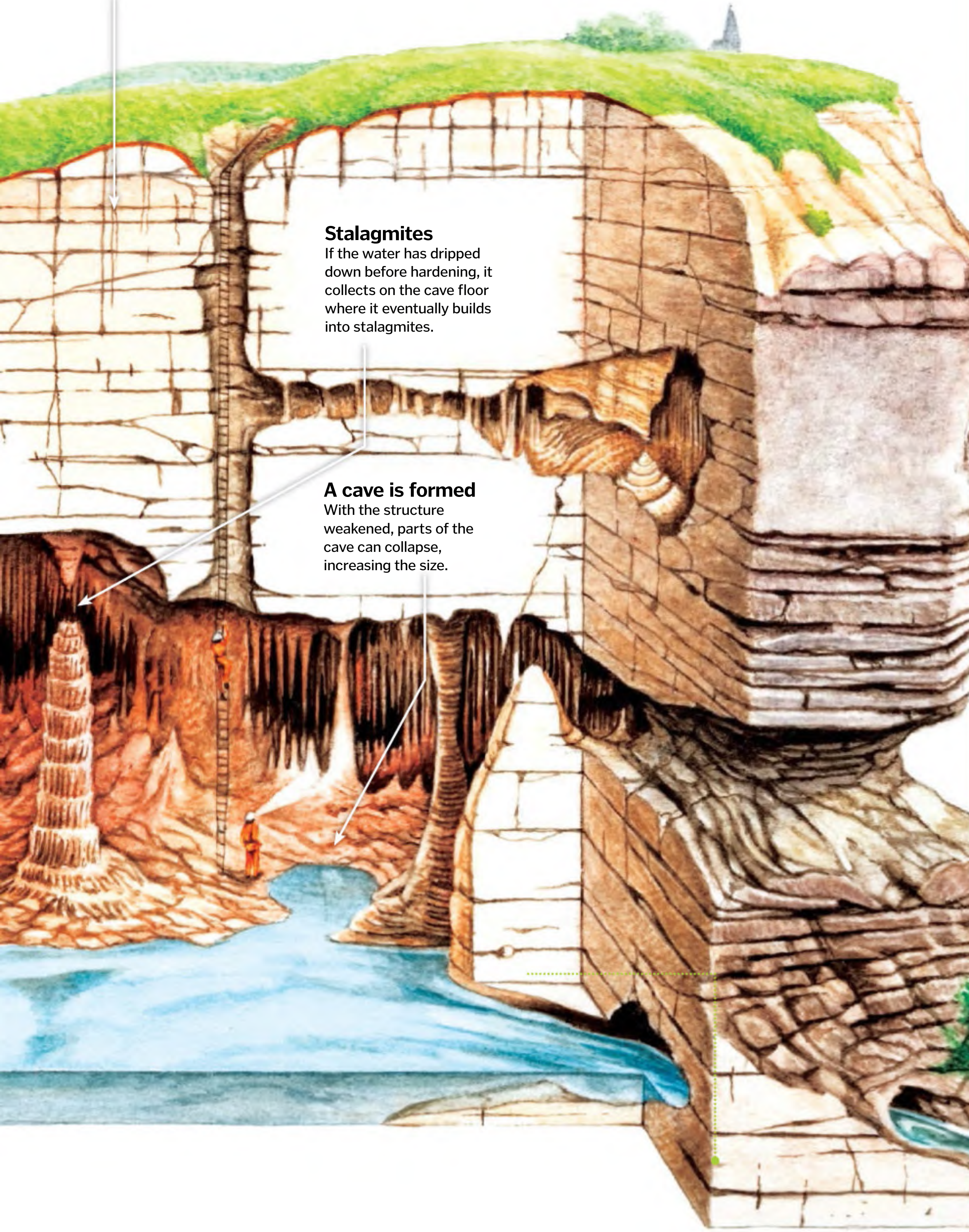
DID YOU KNOW? *Cavemen rarely lived in caves. They used them for shelter but built huts out of wood, mud and animal skins*

"Some of the most incredible formations in cave structures are stalactites and stalagmites"

Rocks
Most caves are made from rocks such as limestone that are easily dissolved.

Stalagmites
If the water has dripped down before hardening, it collects on the cave floor where it eventually builds into stalagmites.

A cave is formed
With the structure weakened, parts of the cave can collapse, increasing the size.



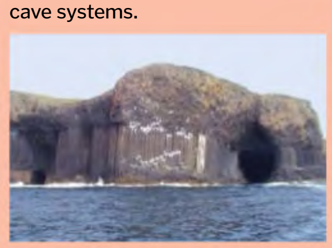
Four main types of cave

Solution cave
This is the most common kind of cave in the world. Formed from water moving through carbonate or sulphate rock, these types of cave grow to form some of the largest caverns on Earth.

Lava cave
Created when lava is flowing along a path and part of it cools and hardens. This leaves the still-molten lava inside to continue flowing, ultimately resulting in hollow lava tubes.

Glacier cave
The most common cause is melt water running through, or under, the glacier. This widens crevices and carves out chutes, which will then increase in size during the summer months.

Sea cave
Underwater and coastal rocks are constantly battered by waves. This action erodes the weaker parts of the rock. Some of these get flooded and become underwater cave systems.



Mountain formation

The Himalayas are home to the world's highest peaks

© NASA

How many ways can you make a mountain?

Mountains are massive landforms rising high above the Earth's surface, caused by one or more geological processes: plate tectonics, volcanic activity and/or erosion. Generally they fall into one of five categories – fold, fault-block, dome, volcanic and plateau – although there can be some overlap.

Mountains comprise about 25 per cent of our land mass, with Asia having more than 60 per cent of them. They are home to 12 per cent of the Earth's population, and they don't just provide beauty and

ON THE MAP

10 major mountain ranges

1. Ural Mountains
TYPE: Fold mountain range in Russia and Kazakhstan

2. Altai Mountains
TYPE: Fault-block mountain range in Central Asia

3. Tian Shan
TYPE: Fault-block mountain range in Central Asia

4. Sumatra-Java range
TYPE: Discontinuous mountain range system containing active volcanoes, ranging the length of Sumatra (the Barisan Mountains) and Java

5. Serra do Mar
TYPE: Discontinuous mountain range system on east coast of Brazil, fault-block formation

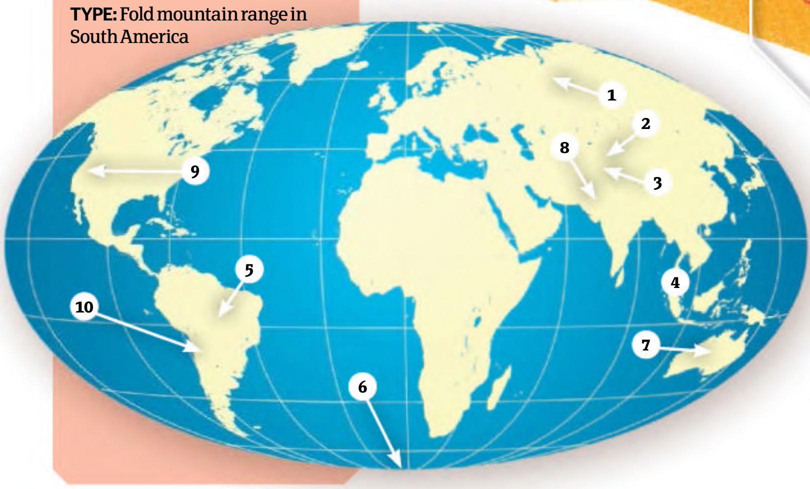
6. Transantarctic Mountains
TYPE: Fault-block mountain chain that serves as a division between East and West Antarctica

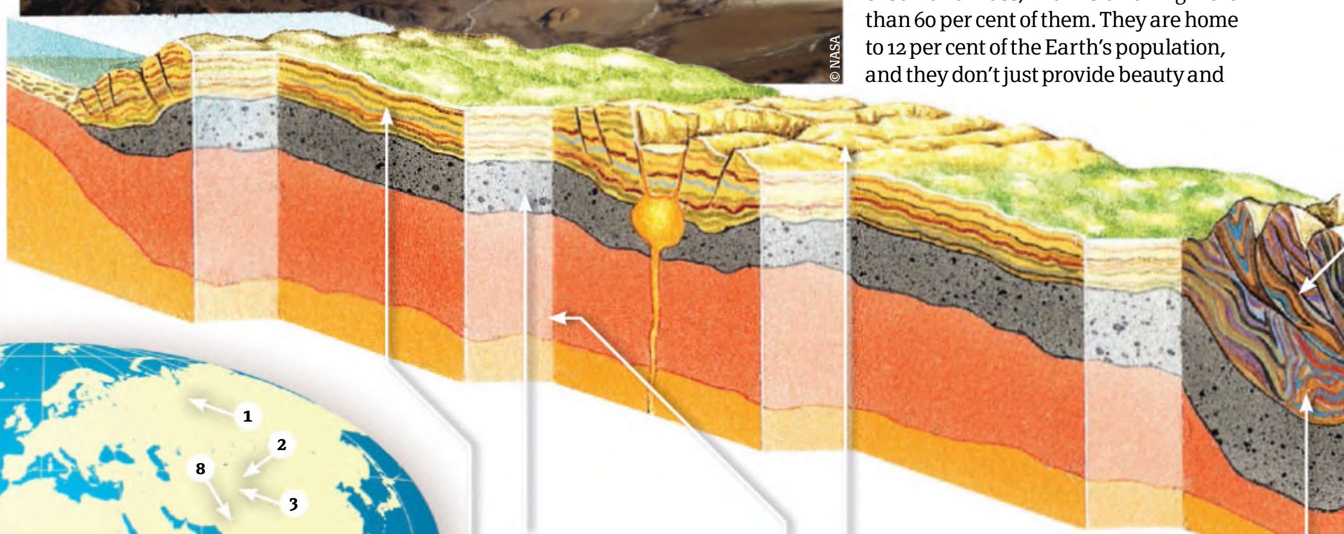
7. Eastern Highlands
TYPE: Discontinuous fold mountain range system dominating eastern Australia

8. Himalayas
TYPE: Fold mountain range system in Asia between India and the Tibetan Plateau

9. Rocky Mountains
TYPE: Fold mountain range in western North America

10. Andes
TYPE: Fold mountain range in South America





THE STATS MOUNTAIN RANGES

TALLEST: MOUNT EVEREST **8,848m**

SHORTEST: MOUNT WYCHEPROOF (AUSTRALIA) **43m (141ft)**

OLDEST RANGE: BARBERTON GREENSTONE BELT (SA) **3.5bn yrs**

YOUNGEST MOUNTAIN RANGE: HIMALAYAS **60-80m yrs**

DID YOU KNOW? *There is no universal definition of a mountain. For some it means a peak over 300m (984ft) above sea level*

recreation; more than half of the people on Earth rely on the fresh water that flows from the mountains to feed streams and rivers. Mountains are also incredibly biodiverse, with unique layers of ecosystems depending on their elevation and climate.

One of the most amazing things about mountains is that although they look solid and immovable to us, they're always changing. Mountains rising from activity associated with plate tectonics – fold and fault-block – form slowly over millions of years. The plates and rocks that initially interacted to form the mountains continue to move up to 2cm (0.8in) each year, meaning that the mountains grow. The Himalayas grow about 1cm (0.4in) per year.

The volcanic activity that builds mountains can wax and wane over time. Mount Fuji, the tallest mountain in Japan, has erupted 16 times since 781AD. Mount Pinatubo in the Philippines erupted in the early-Nineties without any prior recorded eruptions, producing the second largest volcanic eruption of the 20th century. Inactive volcanic mountains – and all other types of mountains, for that matter – are also subject to erosion, earthquakes and other activity that can dramatically alter their appearances as well as the landscape around us. There are even classifications for the different types of mountain peaks that have been affected by glacial periods in Earth's history. The bare, near-vertical mountaintop of the Matterhorn in the Alps, for example, is known as a pyramidal peak, or horn.

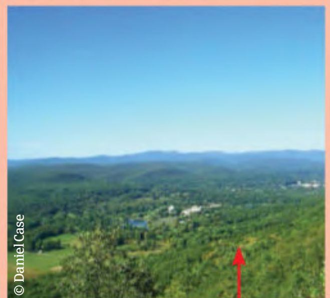
Types of mountain

Fold

This most common type of mountain is formed when two tectonic plates smash into each other. The edges buckle and crumble, giving rise to long mountain chains.
Examples: Mount Everest, Aconcagua

Volcanic

These mountains are created by the buildup of lava, rock, ash and other volcanic matter during a magma eruption.
Examples: Mount Fuji, Mount Kilimanjaro



© Daniel Case

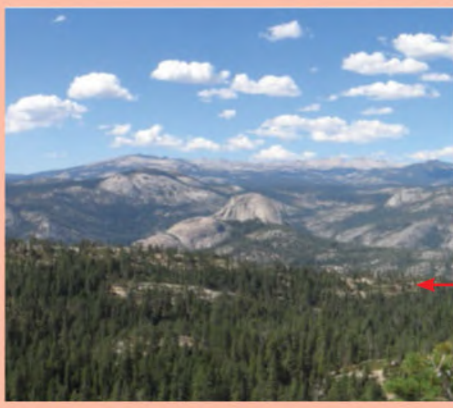
Dome

These types of mountain also form from magma. Unlike with volcanoes, however, there is no eruption; the magma simply pushes up sedimentary layers of the Earth's crust and forms a round dome-shaped mountain.
Examples: Navajo Mountain, Ozark Dome

© NASA

Plateau

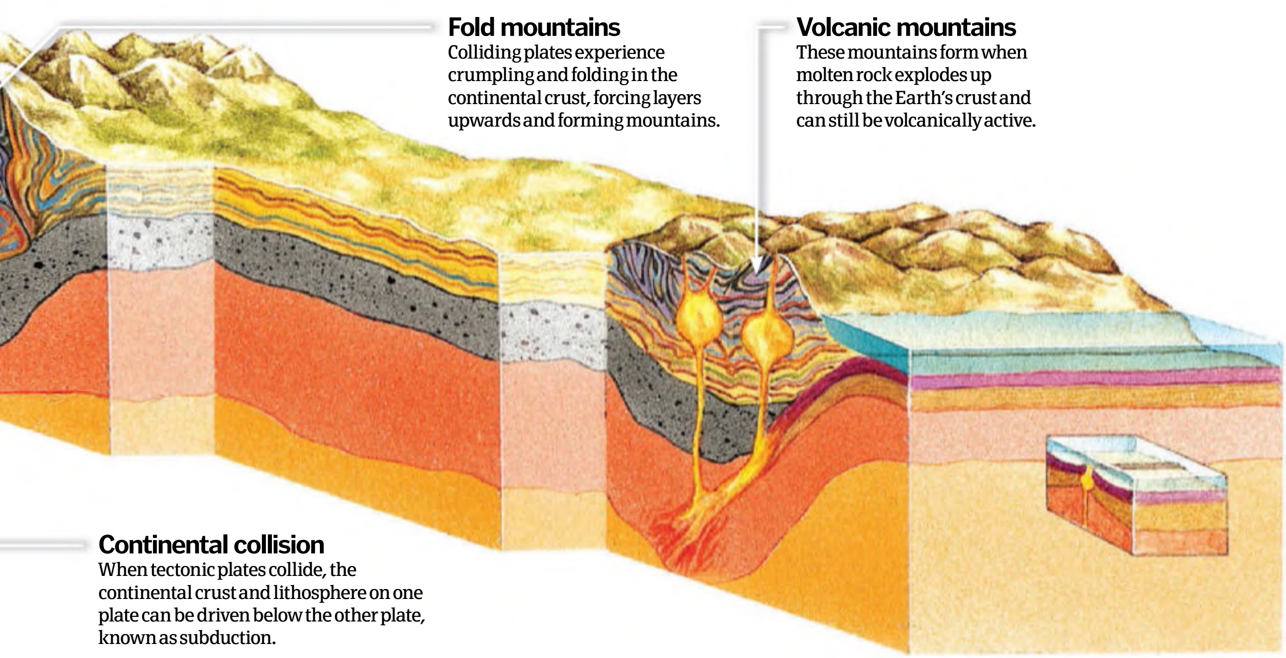
Plateau mountains are revealed through erosion of uplifted plateaux. This is known as dissection.
Examples: Catskill Mountains, Blue Mountains



Fault-block

Fault-block mountains form when cracked layers of crust slide against each other along faults in the Earth's crust. They can be lifted, with two steep sides; or lifted, with one gently sloping side and one steep side. **Examples:** Sierra Nevada, Urals

Mountains made from below



Fold mountains
Colliding plates experience crumpling and folding in the continental crust, forcing layers upwards and forming mountains.

Volcanic mountains
These mountains form when molten rock explodes up through the Earth's crust and can still be volcanically active.

Continental collision
When tectonic plates collide, the continental crust and lithosphere on one plate can be driven below the other plate, known as subduction.

© DK Images

Mountains are home to 12 per cent of the world's population

The Grand Prismatic Spring

What makes it so hot and why is it so colourful?

Yellowstone Park, Wyoming, became the world's first national park when President Ulysses S Grant signed it into law in 1872. It's not hard to see why the government wanted to preserve this area of great natural beauty, especially with features like this: the world's third-largest hot spring.

The Grand Prismatic Spring is Yellowstone's largest at 90 metres (295 feet) wide and 50 metres (164 feet) deep, and works like many of the park's hydrothermal features. Water deep beneath the ground is heated by magma and rises to the surface unhindered by mineral deposits. As it bubbles to the top it cools and then sinks, only to be replaced by hotter water coming from the depths in a continuous cycle. The hot water also dissolves some of the silica in the rhyolite rocks in the ground, creating a solution that's deposited as a whitish siliceous sinter onto the immediate land surrounding the spring.

So what makes all the pretty colours? That's not due to chemicals, anyway. The iridescent pigments are caused by bands of microbes – cyanobacteria – that thrive in these warm to hot waters. Moving from the coolest edge of the spring along the temperature gradient, the calothrix cyanobacteria lives in temperatures of no less than 30 degrees Celsius (86 degrees Fahrenheit), can live out of the water too and produces the brown pigment that frames the spring. Phormidium, meanwhile, prefers a 45-60-degree-Celsius (113-140-degree-Fahrenheit) range and creates the orange pigment, while synechococcus enjoys temperatures of up to 72 degrees Celsius (162 degrees Fahrenheit) and is yellow-green. The deep blue colour seen in the centre is the natural colour of the water and is too hot for most bacteria, although it's suspected that aquifex, a microbe that thrives in near-boiling water, lives off the hydrogen gas dissolved in the emerging Grand Prismatic Spring's waters.

In terms of size, the Grand Prismatic Spring is only beaten by the Frying Pan Lake (New Zealand) and the Boiling Lake (Dominica)

© Milla Zinkova

Can I drink it?

No. While there's no problem with the water itself, the cyanobacteria that give the Grand Prismatic Spring its characteristic colouration can cause all sorts of problems if ingested. They produce a range of dangerous compounds including neuro- and hepatotoxins that cause vomiting, rashes, numbness and worse: long-term liver damage, nervous disorders and even cancer. This isn't exclusive to humans; cyanobacteria are a common sight all over the world and, where they bloom in prolific numbers, they pose a serious threat to local ecosystems. That's one reason why the area immediately surrounding the spring is so barren.

Who opened the Door to Hell?

We take a look at a gas crater in Turkmenistan which has been burning nonstop since 1971

The Derweze natural gas crater is a basin 70 metres (230 feet) across located in the middle of the Karakum Desert in Turkmenistan. The crater, which was created when a natural gas drilling rig and camp collapsed in 1971, is informally referred to by the local people as the 'Door to Hell'.

The flames were instigated when a Soviet Union drilling team decided that, after their rig collapsed, the best way to deal with the large amount of methane gas spilling out into the environment was to burn it off. Geologists at the time predicted that the methane would combust within days, but four decades later the natural gas continues to blaze, lighting up the surrounding region for miles.

The Door to Hell is something of a tourist attraction, with travellers flocking to the nearby village of Derweze – which has a population of only around 350 people – from all over the world. Typically tour groups venture to the site in the evening, as the crater's fiery glow is more dramatic in the low light of dusk than during the day, as shown here.


Russia
Derweze Crater
Iran

Located in Honshu, Japan, Mount Zao's crater lake is sometimes called Five Colour Pond as it changes hues according to the weather

How do crater lakes form?

Dive in to the geology behind these bodies of water with an explosive past

When you look out across a mountain lake it can be easy to think it was always so serene, but this couldn't be further from the truth. From the shifting of Earth's tectonic plates to glaciers gouging out the land, the majority of these tranquil sites are the result of epic geological events.

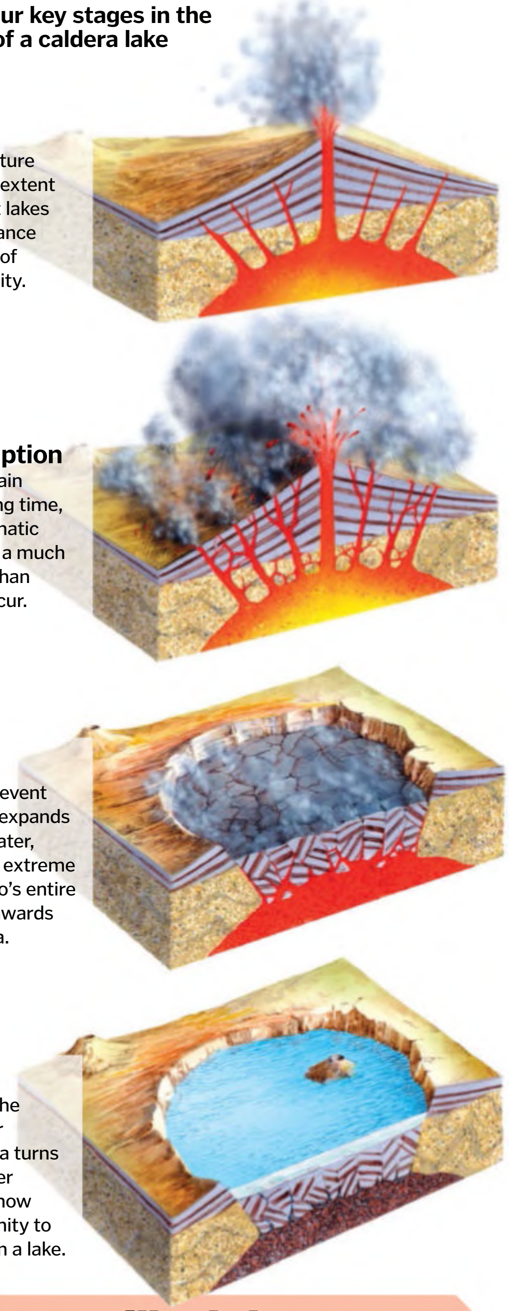
Crater lakes have perhaps the most epic beginnings of them all. While maar lakes are also the result of volcanism, forming in the fissures left behind by ejected magma, they are generally shallow bodies of water; Devil Mountain Maar in Alaska is the deepest at just 200 metres (660 feet). In terms of scale, maars aren't a patch on their bigger cousins.

Crater lakes have very violent origins. During a mega-eruption, or series of eruptions, the terrain becomes superhot and highly unstable. In some cases the volcanic activity is so intense that once all the ash and smoke clears, the cone is revealed to have vanished altogether, having collapsed in on itself. This leaves a massive depression on the top of the volcano known as a caldera.

In the period of dormancy that follows, rain and snow gather in this basin, generally over several centuries, to create a deep body of water; Crater Lake in Oregon is the deepest of any lake in the USA, plunging to 592 metres (1,943 feet). Over time a caldera lake will reach a perpetual level that's maintained by a balance of regional precipitation and annual evaporation/seepage.

Crater lake in the making

We pick out four key stages in the development of a caldera lake



1. Volcano
All volcanoes feature a crater to some extent at their peak, but lakes rarely get the chance to form because of geothermal activity.

2. Mega-eruption
If a volcano has lain dormant for a long time, or if there is dramatic tectonic activity, a much bigger eruption than normal might occur.

3. Collapse
Such a climactic event at the very least expands the size of the crater, however in more extreme cases the volcano's entire cone collapses inwards to leave a caldera.

4. Lake
Over centuries, the magma chamber below the caldera turns solid. In the cooler basin, rain and snow have an opportunity to build up and form a lake.

ON THE MAP

Record-breaking lakes

1. Highest navigable lake: Titicaca, Peru/Bolivia
2. Deepest: Baikal, Russia
3. Biggest lake group: Great Lakes, USA
4. Largest crater lake: Toba, Indonesia
5. Lowest: Dead Sea, Israel/Jordan
6. Most northerly: Kaffeklubben Sø, Greenland

Some like it hot...

Volcanic activity can continue to simmer under the crater, which affects the chemistry of the lake. A lack of productivity often means the water is very clear, hence why jewel-like greens and blues are common. This doesn't mean crater lakes are barren though. Some are a lot more hospitable than others, supporting insects, fish, right through to apex predators. But even ones spewing out deadly gases and minerals can still support ecosystems. For instance, the water of hyper-alkaline (pH 11) Laguna Diamante in the Andes contains arsenic and is five times saltier than seawater, but a research team in 2010 found 'mats of microbes' living on the lake bed, which served as food for a colony of flamingos.

Geode geology

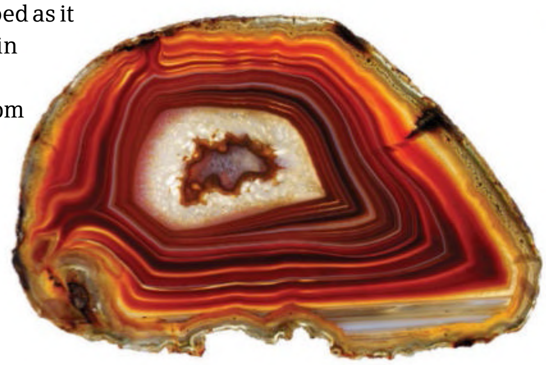
They may look unassuming on the outside, but these rocks are hiding treasure within…

Geodes are the perfect embodiment of the expression: it's what's on the inside that counts. Although there's some dispute over the finer details of how these crystalline structures develop, there are currently two environments known to support them: sedimentary rock (such as limestone) and volcanic rock (such as basalt).

For both, the process starts with a hole within the rock, but where this cavity comes from differs. In igneous rock, gas bubbles in the magma become trapped as it turns to stone. While in sedimentary rock the cavity might result from concretions (accumulations of hard minerals) disintegrating, or even organic matter rotting away to leave a void.

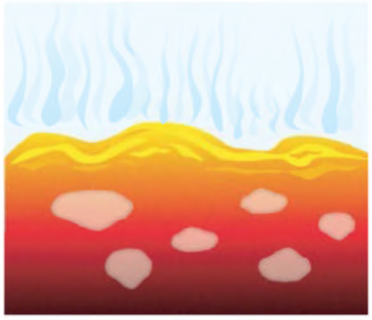
Groundwater containing tiny traces of minerals passes through the rock, including through this hollow, and over millennia a layer of gel-like silica is left lining the cavity, which then hardens into a solid shell of quartz-based chalcedony as it dries out.

Over time, more and more water permeates the cavity and all manner of minerals – like agate, amethyst and jasper – precipitate out, forming inwardly pointing crystals. If the hole becomes completely filled, it's no longer called a geode but a nodule.

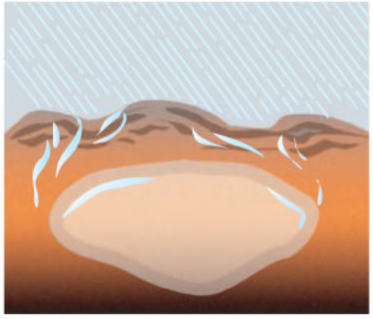


Volcanic geode formation

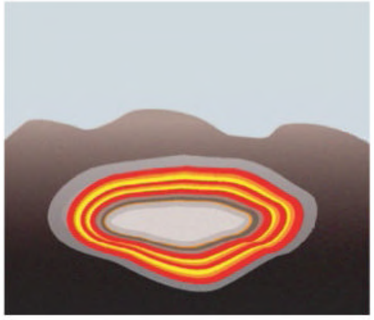
See how one of these colourful crystal structures develops over many years



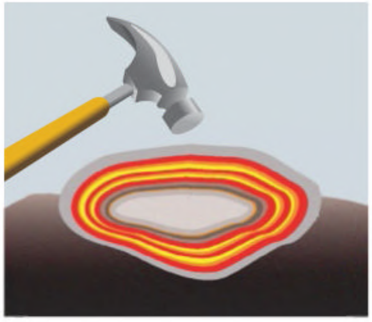
1. Bubble
Volcanoes and tectonic activity push magma towards Earth's surface. As the lava solidifies into sheets of igneous rock like basalt, gaseous bubbles are trapped, leaving variously sized cavities.



2. Mineral-rich water
Groundwater seeps through the rock, absorbing minerals like silicates as it goes. As it passes through the hollow, it deposits tiny traces on the sides that build up to form a layer of chalcedony.



3. Layer by layer
This process repeats, precipitating new crystals, which can vary greatly in type, size and colour, depending on impurities as well as regional geological conditions like temperature and pressure.



4. Exposure
Whether a result of weathering or more dramatic tectonic activity, the rock layer can break up, exposing the geodes within. Gem collectors look out for their telltale egg-like shape and then break them open.

How amber develops

Learn how this beautiful gemstone forms, sometimes freezing tiny critters in time

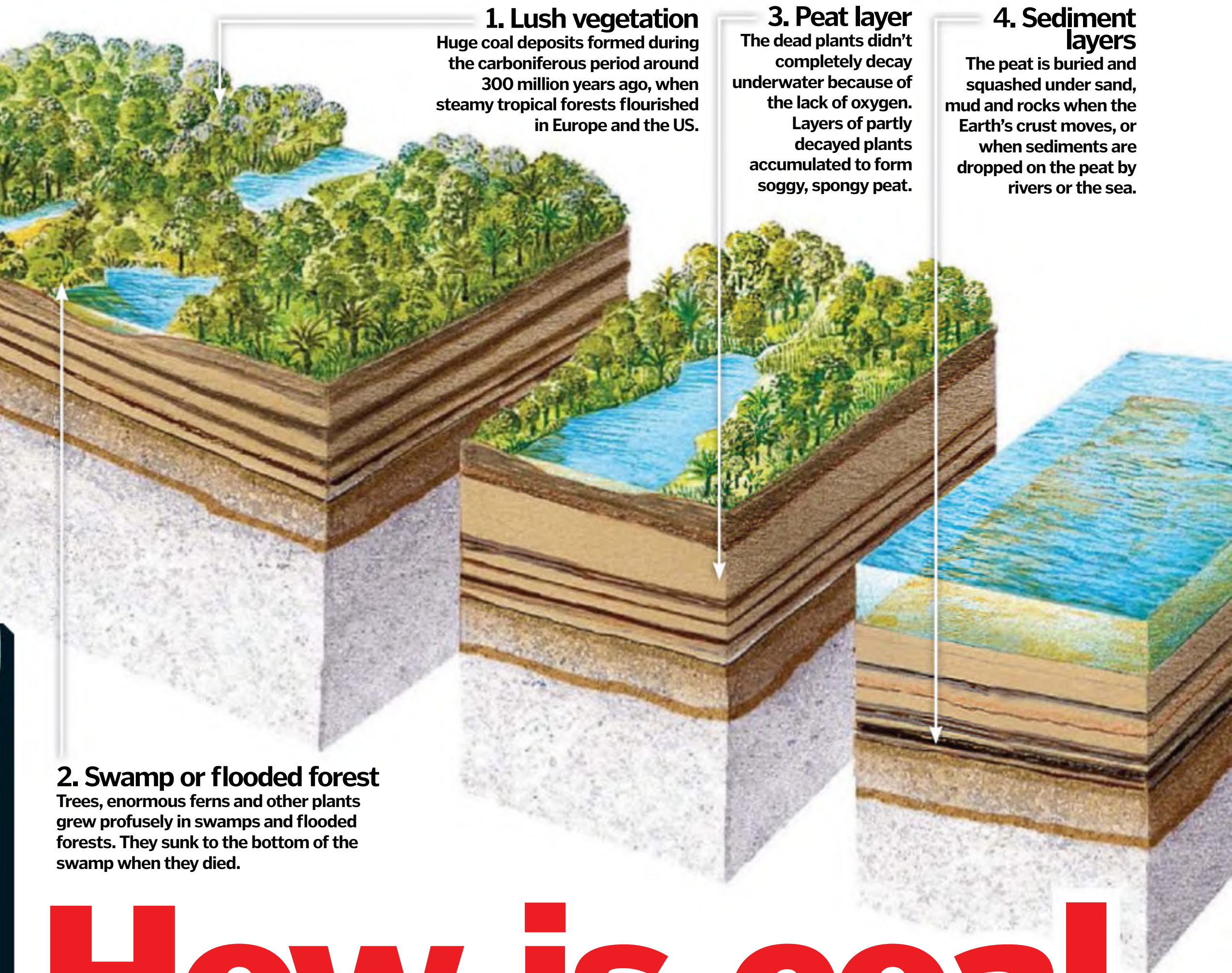
Amber is tree resin that fossilises over millions of years. During the process, the resin loses many of its volatile properties and – placed under intense pressure and temperatures – transforms into a solid, orange-coloured gemstone.

As tree resin starts off in a sticky, viscous state, today many amber deposits feature ancient life forms, like insects and reptiles, or plant foliage – most dating between 30-60 million years old. These organic inclusions are highly prized, both by palaeontologists and jewellers.

Currently, the oldest discovered amber dates from the Upper Carboniferous period, roughly 320 million years ago. This age is rare though – most resin extracted dates from the Early Cretaceous or later. Most amber found today is thought to stem from the Sciadopityaceae family of conifer trees that were once prolific throughout Europe.

How is coal formed?

Discover how your laptop is powered by plants that died before the dinosaurs



Essential to modern life, around 40 per cent of the world's electricity comes from burning coal. The substance is also used to make liquid fuel, plastics, concrete and even domestic products such as head lice shampoo.

You might expect coal to be a high-tech material, because it has many sophisticated applications. But coal is simply a rock made from fossilised plants that died in swamps up to 100 million years before the first dinosaurs. Prehistoric plants captured energy from the Sun during their lives and locked it up as carbon in coal. We burn coal in power stations to release this ancient solar energy. This is why coal is sometimes called 'buried sunshine'.

Coal is mainly carbon and water. Carbon-rich coals contain little water and release lots of energy when burned. Low-carbon coals spent less time buried underground and contain more water and impurities. Coal 'rank' or quality depends on water and carbon content. There are four ranks: lignite, sub-bituminous, bituminous and anthracite. Up to ten per cent of a coal's weight comprises of a yellowish chemical, sulphur. Modern power stations stop sulphur reaching the atmosphere because it causes damaging acid rain.

All the fossil fuels we burn – coal, oil and gas – are the carbon-rich remains of prehistoric organisms. We describe fossil fuels as 'non-renewable' because these ancient stores of energy take millions of years to replenish once used. Rapidly releasing carbon from storage also pollutes the atmosphere. A byproduct of burning coal is carbon dioxide gas, a major cause of global warming.

When will Earth's coal run out?

No one knows exactly when we'll run out of coal, but its use has skyrocketed during the last 200 years. We used a whopping 6.8 billion tons – that's the approximate weight of 4 billion cars – in 2009 alone. Around 860 billion tons of coal remains unmined and major coal producers estimate supplies will last around 130 years at current rates.

Despite this estimate we can't be sure that coal won't run out sooner, as the world's remaining coal may turn out to be hard to reach or bad quality. Worse still, we're uncertain how much coal is buried. India, for example, overestimated its coal reserves by 36 billion tons in 2003. Alternatively, we may develop better sources of energy, stop using coal and never run out.

5 TOP FACTS
USES OF COAL TODAY

Electricity
1 Coal-fired power stations generate 40% of global electricity. Heat from burning coal boils water, and steam spins a propeller. A machine turns this into electricity.

Iron and steel
2 About 70% of steel is created using coke, a high-carbon fuel made from coal. It is burned to melt and remove impurities from iron ore during iron and steel production.

Shampoo
3 The dandruff and head lice-zapping power of some shampoos is thanks to coal tar, a thick, dark-coloured liquid produced when coal is turned into coke or coal gas fuel.

Plant fertiliser
4 Coal can be turned into ammonia fertiliser by breaking it into carbon monoxide and hydrogen gas. The hydrogen mixes with nitrogen to make ammonia.

Concrete
5 Concrete is a building material made with cement. Coal is burned to make heat for cement production. Waste ash from coal-fired power stations can replace cement in concrete.

DID YOU KNOW? *Around 3% of the Earth is covered with peat, which may become coal millions of years in the future*

Coal formation

© Thinkstock

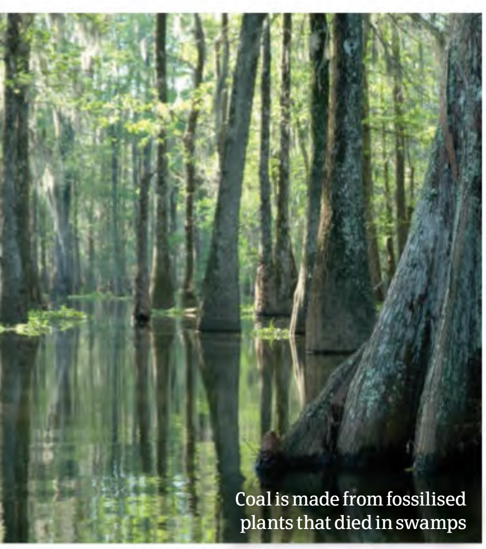
The plants that formed coal died long before dinosaurs roamed the Earth

© Science Photo Library

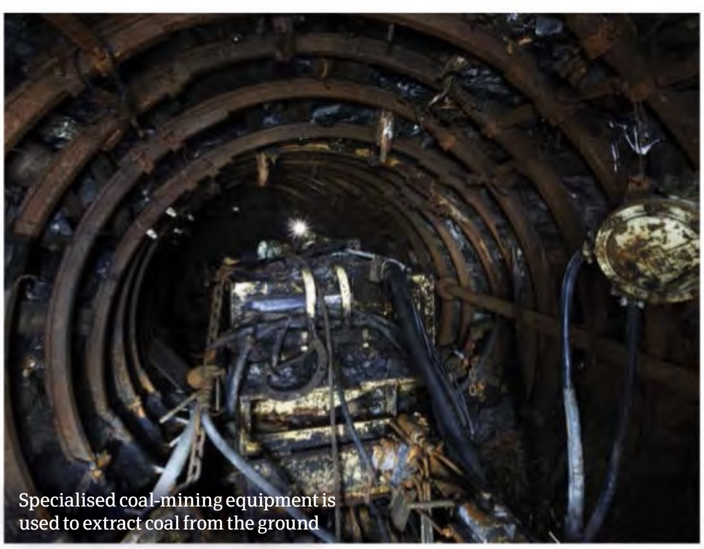
5. Lignite
The peat is crushed and water is squeezed out by the weight of overlying sediments. Eventually, heat and pressure underground turns the peat into a soft, brown coal called lignite.

6. Bituminous and anthracite coal
Continued heat and pressure turn lignite into soft, black bituminous coal and hard, lustrous anthracite. These coals are richer in carbon than lignite because impurities and water are squeezed out.

7. Open-pit coal mine
Millions of years after plants died in the swamp, humans dig coal from the ground. Coal is dug from an open pit when it's found near the surface.



Coal is made from fossilised plants that died in swamps



Specialised coal-mining equipment is used to extract coal from the ground

© Thinkstock

Wind turbines produce electricity

Energy for the future

We can't power our civilisation with ancient plants forever. In the future, we'll harness energy sources that don't run out in human lifetimes. An example is capturing the Sun's vast energy with light-gathering solar panels. Covering one per cent of the Sahara Desert with panels could generate enough energy to power the world.

Solar energy fuels the Earth's water cycle, which keeps rivers rushing downhill. This fast-moving water can spin propellers and generate electricity. Tide and bobbing wave movements can also drive electricity generators. Movements of the Moon, Sun and Earth cause tides and won't stop anytime soon.

Wind turbines are a familiar sight on breezy hills and huge turbine farms can also be built out at sea. The wind spins the turbine blades to generate electricity. Another energy source is the Earth's core, which is as hot as the Sun's surface. This heat can warm homes or generate electricity.

Coal will be replaced by solar panels in the future

© Thinkstock

What are fossils?

Obliterating the traditional perception of the origins and evolution of life on Earth, fossils grant us unique snapshots of what once lived on our ever-changing planet

5 TOP FACTS
FOSSILS

4.4
1 The oldest hominid specimen to be uncovered is Ardi, a fossilised set of skeletal remains that have been dated by scientists as being no less than 4.4 million years old.

Controversy
2 Fossil collecting is a popular hobby. However, important or prominent fossils are often sold to collectors instead of museums, leading to the creation of a black market.

Shell
3 One of the earliest realisations of the nature of fossils came from Ancient Greek polymath Aristotle, who commented that fossil seashells resembled those of living examples.

Climate
4 Fossils allow scientists to deduce information about the Earth's past climate and environment, as the conditions in which they died are specific to these conditions.

DNA
5 Resin fossils are unique in that they often preserve bacteria, fungi and small fragments of DNA. Animal inclusions tend to be small invertebrates such as spiders and insects.

DID YOU KNOW? *Fossils are useful in targeting mineral fuels, indicating the stratigraphic position of coal streams*

Types of fossilisation

Dependent on climate and ground conditions, deceased animals can be fossilised in many ways

Adpression
A form of fossilisation caused by compression within sedimentary rock. This type of fossilisation occurs mainly where fine sediment is deposited frequently, such as along rivers. Many fossilised plants are formed this way.

Resin
Referred to as amber, fossil resin is a natural polymer excreted by trees and plants. As it is sticky and soft when produced, small invertebrates such as insects and spiders are often trapped and sealed within resin, preserving their form.

Bioimmuration
Bioimmuration is a type of fossil that in its formation subsumes another organism, leaving an impression of it within the fossil. This type of fossilisation usually occurs between sessile skeletal organisms, such as oysters.

Permineralisation
A process in which mineral deposits form internal casts of organisms, permineralisation works when an animal dies and then is rapidly submerged with groundwater. The water fills the creature's lungs and empty spaces, before draining away leaving a mineral cast.

Recrystallisation
When a shelled creature's shell, bone or tissue maintains its original form but is replaced with a crystal – such as aragonite and calcite – then it is said to be recrystallised.

Mold
A type of fossilisation process similar to permineralisation, molds occur when an animal is completely dissolved or destroyed, leaving only an organism-shaped hole in the rock. Molds can turn into casts if they are then filled with minerals.

Carbon dating

A crucial tool for palaeontologists, carbon dating allows ancient fossils to be accurately dated

Carbon dating is a method of radioactive dating used by palaeontologists that utilises the radioactive isotope carbon-14 to determine the time since it died and was fossilised. When an organism dies it stops replacing carbon-14, which is present in every carbonaceous organism on Earth, leaving the existing carbon-14 to decay. Carbon-14 has a half-life (the time it takes a decaying object to decrease in radioactivity by 50 per cent) of 5,730 years, so by measuring the decayed levels of carbon-14 in a fossil, its time of death can be extrapolated and its geological age determined.

This scientist is dating archaeological specimens in a Tandetron particle accelerator

The origin of life on Earth is irrevocably trapped in deep time. The epic, fluid and countless beginnings, evolutions and extinctions are immeasurable to humankind; our chronology is fractured, the picture is incomplete. For while the diversity of life on Earth today is awe-inspiring, with animals living within the most extreme environments imaginable – environments we as humans brave every day in a effort to chart and understand where life begins and ends – it is but only a fraction of the total life Earth has seen inhabit it over geological time. Driven by the harsh realities of an ever-changing environment, Armageddon-level extinction events and the perpetual, ever-present force of natural selection, wondrous creatures with five eyes, fierce predators with foot-long fangs and massive creatures twice the size of a double-decker bus have long since ceased to exist. They're forgotten, buried by not just millions, but billions of years. Still, all is not lost. By exploiting Earth's natural processes and modern technology over the last two hundred years, scientists and palaeontologists have begun to unravel Earth's tree of life and, through the discovery and excavation of fossils – preserved remains and traces of past life in Earth's crust – piece the jigsaw back together.

The fossilisation of an animal can occur in a variety of ways (see 'Types of fossilisation' boxout) but, in general, it occurs when a recently deceased creature is rapidly buried by sediment or subsumed in an oxygen-deficient liquid. This has the effect of preserving parts of the creature – usually the harder, solid parts like its skeleton – often in the original, living form within the Earth's crust. The softer parts of fossilised creatures tend not to survive due to the speed of decay and their replacement by minerals contained in their sediment or liquid casing, a process that can leave casings and impressions of the animal that once lived, but not its remains. Importantly, however, creature fossilisation tends to

> *"The softer parts of fossilised creatures tend not to survive due to the rapidity of decay"*

be specific to the environmental conditions in which it lived – and these in themselves are indicative of certain time periods in Earth's geological history. For example, certain species of trilobite (an extinct marine arthropod) are only found in certain rock strata (layers of sedimentary and igneous rocks formed through mineral deposition over millions of years), which itself is identifiable by its materials and mineralogic composition. This allows palaeontologists to extrapolate the environmental conditions (hot, cold, dry, wet, etc) that the animal lived and died in and, in partnership with radiometric dating, assign a date to the fossil and/or the period.

Interestingly, however, by studying the strata and the contained fossils over multiple layers, through a mixture of this form of palaeontology and phylogenetics (the study of evolutionary relationships between organism groups), scientists can chart the evolution of animals over geological time scales. A good example of this process is the now known transition of certain species of dinosaur into birds. Here, by dating and analysing specimens such as archaeopteryx – a famous dinosaur/bird transition fossil – both by strata and by radiometric methods, as well as recording their molecular and morphological data, scientists can then chart its progress through strata layers to the present day. In addition, by following the fossil record in this way, palaeontologists can also attribute the geophysical/chemical changes to the rise, fall or transition of any one animal/plant group, reading the sediment's composition and structural data. For example, the Cretaceous-Tertiary extinction event is identified in sedimentary strata by a sharp decline in species' diversity – notably non-avian dinosaurs – and increased calcium deposits from dead plants and plankton.

Excavating any discovered fossil in order to date and analyse it is a challenging, time-consuming process, which requires special tools and equipment. These include picks and shovels, trowels, whisks, hammers, dental drills and even explosives. There is also an accepted academic method all professional palaeontologists follow when preparing, removing and transporting any discovered fossil. First, the fossil is partially freed from the sedimentary matrix it is encased in and labelled, photographed and reported. Next, the overlying rock (commonly referred to as the 'overburden') is removed using large tools up to a distance of 5-7.5 centimetres (two to three inches) from the fossil, before it is once again photographed. Then, depending on the stability of the fossil, it is coated with a thin glue via brush or aerosol in order to strengthen its structure, before being wrapped in a series of paper, bubble wrap and Hessian cloth. Finally, it is transported to the laboratory.

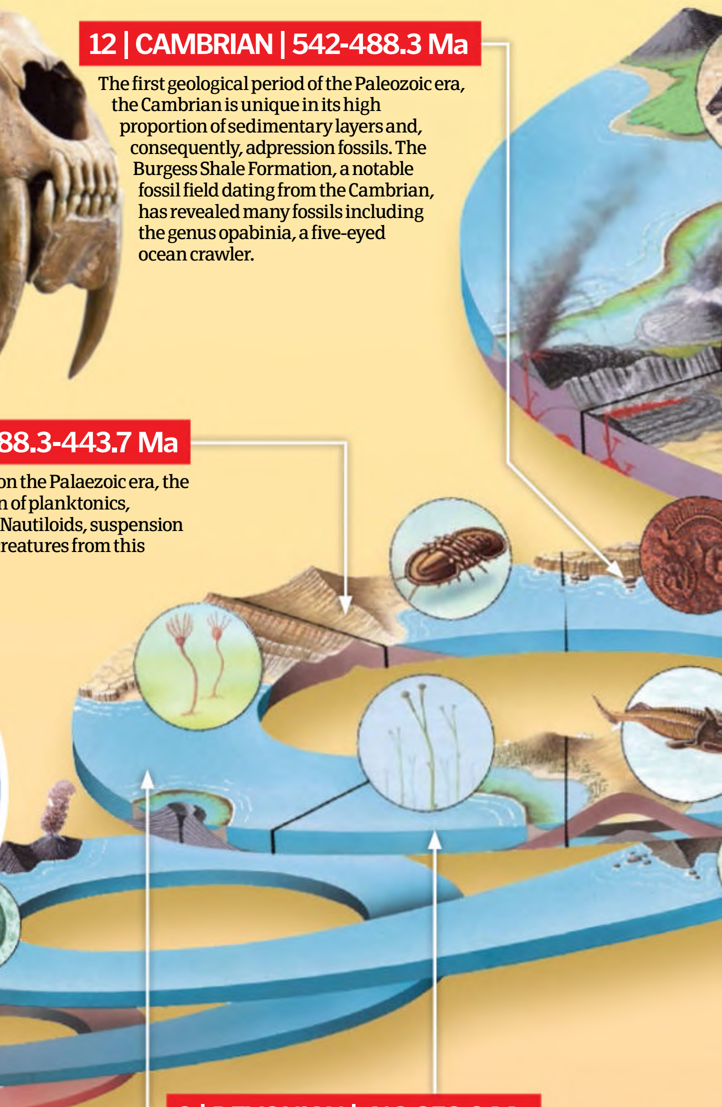

A europasaurus fossil is examined

© Nils Knötschke

THE FOSSIL RECORD

By examining discovered fossils, it is possible to piece together a rough history of the development of life on Earth over a geological timescale


© Wallace63



12 | CAMBRIAN | 542-488.3 Ma

The first geological period of the Paleozoic era, the Cambrian is unique in its high proportion of sedimentary layers and, consequently, adpression fossils. The Burgess Shale Formation, a notable fossil field dating from the Cambrian, has revealed many fossils including the genus opabinia, a five-eyed ocean crawler.

11 | ORDOVICIAN | 488.3-443.7 Ma

Boasting the highest sea levels on the Palaezoic era, the Ordovician saw the proliferation of planktonics, brachiopods and cephalopods. Nautiloids, suspension feeders, are among the largest creatures from this period to be discovered.


© Jlorenz1

10 | SILURIAN | 443.7-416 Ma

With its base set at major extinction event at the end of the Ordovician, the silurian fossils found differ markedly from those that pre-date the period. Notable life developments include the first bony fish, and organisms with moveable jaws.

9 | DEVONIAN | 416-359.2 Ma

An incredibly important time for the development of life, the Devonian period has relinquished fossils demonstrating the evolution of the pectoral and pelvic fins of fish into legs. The first land-based creatures, tetrapods and arthopods, become entrenched and seed-bearing plants spread across dry lands. A notable find is the genus tiktaalik.


© J.M.Luijt

HEAD 2 HEAD
THE AGE OF FOSSILS

OLD


© Verisimilus

1. Mrs Ples
An example of one of our common ancestors (australopithecus africanus), Mrs Ples is a remarkably preserved skull. Carbon dating suggests she lived 2.05 million years ago.

OLDER


© H.Raab

2. Archaeopteryx
The earliest and most primitive bird to be uncovered, archaeopteryx lived in the late Jurassic period (150-148 Ma) and is often cited as evidence of a transitional fossil between dinosaurs and birds.

OLDEST


© Braga/Didier Descouens

3. Ediacara biota
One of the earliest known multicellular organisms discovered by palaeontologists, ediacara biota were tubular and frond-shaped organisms that thrived during the Ediacaran period (635-542 Ma).

DID YOU KNOW? The minimum age for an excavated specimen to be classed as a fossil is 10,000 years


© DanielCD

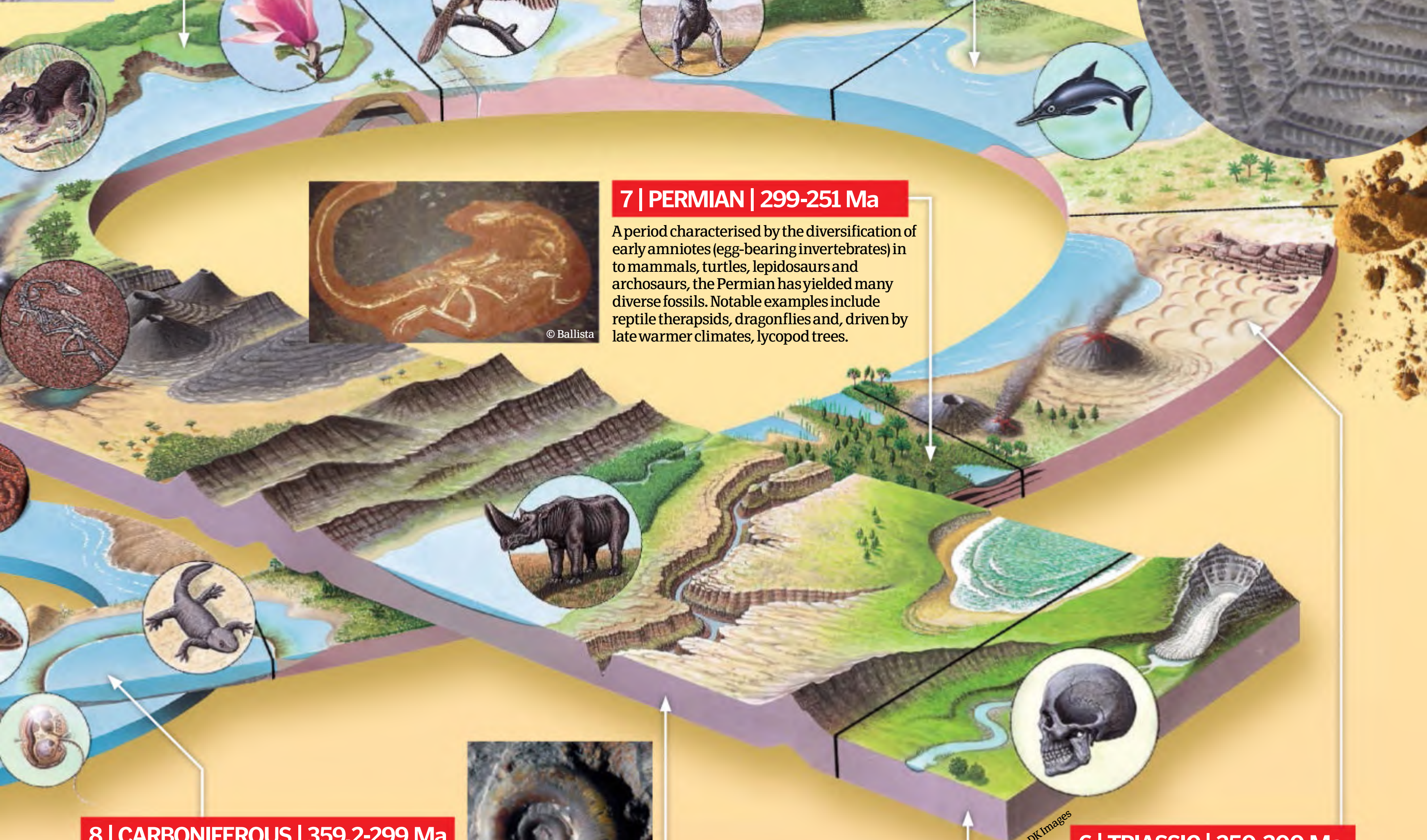
3 | PALEOGENE | 65.5-23.03 Ma
The first period of the Cenozoic era, the Paleogene is notable for the rise of mammals as the dominant animal group on Earth, driven by the Cretaceous-Tertiary extinction event that wiped out the dinosaurs. The most important fossil to be discovered from this period is darwinius, a lemur-like creature uncovered from a shale quarry in Messel, Germany.

4 | CRETACEOUS | 145.5-65.5 Ma


© Petter Bockman

Fossils discovered from the cretaceous indicate an explosion of insect diversification, with the first ants and grasshoppers evolving, as well as the dominance of large dinosaurs such as the colossal tyrannosaurus rex. Mammals increased in diversity, however remained small and largely marsupial.

5 | JURASSIC | 199.6-145.5 Ma
The period in Earth's history when the supercontinent Pangaea broke up in to the northern Laurasia and southern Gondwana, the Jurassic saw an explosion in marine and terrestrial life. The fossil record points to dinosaurs thriving, such as megalosaurus, an increase in large predatory fish like ichthyosaurus, as well as the evolution of the first birds – shown famously by the archaeopteryx fossil find.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7 | PERMIAN | 299-251 Ma
A period characterised by the diversification of early amniotes (egg-bearing invertebrates) in to mammals, turtles, lepidosaurs and archosaurs, the Permian has yielded many diverse fossils. Notable examples include reptile therapsids, dragonflies and, driven by late warmer climates, lycopod trees.

8 | CARBONIFEROUS | 359.2-299 Ma
A period of significant glaciation, the Carboniferous saw the development of ferns and conifers, bivalve molluscs and a wide-variety of basal tetrapods such as labyrinthodontia. Notable fossilised finds include the seed ferns pecopteris and neuropteris.


© Fritz Geller-Grimm


© Dlloyd

2 | NEOGENE | 23.03-2.588 Ma
Covering 23 million years, the Neogene period's fossils show a marked development in mammals and birds, with many hominin remains excavated. The extinct hominid australopithecus afarensis – a common ancestor of the genus homo (that of modern humans) – is one of the most notable fossil finds, as exemplified in the specimens Lucy and Selam.

1 | QUATERNARY | 2.588-0.00 Ma
The most recent period in Earth's history, the Quaternary is characterised by major changes in climate, as well as the evolution and dispersement of modern humans. Due to the rapid changes in environment and climate (ie ice ages), many larger mammal fossils have been discovered, including those of mammoths and sabre-toothed cats.

6 | TRIASSIC | 250-200 Ma
Beginning and ending with an extinction event, the Triassic period's fossils show the evolution of the first dinosaurs such as Coelophysis, a small carnivorous biped animal. Fossil evidence also shows the development of modern corals and reefs.


© H.Zell

Deadly sinkholes

What causes this lurking menace under the ground that could open up beneath our feet at any moment – and can anything be done to stop them?

In March 2014, a huge hole suddenly opened up in a road intersection in the city of Detroit in the United States. It was nine metres (30 feet) wide and five metres (16 feet) deep. This is a type of geohazard known as a sinkhole. They are the result of unstable cavities in the ground, which are created from soluble bedrock dissolution caused by a change in underground moisture content and water levels. Because of this, these massive pits more commonly appear in the calendar's wetter months. The effect is exaggerated even more when sudden flooding follows a drought as the ground is not saturated and cannot handle the unexpected deluge.

The most common rocks where sinkholes form are limestone, chalk and gypsum – all of which are soluble sedimentary rocks. These minerals are found in the overburden soil that covers caves, ravines and streams – topography known as karst. Chalk and limestone are two of the most common rocks in the world, so sinkholes can virtually open up anywhere.

The places most at risk on Earth are Florida, South Africa and the cave systems of the Mediterranean. In the United Kingdom, the Peak District, Yorkshire and, more recently, the south-east of England are all danger zones.

Dr Vanessa Banks, a hydrogeologist at the British Geological Survey (BGS), claims that the unusually high amount of rainfall in Britain in the winter of 2013 contributed to at least 19 collapse features in Britain in February 2014. The fact that normally only ten or so sinkholes

are reported to the BGS each year shows the adverse effect that the weather had on the British Isles that winter.

As well as the initial effects, which can include vehicles or entire buildings being swallowed up, there can be a number of long-term consequences. Sinkholes can cause flooding by blocking underground water flow – and in extreme cases this can transform previously dry land into bogs and even lakes.

One of the largest sinkholes ever recorded was the so-called Winter Park sinkhole in Florida that appeared in 1981. It caused mass devastation, swallowing two streets of buildings and cars, amounting to over £2.4 million ($4 million) worth of damage. It spanned a massive 107 metres (350 feet) across and 23 metres (75 feet) deep.

Sinkholes can be split into three varieties: subsidence, solution and collapse. Subsidence holes are created when the overburden is thin and only some sediment is above the carbonate rock. Solution is where there is no overburden layer and collapse is when the permeable rock is weighed down by a huge mass of residue.

Collapses can either be instant or slow-forming, depending on the material on the surface. If the covering material is noticeably light and weak – such as sand – small, gradual fissures are formed over time, while if the surface material is denser – like clay – there is more pressure and weight so it will cave in more suddenly. Generally, if it is the roof of an underground cavern falling, the holes are deeper and steeper, while if it is the dissolving of rock under a soil mantle, they tend to be considerably shallower.

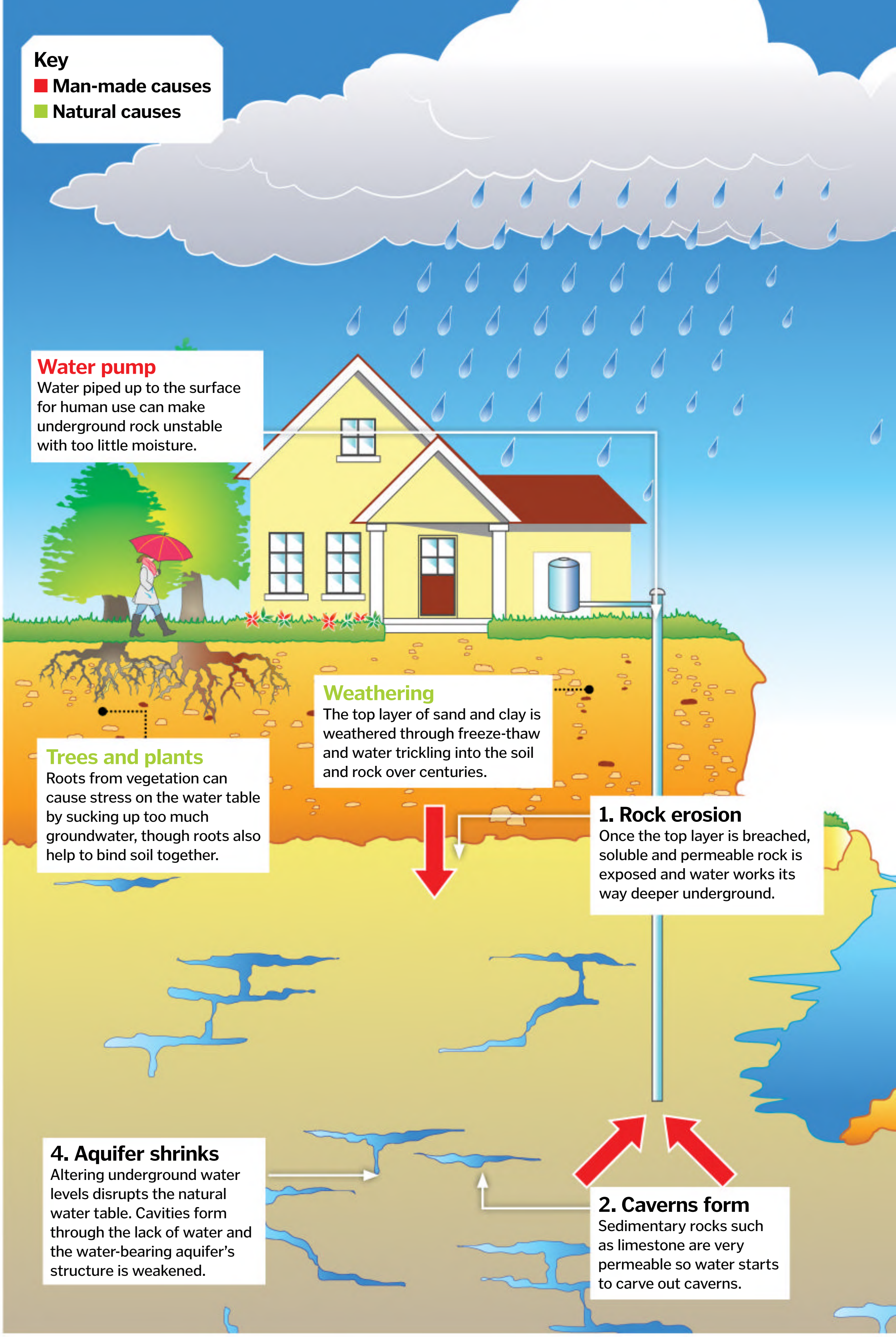
While sinkholes are defined as a collapse over a void of soluble rock, deneholes or 'crown holes' differ. These occur when there is an overburden breakdown over a modern man-made mine, such as a shaft collapse.

As the Winter Park example shows, not all sinkholes occur in the wilderness, with holes evermore frequently opening up in urban areas. The disturbing of groundwater by man-made devices and mechanisms leads to more intense and devastating sinkholes. By altering the natural path of ground water – for instance, in irrigation – we run the risk of exposing soluble rock to more liquid than it can take. In contrast, taking away water for human consumption can open up cavities in the ground and weaken natural foundations.

Above-ground vibration from busy roads and building work can also have a big impact on the ground's structural integrity.

Sinkholes: who's to blame?

Check out the man-made and natural culprits and the process which leads to sinkholes



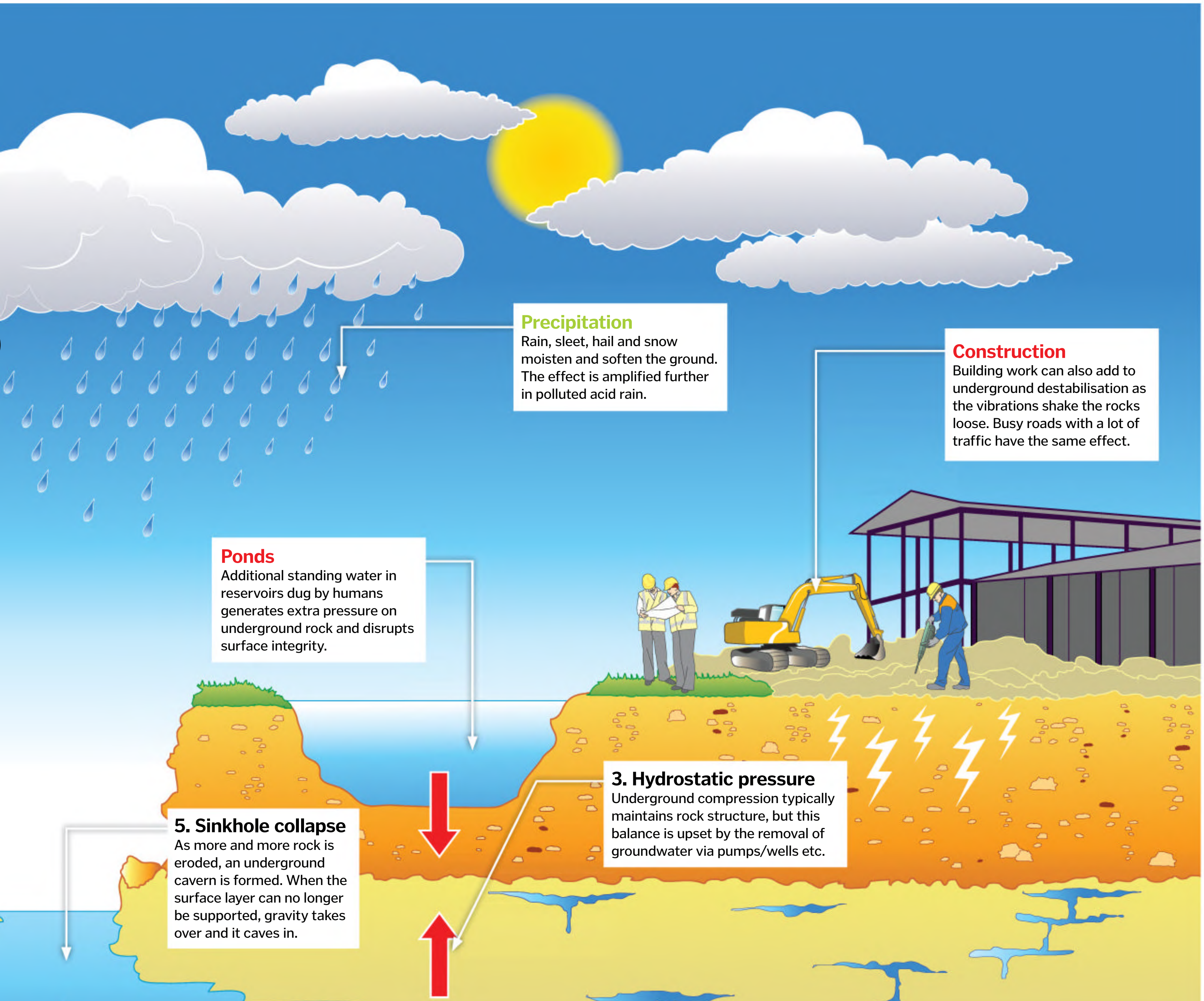
STRANGE BUT TRUE
HOLE-Y ATTRACTION

What is the Bimmah sinkhole in Oman used for?

A Landfill **B** Astronomy **C** Tourist spot

Answer:
Often portrayed as a natural menace, swallowing cars and buildings whole, the Bimmah sinkhole in northern Oman is a popular tourist attraction within the Hawiyat Najm Park, where many visitors come annually for swimming and camping.

DID YOU KNOW? *Around 20 per cent of the USA lies on karst areas, which are susceptible to sinkholes*



Hunting for sinkholes

How can we spot potential holes before it's too late?

To assess sinkholes, various state-of-the-art techniques are used. 2D electrical resistivity imaging involves electrical currents analysing the hydrogeology of areas. Using electrodes and ground-penetrating radar (GPR), the resistivity of the ground is measured. This creates an image that shows not only the subterranean structure, but also its pores and moisture content. 3D techniques are also employed to result in a better, more accurate image. Another type of imaging system is microgravity imaging. This technique detects tiny variations in the area's gravity, which highlights any cavities and can study up to 50 metres (164 feet) underground. Microgravity is used in tandem with seismic refraction, which provides an image profile of rock types. Combined, they can decipher whether you are dealing with dry cracks or wet, soft, porous soil.

As well as using these conventional techniques, NASA uses airborne radar. Known as InSAR, satellites collect images of ground surface layers that show land deformation, which is a known precursor to possible sinkhole formation. NASA predicts that if data is collected continuously and consistently, they will be able to successfully calculate when, where and to what extent sinkholes will occur in a given area.

Indeed, the number of human-induced sinkholes has doubled since 1930 as a consequence of both construction and destruction. However, as Dr Vanessa Banks points out, not all rural sinkholes are reported, meaning the notion that more happen in urban areas is slightly flawed due to a lack of rural sinkhole data.

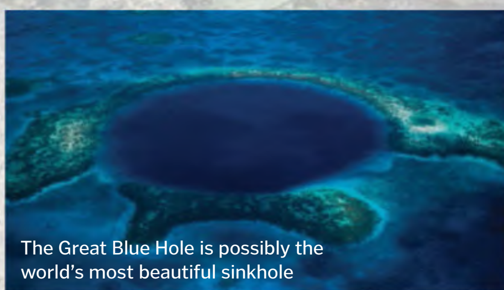
There are a few warning signs to look out for, including slumping and wilting vegetation and cracked walls or foundations. Rain pooling in areas it previously hadn't can also be a telltale sign. If a sinkhole does occur in your proximity, there are a few essential steps you need to take. Engineering geologist Dr Clive Edmonds told us the best course of action:

"It all depends upon the circumstances. If the stability of a building is threatened by a sinkhole occurring beneath it, then contact your insurer and get an experienced geotechnical engineer to quickly action the infilling of the hole to choke it and stop it from expanding laterally and deepening."

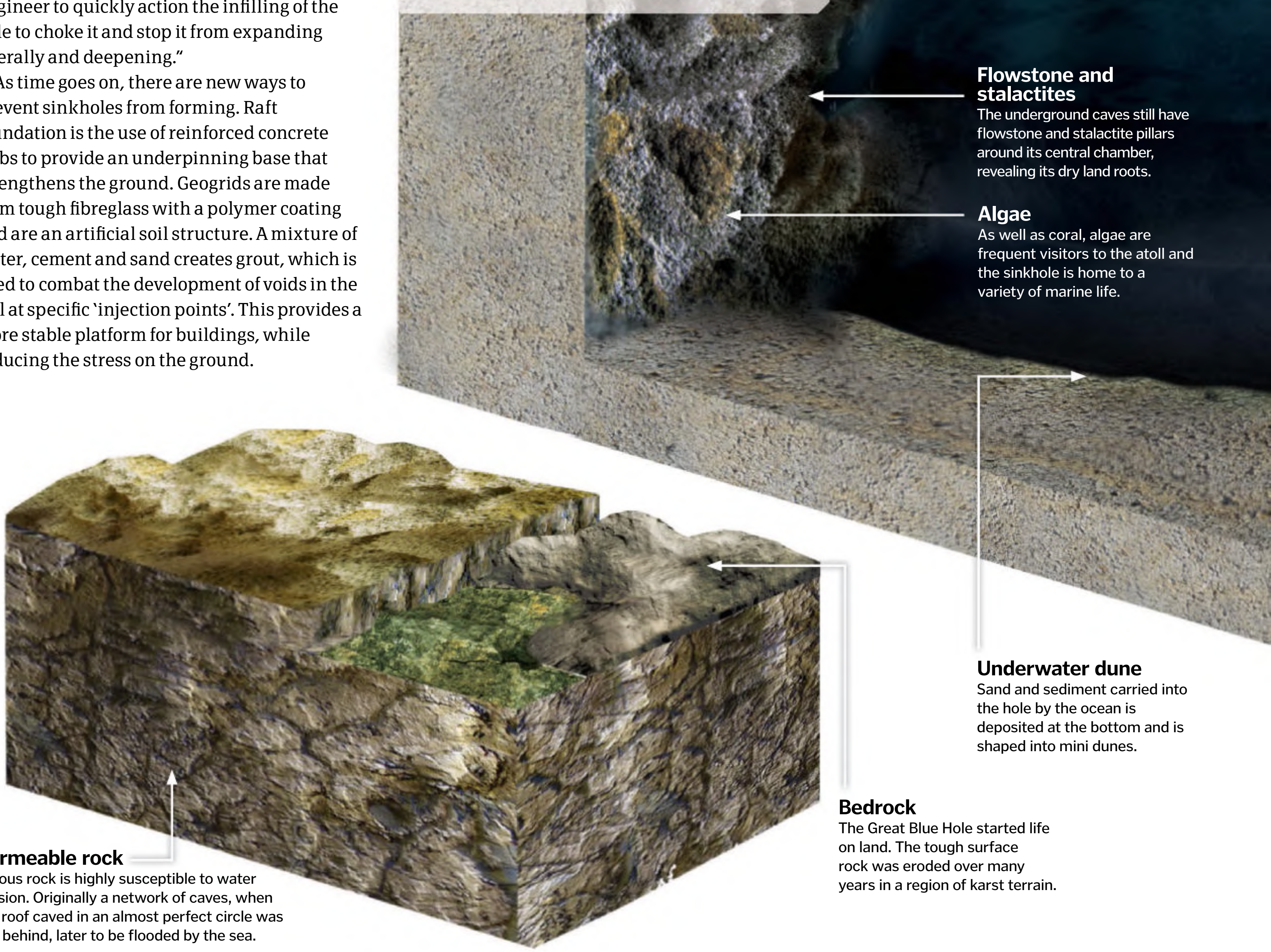
As time goes on, there are new ways to prevent sinkholes from forming. Raft foundation is the use of reinforced concrete slabs to provide an underpinning base that strengthens the ground. Geogrids are made from tough fibreglass with a polymer coating and are an artificial soil structure. A mixture of water, cement and sand creates grout, which is used to combat the development of voids in the soil at specific 'injection points'. This provides a more stable platform for buildings, while reducing the stress on the ground.

Sinkholes at sea

Lying off the coast of Belize, the Great Blue Hole is the widest ocean sinkhole on the planet. A UNESCO World Heritage Site, it is nestled deep within the Lighthouse Reef Atoll and is a staggering 300 metres (984 feet) in diameter and 125 metres (410 feet) deep. Formed by the falling through of an ancient cave, it used to be on land but rising sea levels thousands of years ago plunged it into the water. Its dry origins are evident in the presence of stalactites, which can only develop on land. Today, the sight is a popular attraction for scuba divers who flock to it from all over the globe.



The Great Blue Hole is possibly the world's most beautiful sinkhole



5 TOP FACTS
BIG SINKHOLES

Ripon, North Yorkshire
1 As recently as February 2014, Ripon in North Yorkshire, Britain, experienced a 7.5-metre (25-foot)-wide hole, where three houses had to be evacuated in a hurry.

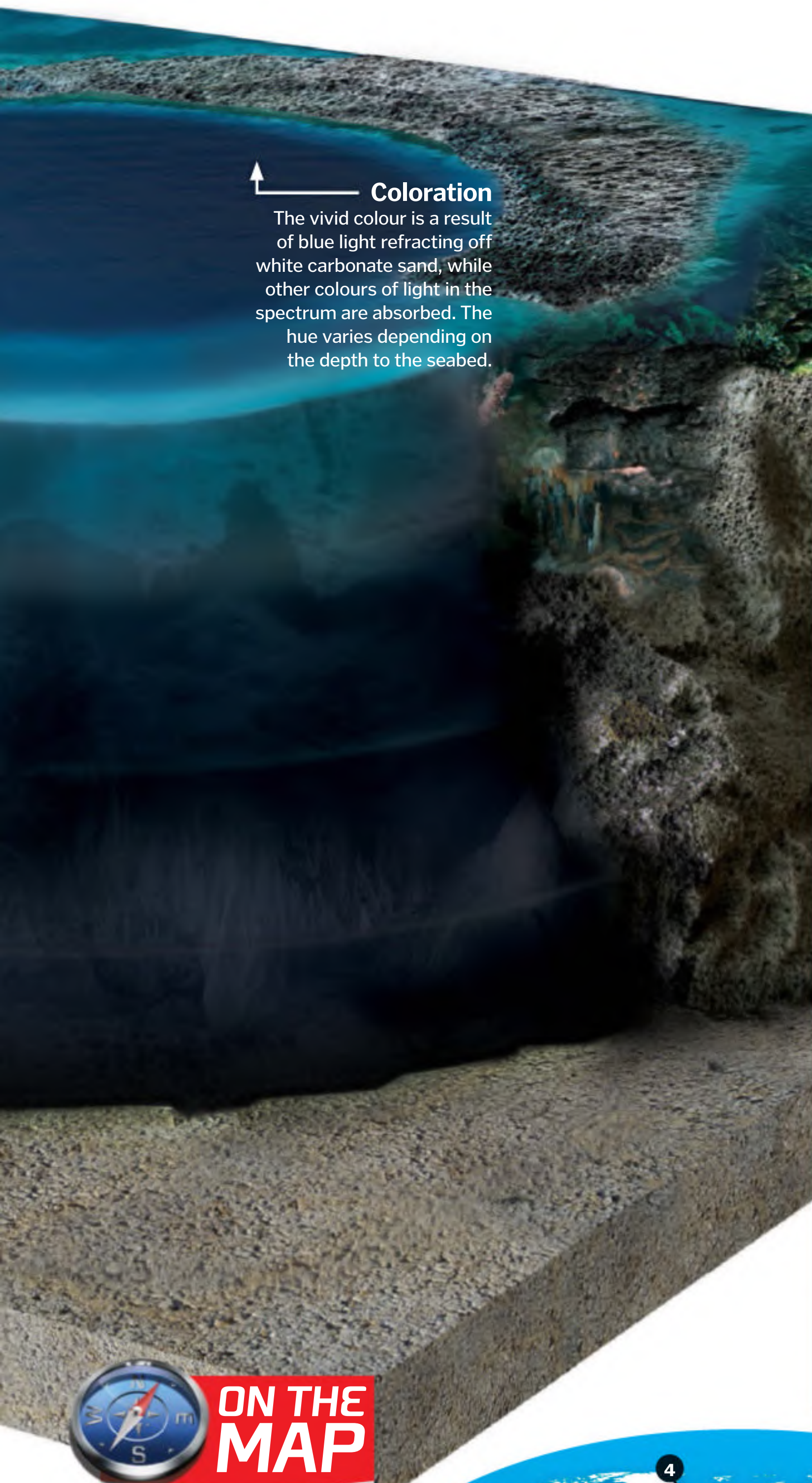
Guatemala City
2 In May 2010, a tropical storm and volcanic eruption resulted in a sinkhole in Guatemala City that swallowed a factory and caused a state of emergency.

Rocksprings, TX
3 In the rural Rocksprings area of Texas, limestone rocks have caused the formation of the 107-metre (350-foot)-deep Devil's Sinkhole, which hosts over 3 million resident bats.

Slovenia
4 Sinkholes have affected man-made infrastructure in Slovenia. Built over areas of karst, small but frequent caverns regularly waylay construction projects.

Yucatán Peninsula
5 This area is strewn with limestone sinkholes, or cenotes, that form from collapsed caves and can be up to a stomach-churning 50 metres (164 feet) deep each.

DID YOU KNOW? *The Great Blue Hole is the widest but Dean's Blue Hole is the deepest ocean sinkhole at 202m (663ft)*

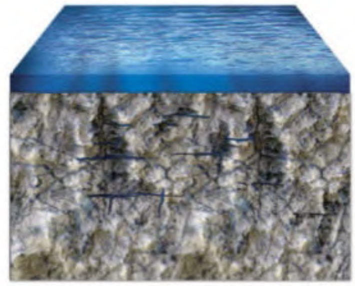


Sinkhole hotspots

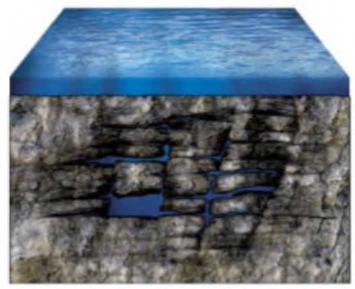
One of the most prominent sinkhole areas on Earth is the US state of Florida. This peninsula is dominated by carbonate platforms like limestone that are covered by sand and clay. These soluble materials are battered by erosion and weathering, resulting in a lot of hazardous topography in the Sunshine State. The karst geology was formed after lowering sea levels during the last ice age created new reclaimed land, which had high underground water levels. The underground water reacts with carbon dioxide to form carbonic acid, which erodes the soluble soil and rock. With this topography making water a constant feature, sinkholes are regularly present in the wetlands and Everglades of Florida. Another suffering area is the Dead Sea; the sea is rapidly drying up, partly as a result of heavy irrigation, opening up sinkholes all over the region.


Sinkholes emerge all over Florida, like this one outside the city of Live Oak

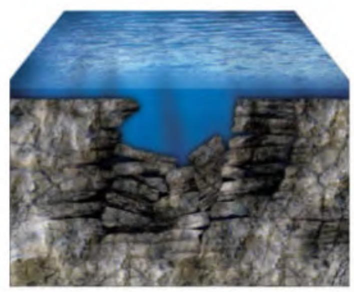
How blue holes are formed



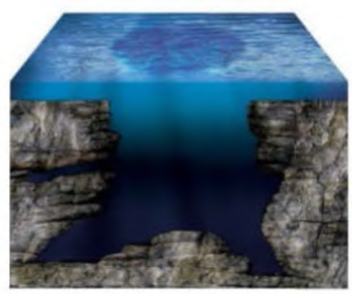
1. Surface erosion
Rain and tidal water gradually eats away an area of hard bedrock, exposing the weaker, soluble carbonate rocks like limestone.



2. Cave network
With no bedrock, the water is now free to corrode the soluble rock. This begins the formation of an underground cavern system.



3. Collapse
The weak limestone is soon dissolved altogether and the cave roof collapses into the crevasse leaving behind a sinkhole.



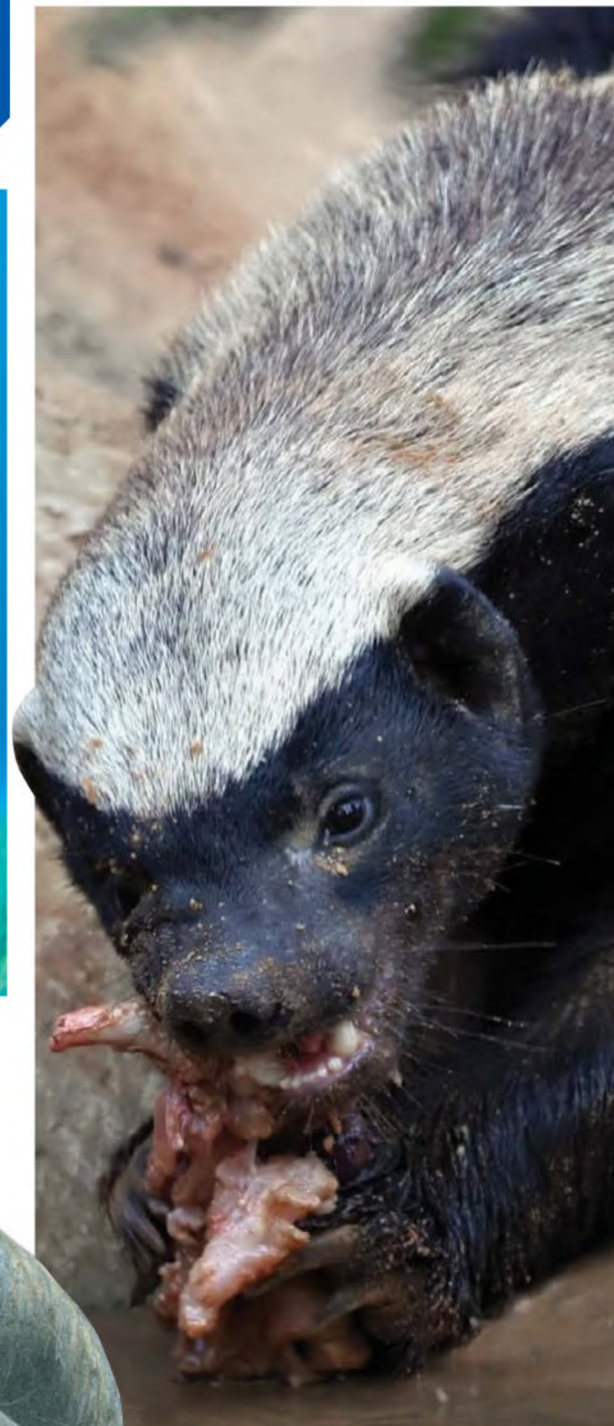
4. Rise of the ocean
As sea levels rise after an ice age, the area is flooded permanently, creating an ocean sinkhole.

ON THE MAP

Major sinkholes around the globe
1 Great Blue Hole, Belize
2 Winter Park, Florida
3 Qattara Depression, Egypt
4 Ripon, North Yorkshire, UK
5 Guatemala City
6 Xiaozhai Tiankeng, China
7 Devil's Sinkhole, Texas
8 Bimmah sinkhole, northern Oman

AMAZING ANIMALS

Nature's satnavs
168



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The animal kingdom

THE ANIMAL KINGDOM

Our family tree is a lot stranger than you might first think

Major phyla

The animal kingdom has approximately 35 phyla. Discover nine of the main ones now…

Chordata

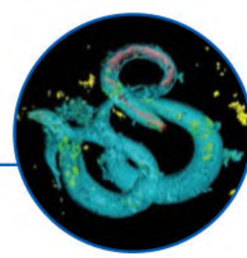
Animals with a notochord (primitive backbone). Vertebrates are chordates but they only have a notochord as embryos. After that it develops into a true spine.

Arthropoda

A hard exoskeleton with jointed legs and a body divided into segments. It is the most diverse phylum, with well over a million known species on Earth.

Mollusca

Molluscs have a mantle cavity for breathing, which is often protected by a shell. But the shell can be spiral, hinged or missing altogether – eg cephalopods.



Nematoda

Thread-like worms ranging from microscopic to several metres in length. They have a distinct head, with teeth or a stabbing syringe, and a simple intestine.

KEY DATES NATURAL HISTORY

3.6 BYA The first life. The earliest organisms were very simple like algae that probably 'fed' on hydrogen sulphide.

2 BYA The first eukaryotes. These are different from bacteria because they have their DNA in a separate nucleus.

1 BYA The first multicellular organisms. Single-celled eukaryotes co-operate to function as a single organism.

530 MYA The first vertebrate. The *Haikouichthys* (right) was 2.5cm (1in) long but had a primitive backbone.

160 MYA The first true mammal. The *Juramaia sinensis* creature looked like a small shrew.

DID YOU KNOW? Four out of every five animals alive today are nematode worms

Sort your life out!

A brief guide to how we structure all life on Earth

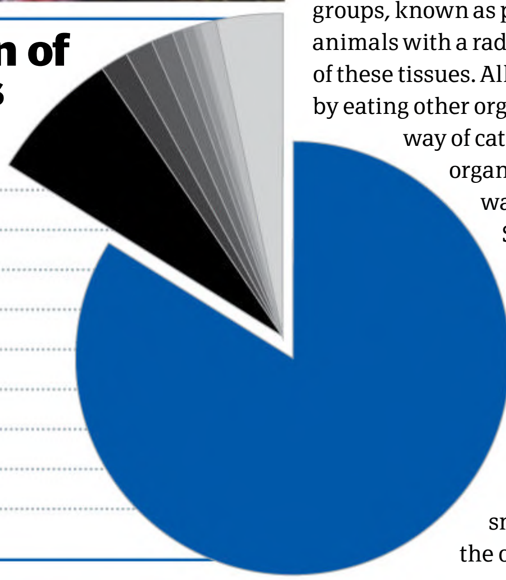
- Domain
- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

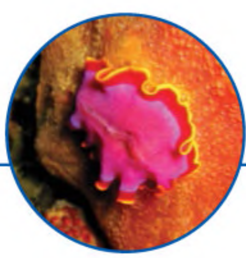
In the fourth century BCE, Aristotle divided the world into animals and plants. The word 'animal' comes from the Latin animalis and means 'having breath'. Animals were all the living creatures that moved and breathed, while plants were the ones that stayed put. For over 2,000 years the living world was divided into just these kingdoms. After the invention of the microscope and later the electron microscope, scientists came to recognise that single-celled organisms couldn't really be classified as animals *or* plants. Bacteria and another type of single-celled organism called Archaea are now counted as fundamentally different groups of their own. That leaves animals, plants and fungi as fairly recent evolutionary offshoots from the larger group of organisms with a cell nucleus, called the eukaryotes.

The animal kingdom consists of the eukaryotes that are multicellular. Their cells are specialised into different types and grouped into tissues that perform different functions. Animals are divided into major groups, known as phyla, and each phylum has animals with a radically different arrangement of these tissues. All animals obtain their energy by eating other organisms, so they need some way of catching and digesting these organisms. But there are a lot of ways of solving this problem. So, for example, the echinoderms, which include starfish, are all radially symmetrical, while the arthropods all have rigid, jointed exoskeletons. There are nine main phyla, with a couple of dozen much smaller ones containing all the odd and difficult to classify

What proportion of species belongs to each group?

- **Arthropoda:** 83.7%
- **Mollusca:** 6.8%
- **Chordata:** 3.6%
- **Nematoda:** 1.4%
- **Platyhelminthes:** 1.4%
- **Annelida:** 1.0%
- **Cnidaria:** 0.6%
- **Echinodermata:** 0.5%
- **Porifera:** 0.3%
- **Others:** 0.7%



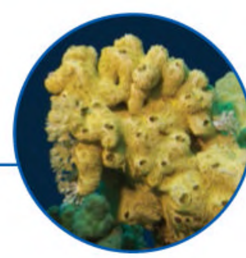


Platyhelminthes
Very simple flatworms with no specialised circulation or respiratory system. The digestive cavity has a single opening serving as both mouth and anus.

Annelida
Roundworms with bodies built from repeating segments. Each segment has the same internal organs and may have bristles or appendages to help them move.

Cnidaria
A body formed from two layers of cells sandwiching a layer of jelly in between. The outer layer has specialised stinging cells (cnidocytes) for catching prey.

Echinodermata
Unusual because of their radial symmetry – usually fivefold but occasionally seven or more. Their skin is covered with armoured plates or spines.



Porifera
Very simple animals with no nervous, digestive or circulatory systems. Instead, nutrients and waste are carried through their porous bodies by water currents.

creatures. Indeed, between them, these nine groups account for more than 99 per cent of all animal species alive today.

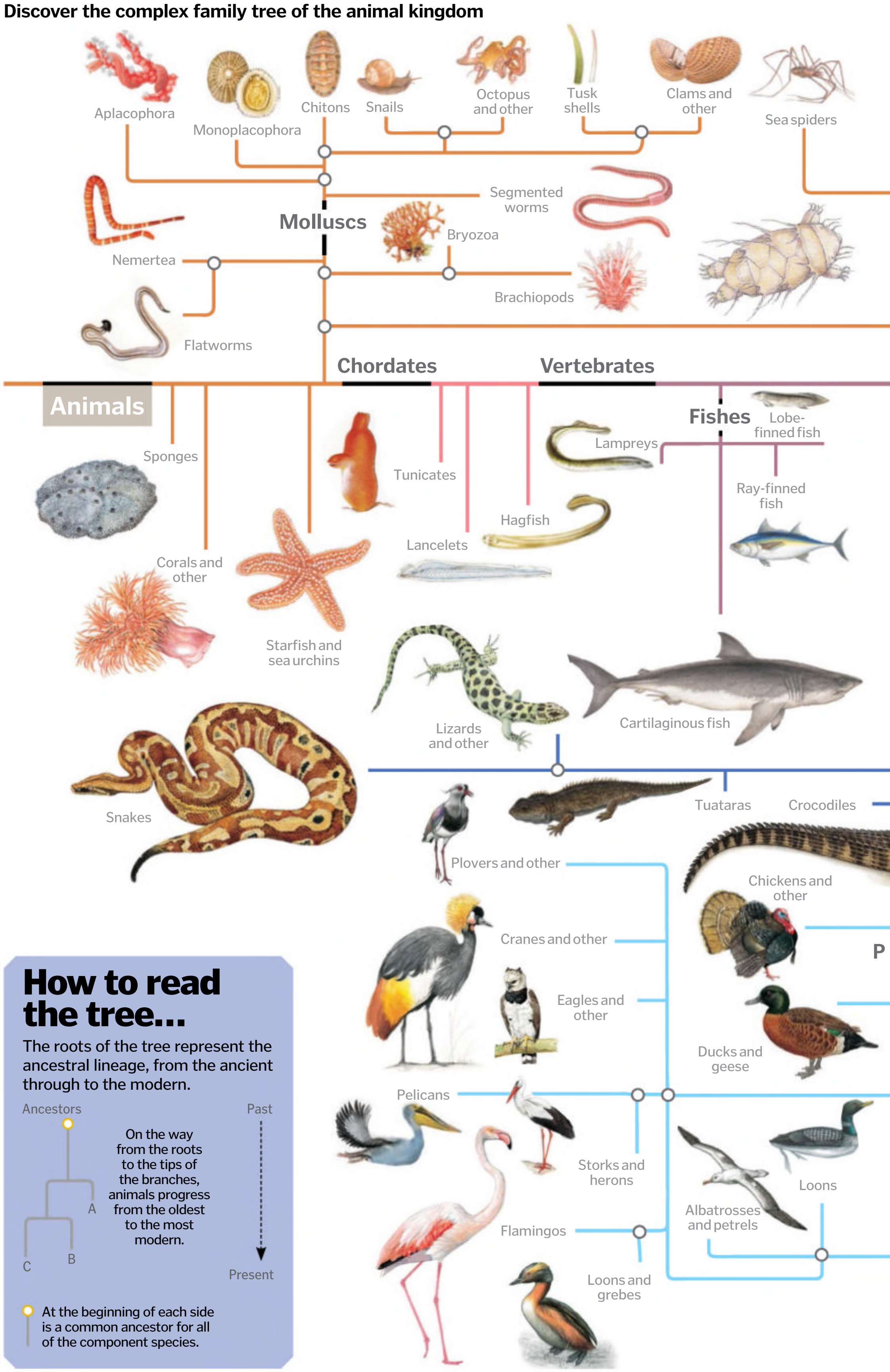
At a first glance, some of the groups seem very similar. The annelids are segmented worms, while the nematodes are roundworms and the platyhelminths are flatworms. Why aren't they all just grouped together as worms? Even a brief look at their internal structure shows the reason. Flatworms have bodies that are left/right symmetrical and their digestive system is just a simple sock shape with only one opening. Roundworms have a radially symmetrical head and a tubular digestive system that has an opening at each end. Annelids are even more sophisticated internally, with bodies made of repeating segments and distinct organ systems. The characteristics that separate these three groups of animals are far more important than the things that link them together. Being called a 'worm' just means that your body is long and thin with no legs, after all. That also applies to a snake, and snakes clearly aren't worms.

Snakes are vertebrates, of course, but surprisingly, the vertebrates aren't considered a phylum of their own. Instead they are grouped within the chordates. That's because the backbone itself isn't the most important distinguishing feature; rather it's the nerve cord running the length of the body that the backbone protects. There are some simple fish-like creatures that have a spinal cord even though they don't have bony vertebrae. The spinal cord was the adaptation that led to the development of our complex nervous systems, and it is such an important feature that all creatures with a spinal cord are grouped together in the chordates. However, 97 per cent of all animals are still invertebrates. The vertebrate animals – which include us – are just a subgroup of a single phylum.

So which is the largest of the groups then? It depends on how you count it. In terms of the sheer number of individuals, the nematodes are the most numerous. But they are also very small, so it's not an entirely fair measure. There are over a million nematodes in every square metre of soil! Biologists generally prefer to look at the number of different species in a group. This is a way of measuring how successful a particular body plan has been in adapting to different environments. By that measure, the arthropods are currently in the lead – around 84 per cent of all known species are arthropods, mostly in the subgroup of insects. But this is also a somewhat misleading statistic. There are

The animal tree of life

Discover the complex family tree of the animal kingdom



How to read the tree...

The roots of the tree represent the ancestral lineage, from the ancient through to the modern.

Ancestors

Past

On the way from the roots to the tips of the branches, animals progress from the oldest to the most modern.

A

B

C

Present

At the beginning of each side is a common ancestor for all of the component species.

HEAD 2 HEAD WATERY WEIRDOS

1. WEIRD

Moss animals

The phylum Bryozoa, commonly known as moss animals, live in colonies in the oceans, and form branching plant-like structures.

2. WEIRDER

Sponges

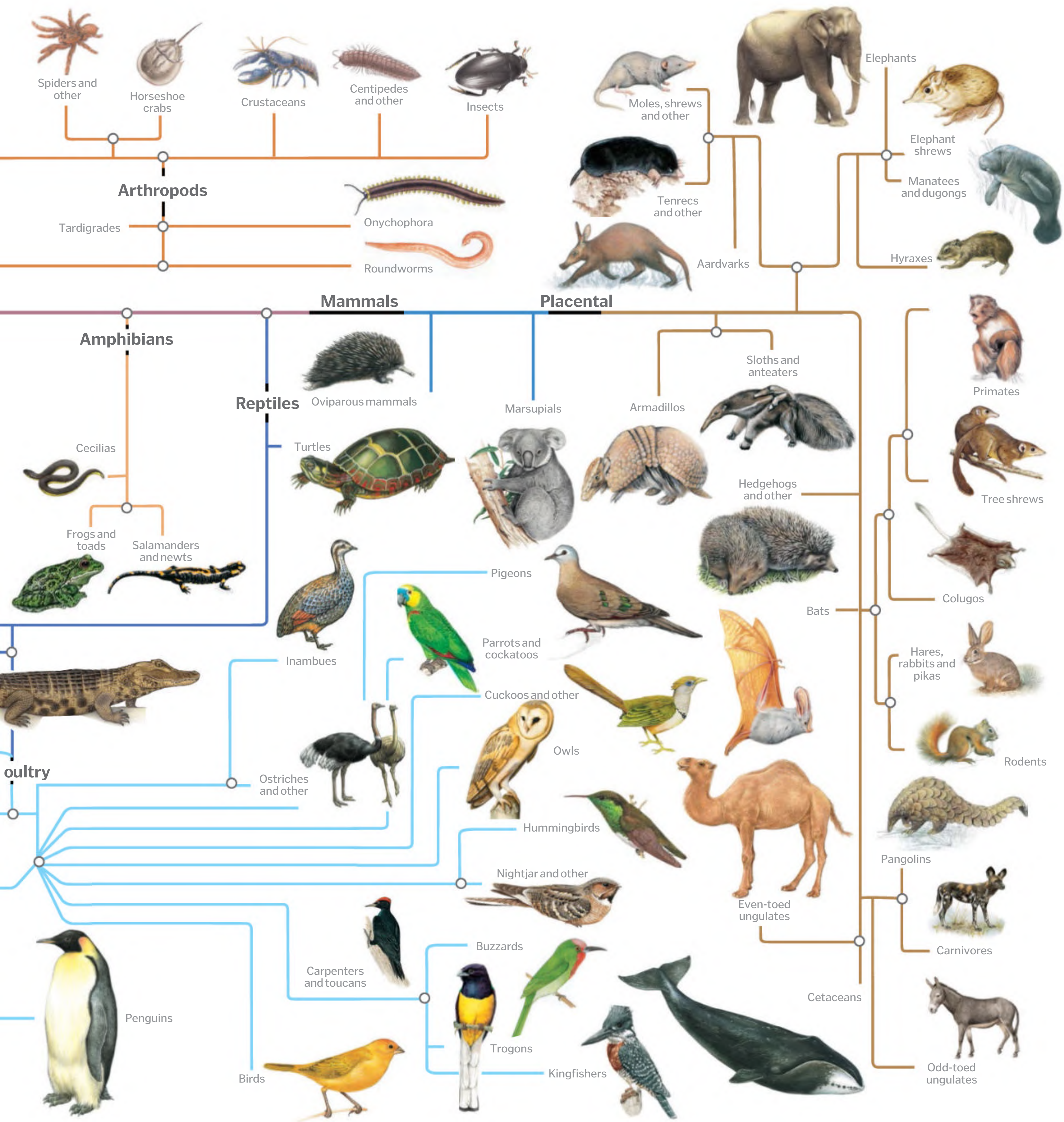
Instead of true organs and tissues, the Porifera are full of holes and channels allowing them to gain nutrients directly from their watery habitat.

3. WEIRDEST

Water bears

The phylum Tardigrada are eight-legged animals. Just 1mm (0.04in) long, they can survive at the very bottom of the sea and even in outer space!

DID YOU KNOW? *The extinct Moa bird wasn't just flightless; it actually had no wings. All living birds at least have vestigial wings*



a lot of species still waiting to be discovered and identified. Insects are easy to catch, preserve well and most of their distinguishing characteristics can be seen with nothing more sophisticated than a magnifying glass. Nematodes, on the other hand, are mostly microscopic and, although tens of thousands of species have been described so far, they all look very similar. It's possible that there are as many as a million more species of nematode out there waiting to be discovered and named. If so, this would make them roughly level with the arthropods in species numbers.

The system of naming animals that we use today was devised by the Swedish naturalist Carl Linnaeus (or Carl von Linné as he was known after he was made a noble). He used a two-part name to uniquely identify every animal and plant. It consists of a genus and a species, like a surname and a first name, except that it is written with the genus first and then the species. So the chimpanzee belongs to the genus Pan and the species troglodytes. The name is often written in italics with the genus capitalised: Pan troglodytes. The bonobo chimp, meanwhile, belongs to the same genus but has a different species: Pan paniscus.

Above the level of genus, animals are grouped together into families, then orders, then classes, then phyla. So, for example, the dromedary camel belongs to the kingdom of animals, the phylum of chordates, the class of mammals, the order Artiodactyla, the family Camelidae, the genus Camelus and the species dromedarius. The higher groupings are used to show the evolutionary relationships between animals, but Camelus dromedarius is all you need to precisely identify which organism you are talking about, from the entirety of the natural world. The genus name is often abbreviated, particularly when it is long. So the bacterium E coli is actually Escherichia coli.

In general, the division of the animal kingdom into groups reflects how closely related the animals in that group are to each other, but there are exceptions. Birds are actually more closely related to crocodiles than snakes are, and yet both crocodiles and snakes are in the class of reptiles, and birds have their own class: Aves. This is because birds all have lots of physical resemblances to each other that make them feel like a coherent group, whereas reptiles are actually a grab-bag class with only superficial physical resemblances. The reptiles are really just the leftover vertebrates that aren't birds, mammals or amphibians.

Invertebrate anatomy

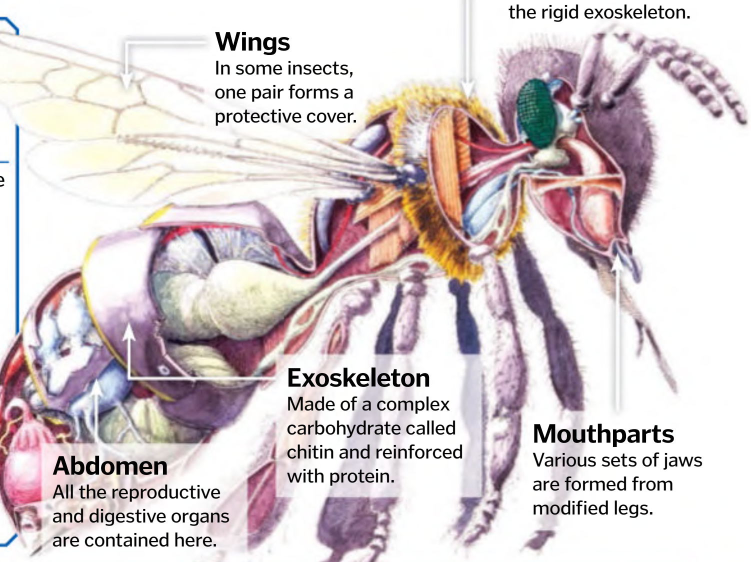
United by their lack of backbone, what are invertebrates really like?

INSECTS

Phylum: Arthropoda

Phylum also includes: Spiders, scorpions, centipedes, millipedes, crustaceans

Info: Insects are the most diverse group of animals on Earth. It's possible that 90 per cent of all species are insects. They have three body segments, with three pairs of legs and one or two pairs of wings on the middle segment. The whole body is protected by a waterproof, rigid exoskeleton that also provides an attachment point for the muscles. Insects have a larval form that is often aquatic but very few insects live in saltwater.



SPONGES

Phylum: Porifera

Phylum also includes: Calcareous sponges, glass sponges

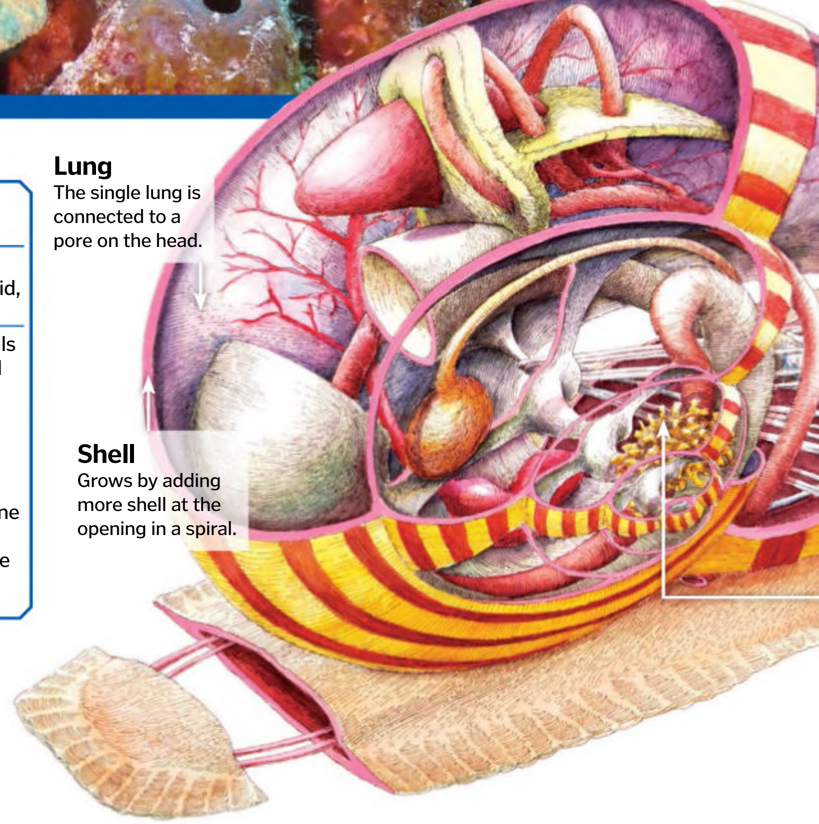
Info: Most sponges belong to the class Demospongiae. Although a sponge has different cell types, the body structure is very loosely organised. Amazingly if you pass a sponge through a sieve to separate the cells, they will reform into sponges. Most sponges photosynthesise using symbiotic bacteria, though a few prey on plankton and even shrimp.

GASTROPODS

Phylum: Mollusca

Phylum also includes: Clams, razorshells, oysters, squid, octopuses

Info: Gastropods are slugs, snails and limpets. Snails have a spiral shell large enough for them to retreat into, to prevent them drying out or being eaten. They use a chainsaw arrangement of microscopic teeth (a radula) to graze on algae and plants. Marine snails use their radula plus secreted acid to drill through the shells of other molluscs.



PHYLA **35** | UNDISCOVERED SPECIES **5mn+** | LARGEST **30m**
KNOWN SPECIES **2mn+** | SMALLEST **0.05mm** | TOTAL MASS **5bn tons**

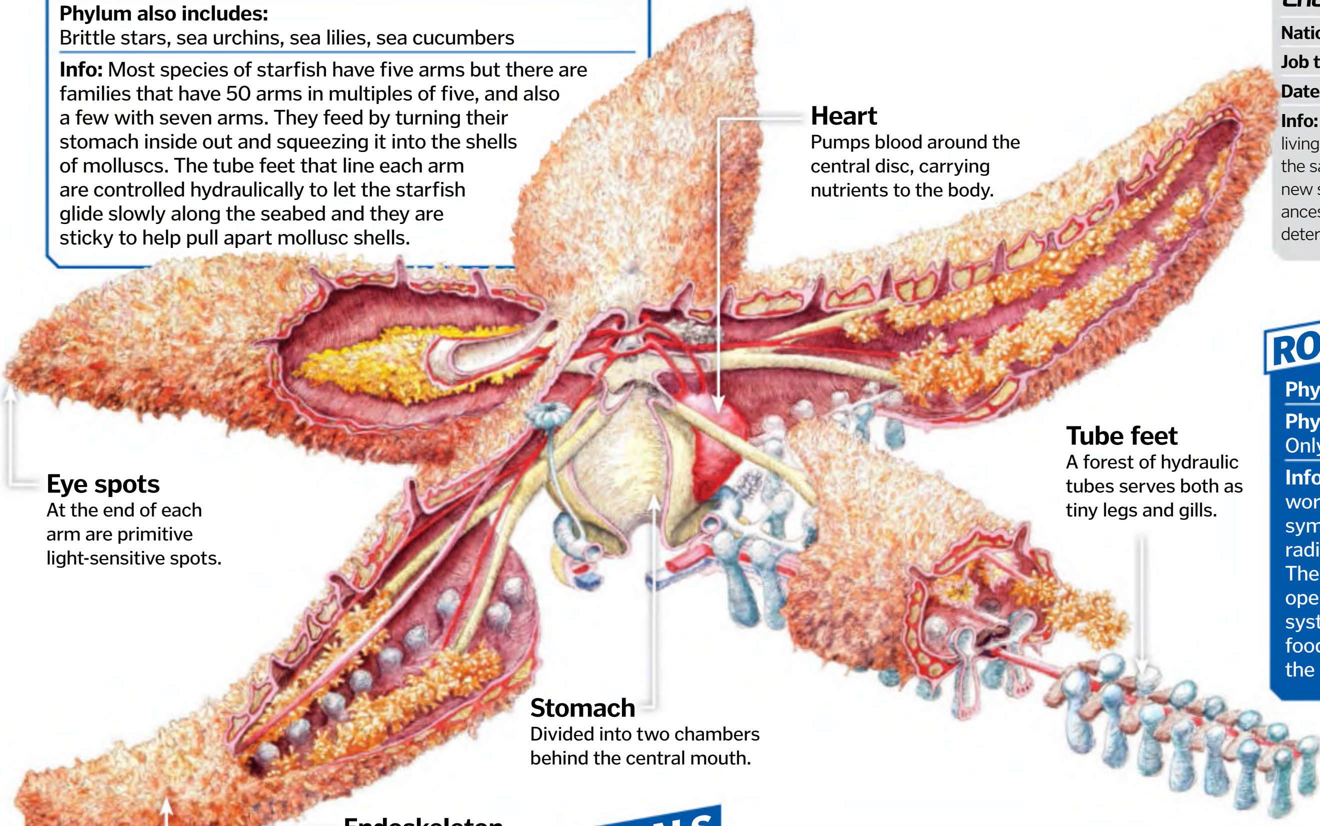
DID YOU KNOW? *The total weight of all the ants in the world is the same as the total weight of all humans*

SEA STARS

Phylum: Echinodermata

Phylum also includes:
Brittle stars, sea urchins, sea lilies, sea cucumbers

Info: Most species of starfish have five arms but there are families that have 50 arms in multiples of five, and also a few with seven arms. They feed by turning their stomach inside out and squeezing it into the shells of molluscs. The tube feet that line each arm are controlled hydraulically to let the starfish glide slowly along the seabed and they are sticky to help pull apart mollusc shells.



KEY PLAYER

Charles Darwin

Nationality: British

Job title: Naturalist

Date: 1809-1882

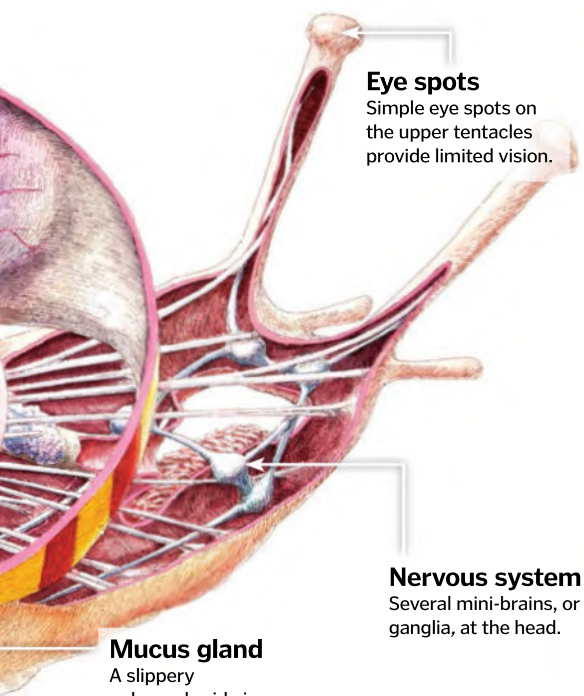
Info: Established all living species are part of the same family tree. Evolution causes new species to branch away from ancestral ones. Natural selection determines survival and extinction.

ROUNDWORMS

Phylum: Nematoda

Phylum also includes:
Only roundworms

Info: Nematodes are thin worms with a bilaterally symmetrical body and a radially symmetrical head. Their digestive system has an opening at each end with a system of valves that pushes food through the intestine as the worm wriggles around.



CORALS

Phylum: Cnidaria

Phylum also includes:
Jellyfish, sea wasps, freshwater hydra

Info: Corals and sea anemones belong to the class Anthozoa. They have a jellyfish-like larval stage that settles onto a rock and permanently anchors there. Adults have a single opening for the digestive system, which is surrounded by a fringe of often colourful tentacles. These are lined with stinging cells called nematocysts that harpoon tiny plankton. Reef-building corals also have symbiotic algae within their bodies that help them to secrete the protective calcium carbonate skeletons which make up this biodiverse habitat.

TAPEWORMS

Phylum: Platyhelminthes

Phylum also includes:
Flukes, flatworms

Info: The Cestoda, or tapeworms, are intestinal parasites of vertebrates. They have absolutely no digestive system and are hermaphroditic. They absorb nutrients from their host and reproduce by detaching the egg-filled tail segments into the host's faeces.

CLITELLATA

Phylum: Annelida

Phylum also includes:
Lugworms, ragworms

Info: The Clitellata is the class that includes the common earthworm. They have segmented bodies with internal dividing walls. The gut, circulatory and nervous system run the length of the worm, but other organs are repeated in each of the body segments.

Species though are a much more fundamental unit of classification. Animals in the same species are those that can interbreed to produce healthy offspring. You can cross a lion and a tiger to produce a liger, but this hybrid animal is almost always sterile, because lions and tigers belong to different species (Panthera leo and P tigris, respectively).

Charles Darwin's crucial insight was to see that new species arose when an existing population split into two groups that stopped breeding with each other. This can happen in two main ways. Allopatric speciation occurs when animals are geographically isolated. The islands of the Galápagos archipelago, for example, are just close enough together to allow birds to fly between them – when blown off course by a severe storm, for instance – but far enough apart to prevent the populations of two islands from routinely interbreeding.

Over time, the random shuffling of genes from generation to generation, as well as natural selection caused by the different conditions on each island, leads the populations to evolve in completely different directions. Darwin found that each isle had its own unique species of mockingbird. An ancestral species of mockingbird had split into four new species. Similarly, the chimpanzee and bonobo species formed when the Congo River divided the population of ancestral apes in half, around 2 million years ago.

The opposite of allopatric speciation is sympatric speciation. This is where a species splits into two distinct forms that don't interbreed, even though they still share the same territory. An example of this happening today is the American apple maggot fly (Rhagoletis pomonella). Despite its name, the larvae of this species originally fed on hawthorn berries. When the apple was introduced to America around 200 years ago, a few flies must have laid their eggs on apples instead. Female flies normally choose to lay their eggs on the same fruit as they grew up in, and male flies generally mate with females near to the fruit that they grew up in. This means that even though the two populations of flies could theoretically interbreed, in practice they do not.

In the last two centuries, some genetic differences between the two populations have emerged and eventually R pomonella could diverge into two different species. These two processes have transformed us from single cells to every single species alive today.

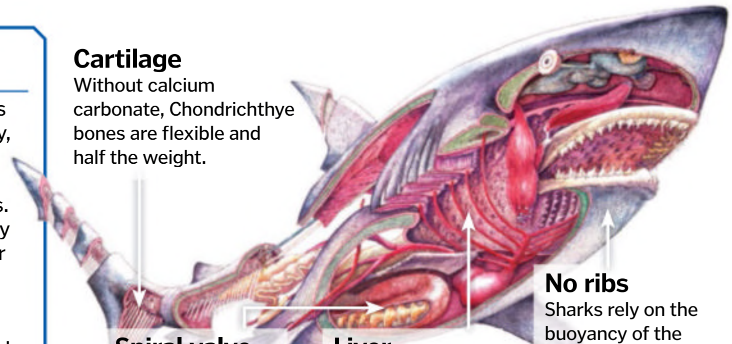
Vertebrate biology

Discover what characteristics are shared by creatures with a backbone

FISH

Phylum: Chordata

Info: Most fish belong to the class Actinopterygii, which are the bony, ray-finned fishes. The other main class of fish contains the sharks, rays and skate, or Chondrichthyes. The two groups aren't actually any more closely related to each other than, say, birds and reptiles. The bony fishes have a calcified skeleton, swim bladder and large scales on the skin. Sharks may look externally quite similar to bony fish, however their body structure is quite different, as we see here.



REPTILES

Phylum: Chordata

Info: Reptiles are air-breathing vertebrates that lay their eggs on land, though some actually live in water. They have scaly skin, and modern reptiles are cold-blooded, although some large prehistoric ones may have been warm-blooded. Reptiles are a leftover category; rather than having defining features of their own, they are classified as the vertebrates that produce eggs with an amniotic sac that aren't mammals or birds.

AMPHIBIANS

Phylum: Chordata

Info: Amphibians were the first vertebrates to emerge onto the land. They still lay their eggs into water and most have an aquatic larval stage. The adults have air-breathing lungs but can also breathe underwater through their skin. They are cold-blooded and need to keep their skin moist. Amphibians have tiny teeth or none at all, but often have a large muscular tongue that can be used to catch prey.

Pain in the class

The duck-billed platypus lays eggs, but also has a bill and webbed feet. It also has mammary glands and fur. Is it a bird or a mammal? It's actually a monotreme, once treated as a separate group on the same level as mammals. Nowadays taxonomists class them as a subgroup of mammals. Another problem animal is Peripatus, which looks like a caterpillar but actually has more in common with an earthworm. Its evolutionary journey has got stuck halfway between the annelids and arthropods, which makes it hard to know which group to put it in. The lungfish are a similar halfway house between the bony fish and the amphibians. Worst are the microscopic Myxozoa that have variously been classed as protozoa, worms and jellyfish – though they actually look nothing like any of them!

MAMMALS

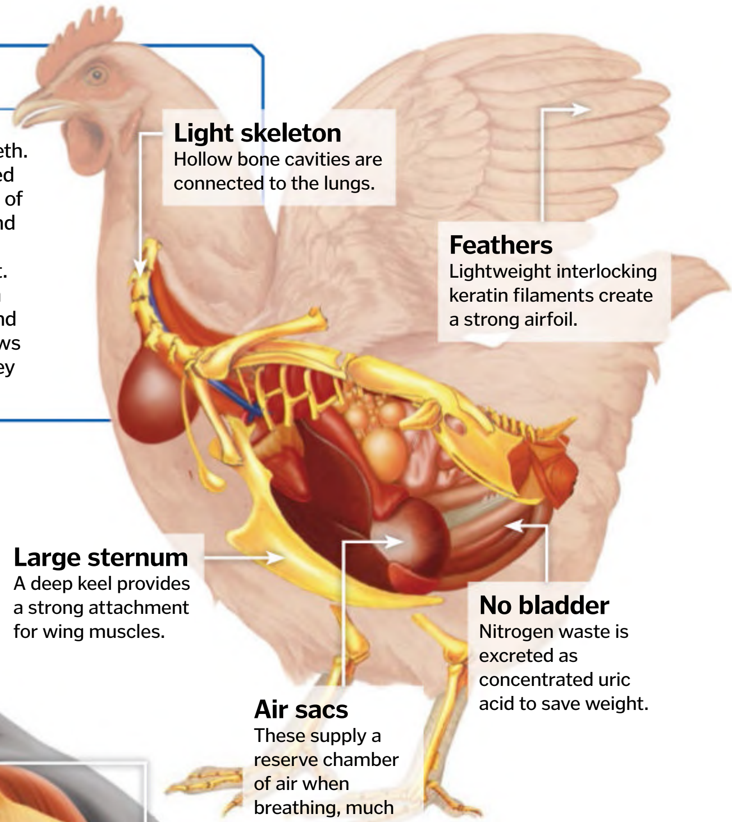
Phylum: Chordata

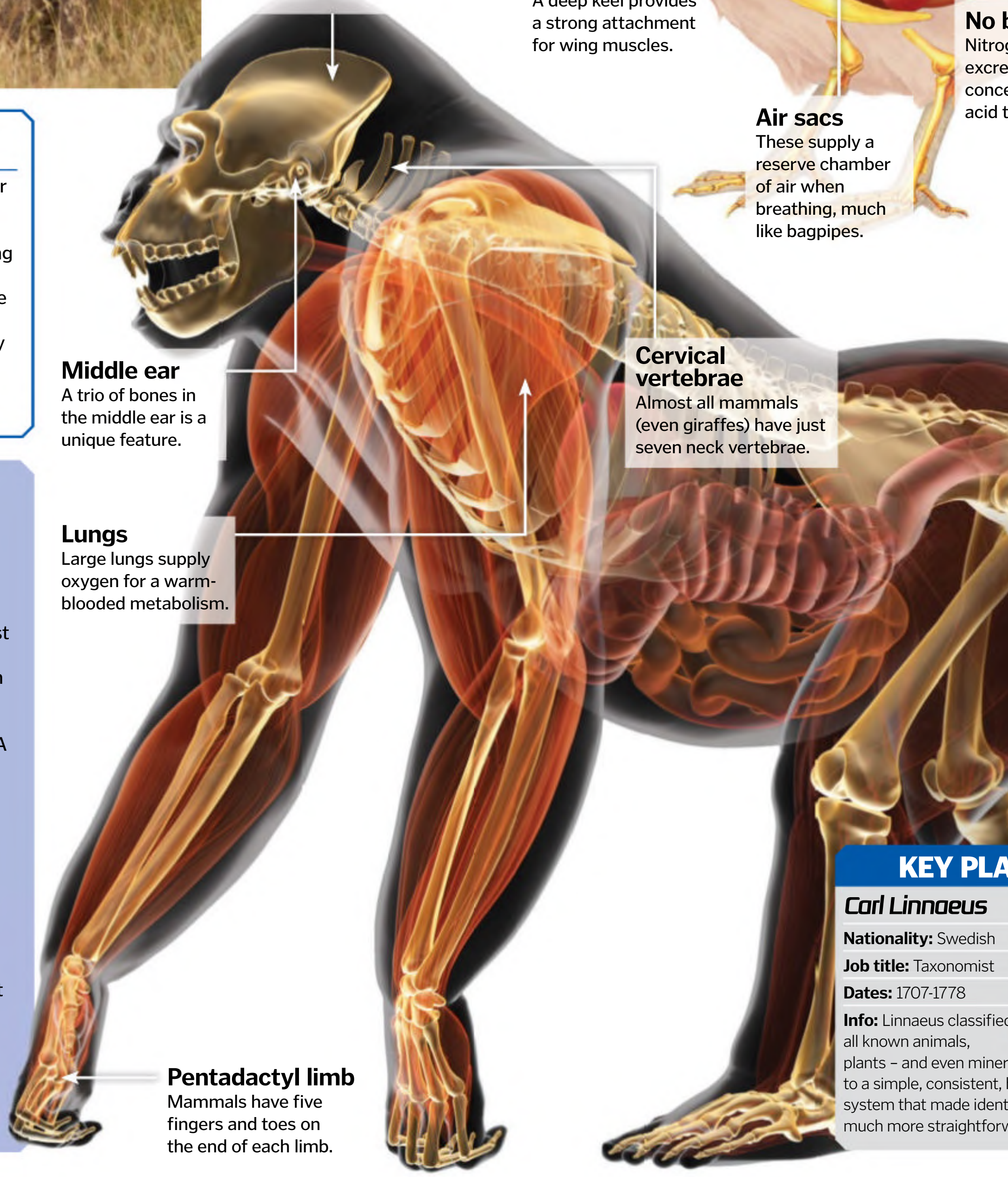
Info: Mammals are defined by their body hair and their mammary glands for feeding young. Most mammals nourish the embryo using a placenta that grows out of the uterus. Monotremes are a primitive group of mammals that comprise the platypus and echidnas; they lay eggs, but even then the egg develops for a long time inside the mother and is nourished by her.

BIRDS

Phylum: Chordata

Info: Birds are vertebrates with feathers and a beak instead of teeth. They lay eggs with a hard, calcified shell, instead of the leathery shell of reptile eggs. Most birds can fly and almost all their characteristic features are adaptations for flight. Their breathing system involves a complicated system of air sacs and chambers in their bones that allows them to refill their lungs when they breathe out as well as in.



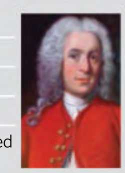


A molecular family tree

A good classification system doesn't just group animals that *look* similar; it groups those that are related evolutionarily. The best way to do this is by comparing their DNA. All animal cells contain organelles called mitochondria and these have their own DNA. Assuming that mitochondrial DNA only changes as a result of random mutation, the amount of mutation over evolutionary time can be used to create a family tree. Molecular phylogenetics is the scientific discipline that compares the mitochondrial DNA barcode of different animals, and groups the most similar ones together. It is certainly not a perfect system though because it has to make some assumptions about the background mutation rate, and we now know that mitochondria can also acquire new DNA from other sources by horizontal gene transfer.

KEY PLAYER

Carl Linnaeus



Nationality: Swedish

Job title: Taxonomist

Dates: 1707-1778

Info: Linnaeus classified all known animals, plants – and even minerals – according to a simple, consistent, hierarchical system that made identification much more straightforward.

Shoaling versus schooling

Discover how and why fish stick together as they travel the oceans

A group of hundreds or sometimes thousands of fish swimming together in unison is one of the most spectacular sights in all of nature, but what is the reason for this incredible phenomenon?

First, it is important to understand the subtle difference between shoaling and schooling. A shoal is a social group of fish swimming closely together but foraging for food individually. Those shoals can consist of different species and sizes of fish. A school of fish swim in a more synchronized fashion, moving at the same speed and turning simultaneously. These groups often consist of a single species.

Some species, including tuna and herrings, are obligate shoalers, meaning they spend all of their time either shoaling or schooling. Others, such as Atlantic cod, will only shoal some of the time, often when they are looking for a mate.

In addition to reproduction, there are several other reasons why fish congregate in shoals or schools. One is that it gives them the advantage of safety in numbers, as being part of a group reduces the chance of a fish being eaten by a predator. Large schools of fish can also confuse an attacker by making it difficult for it to single out its prey or even scare the predator off by resembling one large fish.

Another benefit is that several eyes are better than one, and so a shoal of fish is much quicker at spotting food or a potential predator than one fish is on its own.

Scientists also believe that swimming in unison gives the fish more hydrodynamic efficiency, as the beating of the front fish's tail helps to propel those in its wake.

How do herrings communicate at night?

A Farting **B** Singing **C** Morse code

Answer:
Herrings communicate with the rest of their school at night by breaking wind. They create high-frequency sounds and a stream of bubbles by releasing air from their anuses, informing other fish of their whereabouts.

DID YOU KNOW? *Shoaling reduces stress, as a solitary fish's heart rate is often much faster than that of a fish in a shoal*

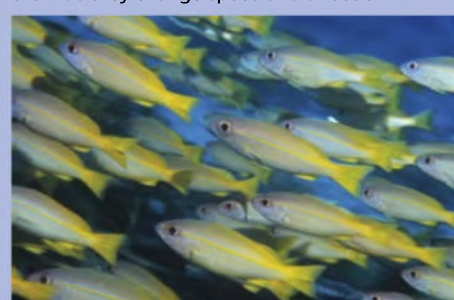
A shoal, such as this group of oriental sweetlips, has a loose formation

Fast-moving schools typically form a wedge shape, while feeding schools are usually circular

How fish swim in unison

Schools of fish move very quickly and can change direction at a moment's notice, yet the fish manage to never break formation or collide. Their fast reaction speed allows them to instantly copy the movements of the fish next to them, which they can see thanks to the position of their eyes on the side of their head.

Vision plays a big part in a fish's ability to school, as most schools become shoals when it gets too dark to see. However, many species of fish also have a lateral line down the side of their body, which contains cells similar to the hair cells found in the human ear. This enables the fish to sense changes in water currents, helping them to detect the movements of nearby fish when visibility is poor and keep a safe distance from them as they change speed and direction.



Amazing animal architects

Take a closer look at the incredible engineering achievements of the animal kingdom

Humans are not the only species capable of building extraordinary structures. The natural world is full of ingenious animals that can achieve just as impressive feats of engineering.

Building behaviour is common in mammals, birds, insects and arachnids. Many animals learn to build by observation and even through communication. However, in some cases building is thought to be instinctive.

Animals will often construct their own habitats for shelter against potential predators and the outside elements. Many dwellings are also built for nesting purposes and to catch, store and even cultivate food.

Animal architecture can also be quite sophisticated, with many structures incorporating clever ventilation systems for temperature control, and even secure entry and exit points to keep unwanted visitors away. Complex builds are often undertaken as a group, which helps speed up construction time. For example, an army of ants can move up to 50 tons of soil per year in just 2.6 square kilometres (one square mile)!

Maintaining a habitable structure is also a collective effort, and most animals work together to ensure they are regularly repaired or expanded as the colony grows. For some species, such as the beaver, this will involve sourcing materials from their environment. Animals that dwell underground, however, like ants and rabbits, will simply hollow out soil from their surroundings.

Many animal-made structures also play an important role in the ecosystem and even support other life forms. This includes termite mounds, beaver dams and sociable weaver nests, which can also be home to other species. This is largely due to the fact that a lot of structures are designed to protect against predators, an appealing realty prospect for smaller species. Many are also camouflaged well in their surroundings, as they can appear unassuming from the exterior, but inside you'll often find a hive of activity.

Animal structures can vary significantly in design, size and strength, from intricate spider webs to complex beehives and bird nests. But the thing they all share in common is that each can help ensure a species' survival.

Ants are among the strongest species on Earth in relation to their size

Ant architects

An army of ants can construct vast underground cities in a week

A single ant is capable of carrying up to 50 times its own weight, so working together as a colony means they're able to accomplish some seriously impressive feats. In fact, within a week a large army of garden ants can construct an underground city big enough to house thousands of insects.

Established deep underground, ant nests are made up of multiple chambers and connecting tunnels. Each chamber has a different use; some store food while others are used as nurseries for the young and resting spaces for busy worker ants. You'll find the queen ant in the central chamber where she will lay her eggs.

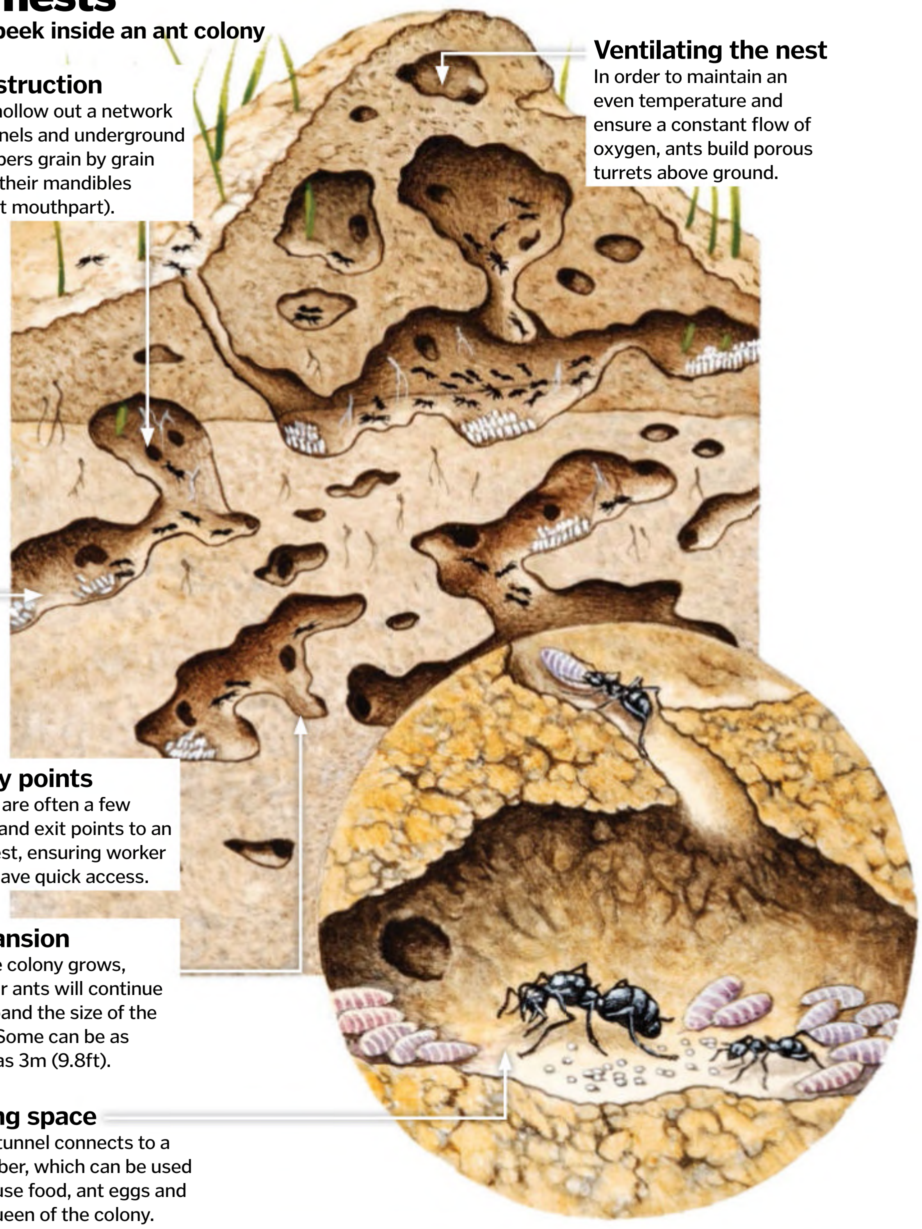
Porous turrets are also built above ground to ventilate the nest and maintain an even temperature inside.

"Building behaviour is common in mammals, birds, insects and arachnids"

Ants have separate entry and exit points on their hives

Ant nests

Take a peek inside an ant colony



Termite megacities

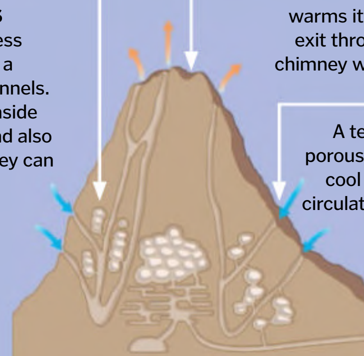
A towering termite mound, made up of soil, dung and termite saliva, can take four to five years to build and will continually evolve over time. Like ants, termites are social animals and work together to erect these impressive structures, which can be over five metres (16.4 feet) tall.

Although a mound appears solid, it's actually porous, enabling air to circulate through interior tunnels and chambers. Its unique ventilation system helps to maintain the temperature inside, which is where termites reside, raise larvae, store food and even farm and tend to symbiotic fungi to feed on.

Towers are built facing north to south to help regulate heat. Air will enter the mound through tiny exterior holes and then circulate around the structure, helping to lower the temperature as well as provide fresh oxygen to the insects. As this air then warms, it will rise and exit the mound via the central chimney.

Termite towers

Find out how they protect termites and ventilate the nest



Beaver lodges

Nestled safely in the centre of a pond, discover how beavers build their warm and dry abodes

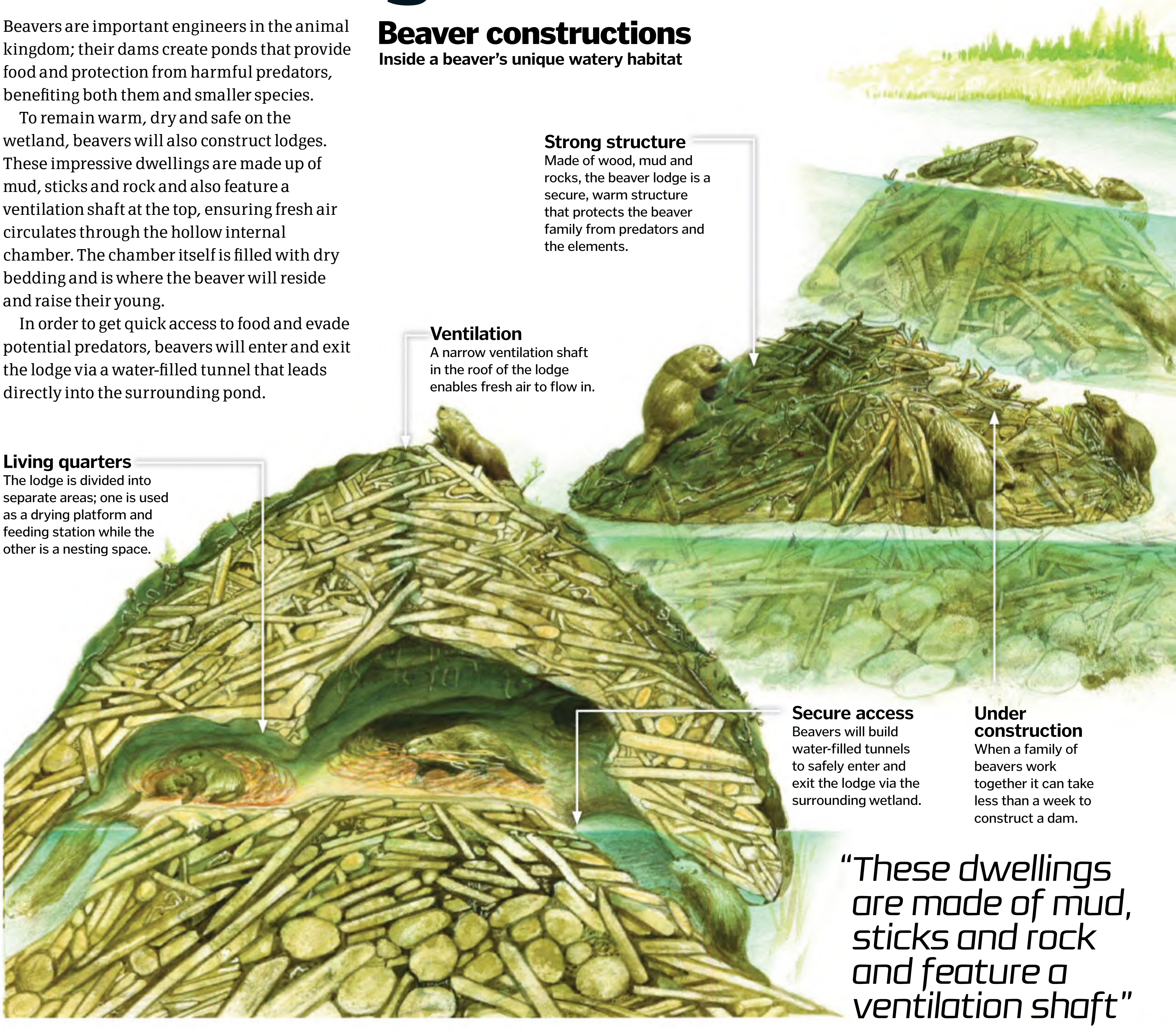
Beavers are important engineers in the animal kingdom; their dams create ponds that provide food and protection from harmful predators, benefiting both them and smaller species.

To remain warm, dry and safe on the wetland, beavers will also construct lodges. These impressive dwellings are made up of mud, sticks and rock and also feature a ventilation shaft at the top, ensuring fresh air circulates through the hollow internal chamber. The chamber itself is filled with dry bedding and is where the beaver will reside and raise their young.

In order to get quick access to food and evade potential predators, beavers will enter and exit the lodge via a water-filled tunnel that leads directly into the surrounding pond.

Beaver constructions

Inside a beaver's unique watery habitat

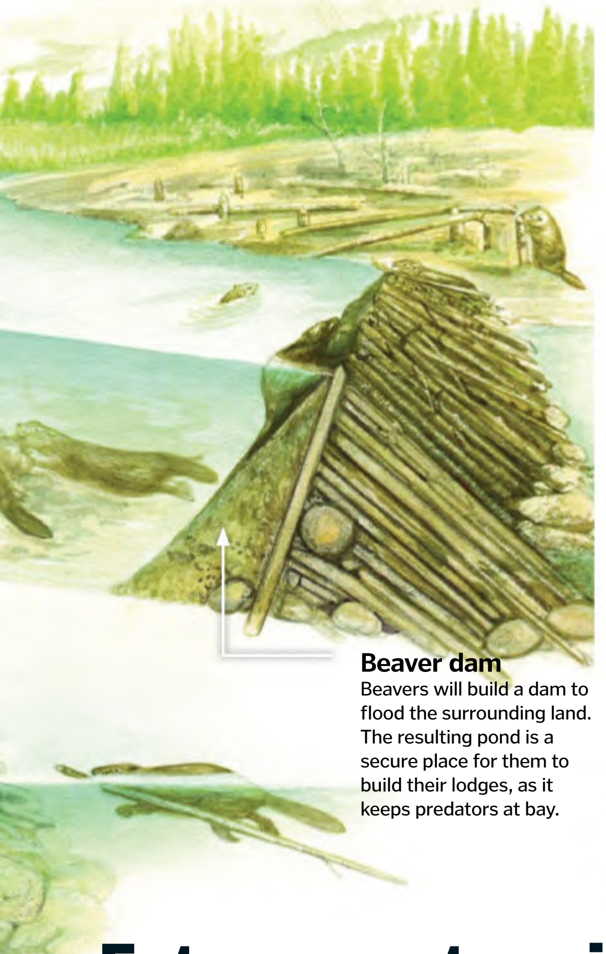


"These dwellings are made of mud, sticks and rock and feature a ventilation shaft"


Beavers eat grass, shrubs and woody plants. They carry food in their mouths to take back to the lodge for their young


Beavers forage for wood and rocks to build their lodges on ponds


Beavers use their front teeth to fell trees for building materials as well as food



Beaver dam
Beavers will build a dam to flood the surrounding land. The resulting pond is a secure place for them to build their lodges, as it keeps predators at bay.

Underground rabbit warrens

Rabbits are sociable animals that live close together in colonies underground. As a nocturnal species their unique warren system provides protection from predators while they rest during the day. It's also a safe and secure place in which they can raise their young.

Warrens can be extensive in size and often go as deep as three metres (9.8 feet) underground. To build one, rabbits will burrow through soil using their front claws, creating an often-vast system of interconnecting tunnels that lead on to larger living and nesting areas. There are also at least two entry and exit points, commonly positioned at either end of the warren, ensuring inhabitants have safe access to their underground lair as well as the outside when in danger. Entry and exits points are also small in diameter, or around 15 centimetres (5.9 inches), which helps to stop predators from following them inside.

Rabbits burrow underground and create chambers where they can safely rest and raise their young

Extravagant sociable weaver nests

A flock of sociable weaver birds will build a home like no other. These nests can take over an entire acacia tree and house hundreds of birds. What's more, some of these unique structures are over 100 years old!

Building and maintaining the nest is a communal effort. Large twigs and dry grass are used to construct the small internal nesting chambers, which is where the birds reside and raise young. These are then lined with fur and soft plant material for insulation. However, the exterior and entrance tunnels are covered in sharp straw and sticks for protection.

During the hot summer months in South Africa, many birds will occupy the outer nesting areas, but in winter they move further in toward central chambers for added warmth.

Other bird species will often take up residence in a sociable weaver's nest, including pygmy falcons and red-headed finches. This can provide the sociable weavers with extra protection, as it means more birds are on the lookout for potential predators.

Sociable weavers create huge nests out of twigs, dry grass and straw

DEADLY VENOM

Related to the Brazilian wandering spider, but the venom of the cupiennius getazi (above) is nowhere near as potent

It's the tiniest bite that does the most damage. Find out how these poisonous predators bring pain and paralysis on their prey

Venom is a force multiplier. It allows small animals to tackle prey that approach or even exceed their own body size. Killing your prey with brute strength alone requires a large body, which in turn means that you need to catch more food to sustain it. Venom enables a predator to make a single strike from ambush and completely incapacitate its victim in less than five seconds. This is much more energy efficient than a prolonged tussle and eliminates the risk of injury to the predator.

Most venom is secreted by modified salivary glands. Ordinary saliva already contains digestive enzymes to begin breaking down food before it reaches the stomach. Venom probably first evolved in animals that killed their prey with a bite and then injected saliva to 'marinade' the meat so that it was easier to consume. After that, natural selection would favour those animals with evermore potent combinations of enzymes until the saliva itself did enough damage to kill the prey. Modern venom is often a cocktail of hundreds of different enzymes and peptides. As well as digestive enzymes, most species also include specific compounds that block the transmission of nerve impulses; this causes paralysis and suffocation.

Of course, while venomous animals are continuously evolving new toxins, their prey are also frantically evolving venom resistance. To counter this, most animals inject vastly more than the minimum lethal dose of venom with each bite. This guarantees the kill and also hastens it, which stops the victim from escaping to die alone, or injuring the predator.

Venom is less effective against large animals because of the time it takes to spread through the body, so larger animals are less likely to be venomous. The main exception to this is snakes, which use venom to compensate for their lack of claws to hold struggling prey in place. There are about 650 venomous species of snake but only a few venomous lizards.

Mouth
Red chelicerae, or mouthparts, may serve to warn birds and mammals.

DEADLY FACTOR
Brazilian wandering spider

AGGRESSION: High. Often hides in houses and bites when cornered.

INTELLIGENCE: Limited. A deadly, instinctive assassin.

SPEED: High. A speedy scuttler that jumps when it strikes.

STRENGTH: Low. But the fangs will puncture skin and clothes.

DEADLY RATING: ☠☠☠☠☠

DEADLY

1. Yellow-bellied sea snake
This marine serpent has a venom more toxic than any land snake, which causes muscle breakdown, renal failure and cardiac arrest.

© Alnazia

DEADLIER

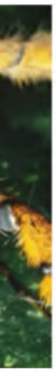
2. Lonomia moth caterpillar
The spines of this bug inject a powerful anticoagulant. Brushing past a group of them can cause inner haemorrhaging as well as kidney failure.

DEADLIEST

3. Box jellyfish
Virtually transparent and carrying around half a million stingers per tentacle, the box jellyfish is one of the deadliest creatures in the sea.

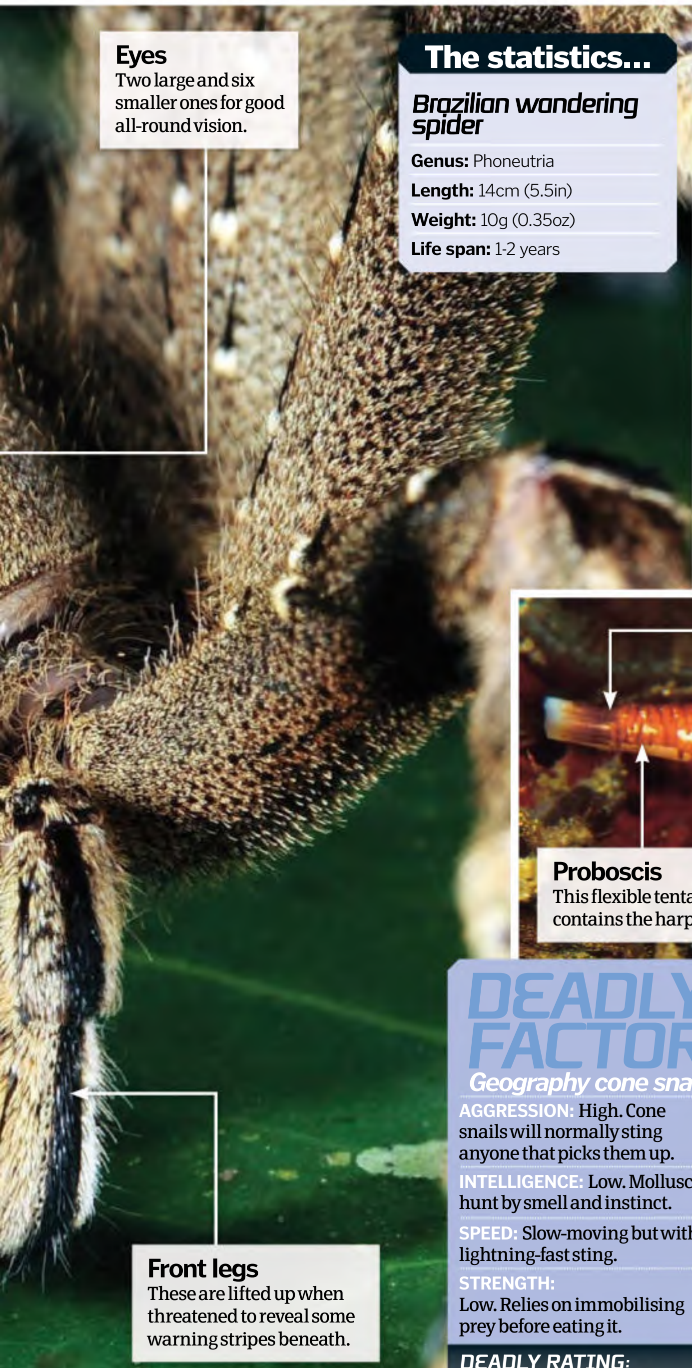
© Mithril

DID YOU KNOW? Although the inland taipan is the world's most venomous snake, there's no recorded case of a human fatality



BRAZILIAN WANDERING SPIDER

Wandering spiders do not spin webs. They stalk the forest floor at night and attack anything they come across, from insects to mice. In the day they hide somewhere dark and moist and this can bring them into contact with humans as they are often found near houses or in bunches of bananas. The Brazilian wandering spider has the deadliest venom of any spider – a neurotoxin two to five times more toxic than the black widow's. The relatively low fatality rate of victims is thought to be partly because the spider will often 'dry bite' to conserve venom. Bites cause instant, intense local pain and swelling, followed by irregular heart rhythm, vomiting and internal haemorrhaging.



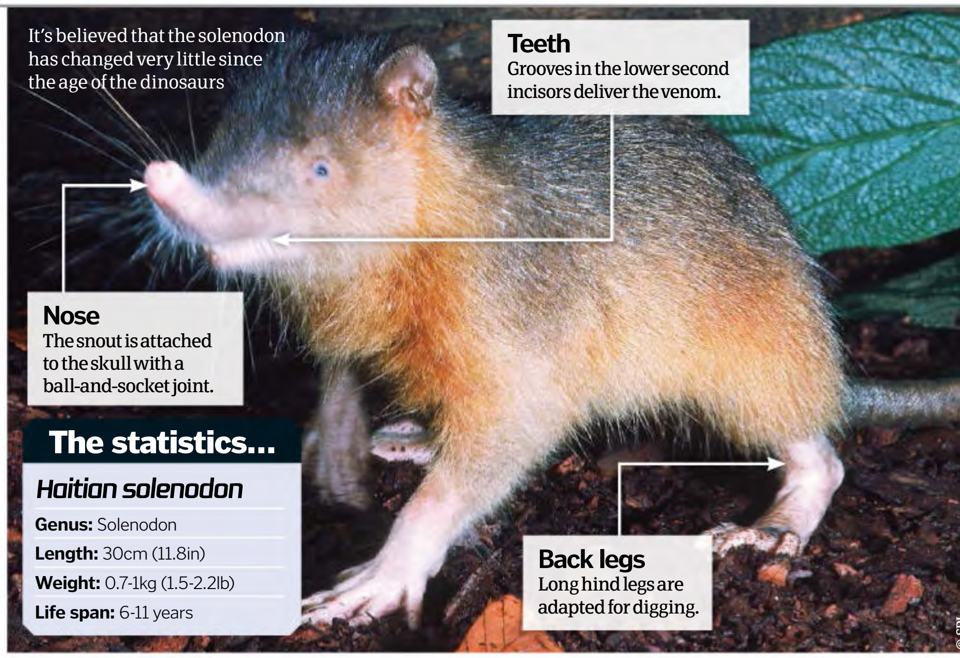
Eyes
Two large and six smaller ones for good all-round vision.

Front legs
These are lifted up when threatened to reveal some warning stripes beneath.

The statistics...

Brazilian wandering spider

Genus: Phoneutria
Length: 14cm (5.5in)
Weight: 10g (0.35oz)
Life span: 1-2 years



It's believed that the solenodon has changed very little since the age of the dinosaurs

Teeth
Grooves in the lower second incisors deliver the venom.

Nose
The snout is attached to the skull with a ball-and-socket joint.

Back legs
Long hind legs are adapted for digging.

© SPL

The statistics...

Haitian solenodon

Genus: Solenodon
Length: 30cm (11.8in)
Weight: 0.7-1kg (1.5-2.2lb)
Life span: 6-11 years

HAITIAN SOLENODON

Solenodons are related to the shrew but much larger – about the size of a hedgehog. The word solenodon means 'slotted tooth' in Greek and these slots, or grooves, are used to inject the venomous saliva into their prey. They evolved on the islands of the Caribbean, without any natural predators. The introduction of cats and dogs has left them extinct everywhere except for Cuba and Hispaniola. The Haitian, or Hispaniolan, solenodon is the more aggressive of the two and will attack without provocation. In the wild they eat earthworms and insects, as well as the occasional frog or lizard. Their venom is not lethal to humans but, in smaller animals, it causes paralysis, convulsions, bulging eyeballs and death. Interestingly, solenodons aren't immune to their own venom.

DEADLY FACTOR

Haitian solenodon

AGGRESSION: High. Evolved without natural predators and shows no fear.
INTELLIGENCE: A mammal's brain makes this one shrewd shrew.
SPEED: Slow. Solenodons run in an awkward zigzag pattern.
STRENGTH: High. Solenodons have been known to tear a chicken to pieces.

DEADLY RATING: ☠☠

Harpoon
A modified barbed tooth that is made of chitin.

Proboscis
This flexible tentacle contains the harpoon.

Shell
Attractive patterning makes it popular with shell collectors.

© Getty

DEADLY FACTOR

Geography cone snail

AGGRESSION: High. Cone snails will normally sting anyone that picks them up.
INTELLIGENCE: Low. Molluscs hunt by smell and instinct.
SPEED: Slow-moving but with a lightning-fast sting.
STRENGTH: Low. Relies on immobilising prey before eating it.

DEADLY RATING: ☠☠☠☠

The statistics...

Geography cone snail

Genus: Conus
Length: 15cm (5.9in)
Weight: 300g (10.6oz)
Life span: Unknown

GEOGRAPHY CONE SNAIL

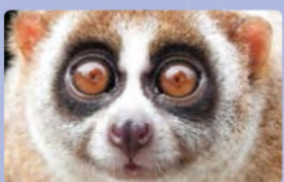
There are over 600 species of cone snail and all of them are venomous. Cone snails deliver their venom using a thin harpoon made from a modified tooth. This is fired from a flexible proboscis that enables the snail to fire in any direction, even directly behind it; this means that there is no safe way to pick up this gastropod. The venom of the cone snail contains over 200 different compounds that can paralyse a small fish in less than two seconds. The geography cone is a particularly large and venomous species. It can deliver enough venom to kill 15 humans in a single sting. There is no antidote; medical care consists of just treating the symptoms until the venom is metabolised.

THE ODD ONE OUT

Which of these is deadly?

BLUE POISON ARROW FROG

The bright colours warn of the deadly toxins in its skin. The most toxic species can kill a human after one brief touch.



SLOW LORIS

This sleepy creature has a special gland on each arm that it licks to give itself a toxic bite. Mothers also lick the fur of their young to deter predators.

© Dr Philip Bethge

DUCK-BILLED PLATYPUS

The male platypus has a sharp spur on its hind legs. The venom isn't powerful enough to kill a human but it can cause excruciating pain.

© Nigel Voaden

HOODED PITOHUI

Its diet of beetles provides a supply of the neurotoxin homobatrachotoxin. This chemical seeps into the feathers and just touching the bird can cause numbness.

ANSWER: THEY ALL ARE!

BLUE-RINGED OCTOPUS

Although one of the smallest octopuses, this is easily the most lethal. The main ingredient in its venom is tetrodotoxin, which is 10,000 times more toxic than cyanide. Tetrodotoxin is found in many other venomous animals, including cone snails, but it's present in much higher concentrations in blue-ringed octopus venom. Bites are tiny and almost painless but, within ten minutes, the venom blocks the action of all the nerves that control the muscles. General paralysis and breathing difficulty ensue, but because the venom can't cross the blood-brain barrier, the victim remains aware throughout. The paralysis even results in fixed, dilated pupils and rescuers may give up resuscitation attempts while the victim is still alive and conscious.

DEADLY FACTOR

Blue-ringed octopus

AGGRESSION: Docile. Will only attack if provoked or stepped on.

INTELLIGENCE: High. Can solve mazes and imitate its surroundings.

SPEED: Moderate. Uses jet propulsion for extra speed when making a getaway.

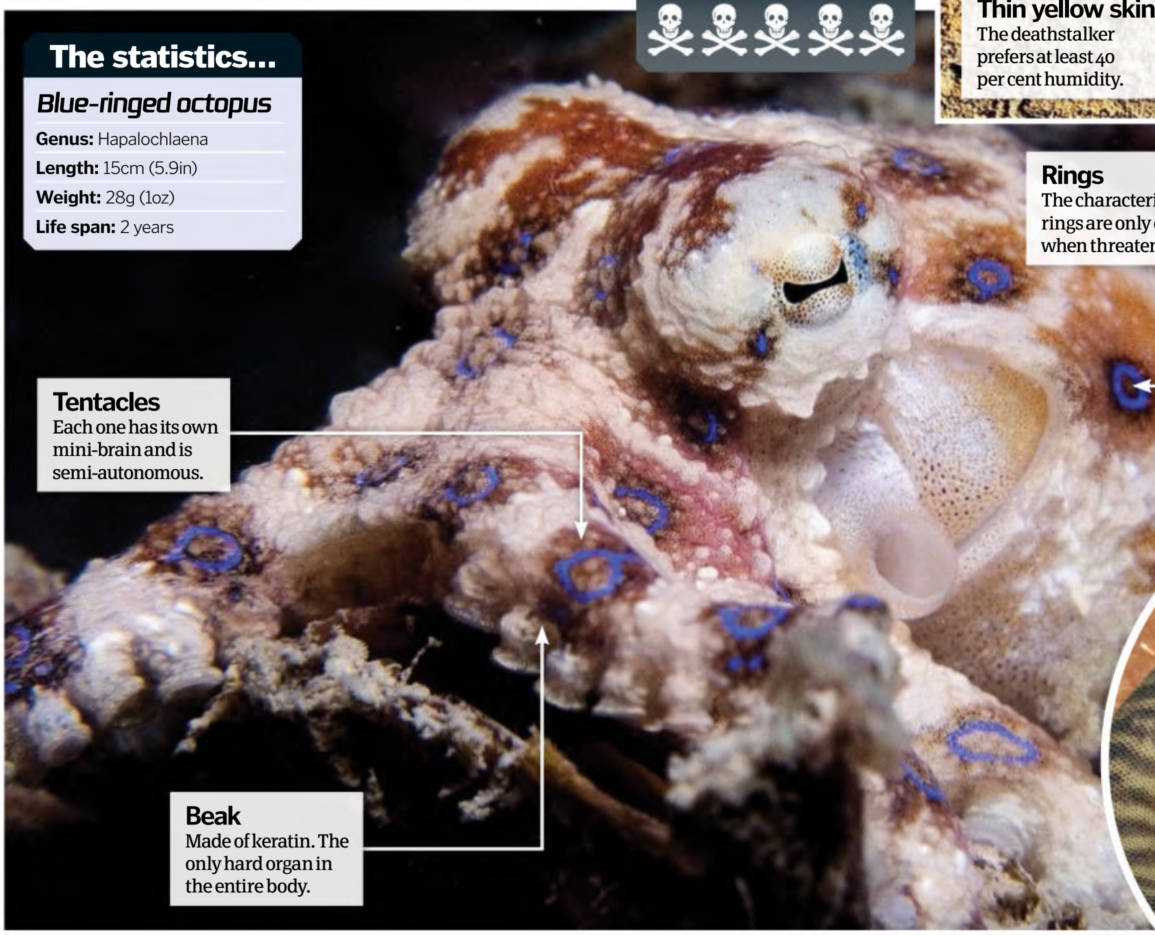
STRENGTH: Moderate. Powerful, muscular tentacles but small overall size.

DEADLY RATING: ☠☠☠☠☠

The statistics...

Blue-ringed octopus

Genus: Hapalochlaena
Length: 15cm (5.9in)
Weight: 28g (1oz)
Life span: 2 years



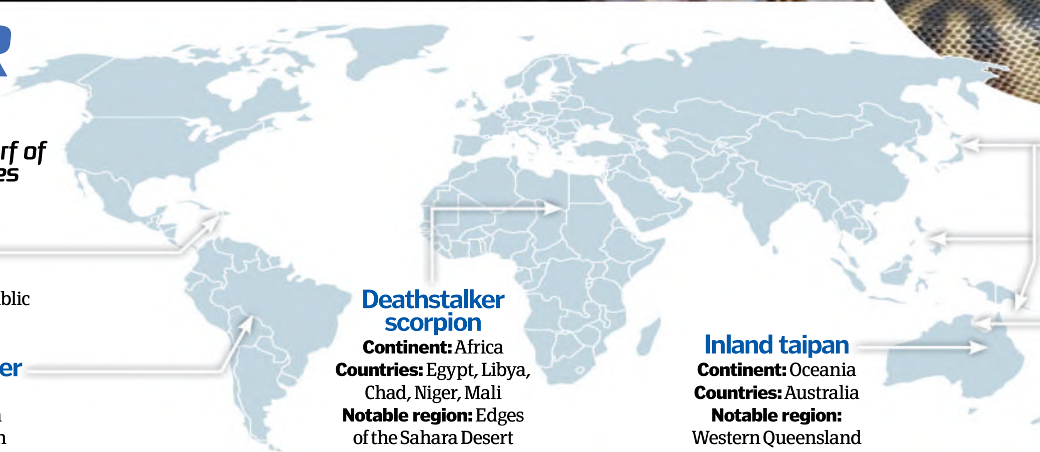
The statistics...

Deathstalker scorpion

Genus: Leiurus
Length: 3-7.7cm (1.2-3in)
Weight: 10g (0.35oz)
Life span: 5-6 years

DANGER MAP

We pinpoint the home turf of some of the toxic beasties featured in this article



Haitian solenodon
Continent: North America
Countries: Haiti, Dominican Republic
Notable region: Hispaniola

Brazilian wandering spider
Continent: South America
Countries: Costa Rica to Argentina
Notable region: Brazilian Amazon

Deathstalker scorpion
Continent: Africa
Countries: Egypt, Libya, Chad, Niger, Mali
Notable region: Edges of the Sahara Desert

Inland taipan
Continent: Oceania
Countries: Australia
Notable region: Western Queensland

5 TOP FACTS VENOM

Different strokes
1 Bees and wasps look similar but strike in different ways. Bee venom is acidic, to cause pain and drive attackers away. Parasitic wasps, meanwhile, use a neurotoxin to paralyse their host.

Small but deadly
2 Baby inland taipans are actually more lethal than adults as they haven't yet learned to regulate their venom dose so will inject their entire supply with a single bite.

Painless stinger
3 Cone shell toxin contains a compound that is 100-1,000 times more effective than morphine as an anaesthetic. This helps to calm prey so they don't struggle too much.

Poisoner by proxy
4 The blue-ringed octopus doesn't even need to bite to poison you; the venom can be absorbed directly through the skin so even swimming near one can result in mild symptoms.

Stiff medicine
5 One unusual side-effect of a bite from the Brazilian wandering spider is that the venom causes acute and painful erections in men that can last for hours.

DID YOU KNOW? *In 2005, a chef in Somerset, UK, bitten by a Brazilian wandering spider only survived after a week in hospital*

Stinger
The penultimate segment is darker due to the venom glands.

© Yair Goldstof

© Estel Inbar

DEATHSTALKER SCORPION

The deathstalker is the most venomous scorpion with a lethal dose of around a third of a milligram of venom per kilo of bodyweight. A cocktail of toxins causes heart failure and pulmonary oedema (fluid in the lungs). The deathstalker's normal prey is locusts and crickets but it is a twitchy and aggressive creature that will sting anything that comes too close. Only its small size reduces the danger to humans; a typical sting only delivers 0.225 milligrams of venom and deaths are rare, except in small children and cases of allergic reaction. Nevertheless, antivenom is not as effective as it is for snakebites and a sting from a deathstalker is regarded as a medical emergency, even with prompt hospitalisation.

DEADLY FACTOR
Deathstalker scorpion

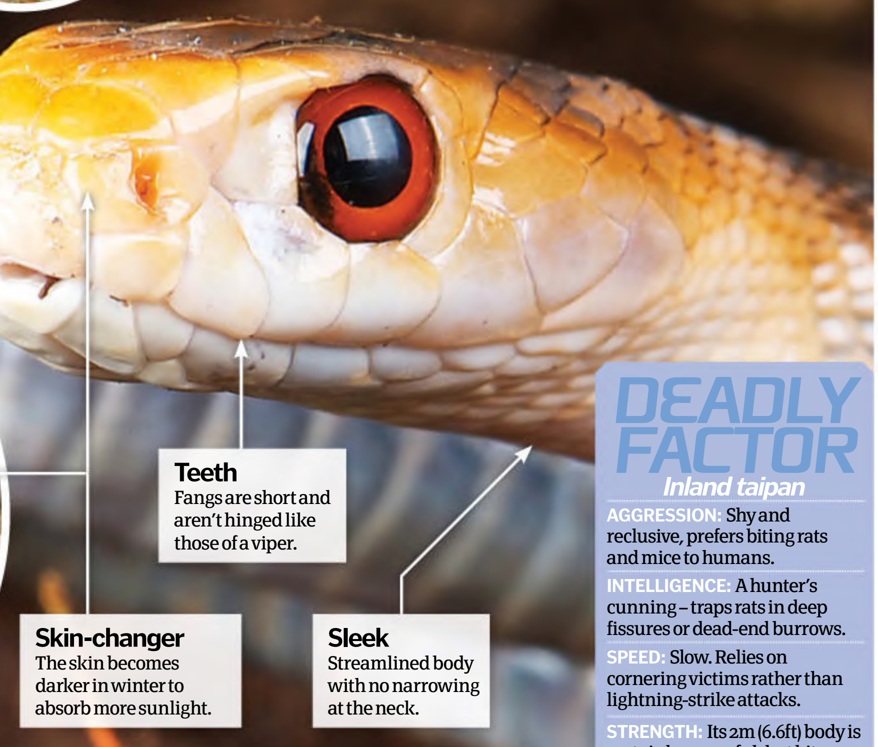
AGGRESSION: High. A twitchy, trigger-happy stinger that attacks anything nearby.

INTELLIGENCE: Low. Simple arachnid cunningly designed to hunt down insects.

SPEED: High. The strike from the tail is impossible to dodge.

STRENGTH: Low. The pincers are there to grip small prey only.

DEADLY RATING: ☠☠☠☠



"The lethal dose for a typical adult human is calculated to be around two milligrams"

Teeth
Fangs are short and aren't hinged like those of a viper.

Skin-changer
The skin becomes darker in winter to absorb more sunlight.

Sleek
Streamlined body with no narrowing at the neck.

Blue-ringed octopus
Continents: Oceania/Asia
Countries: Japan, Australia, Indonesia
Notable region: Southern New South Wales

Geography cone snail
Continent: Oceania
Countries: Australia
Notable region: Northern coast of Australia

INLAND TAIPAN

The inland taipan has the deadliest venom of any land animal; in fact, it is one of the most deadly substances of any kind. At least 40 times more powerful than the venom of a cobra, the lethal dose for a typical adult human is calculated to be around two milligrams; that's about as much as the blood you lose from a mosquito bite. A typical bite injects enough venom to kill 25 humans, or a quarter of a million mice! Fortunately, the inland taipan lives in extremely remote parts of central Australia where it very rarely comes into contact with people. For such a deadly creature, it is also very shy and, despite its other name – the fierce snake – it never attacks unprovoked.

DEADLY FACTOR
Inland taipan

AGGRESSION: Shy and reclusive, prefers biting rats and mice to humans.

INTELLIGENCE: A hunter's cunning – traps rats in deep fissures or dead-end burrows.

SPEED: Slow. Relies on cornering victims rather than lightning-strike attacks.

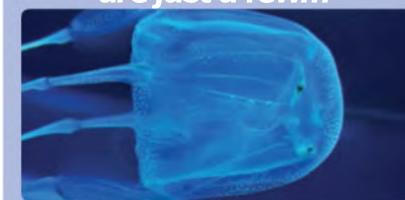
STRENGTH: Its 2m (6.6ft) body is certainly powerful, but bite strength is relatively weak.

DEADLY RATING: ☠☠☠

The statistics...
Inland taipan

Genus: Oxyuranus
Length: 1.8-2.5m (5.9-8.2ft)
Weight: 6kg (13.2lb)
Life span: 10-15 years

BEST OF THE REST...
Nature has plenty more toxic creatures – here are just a few...

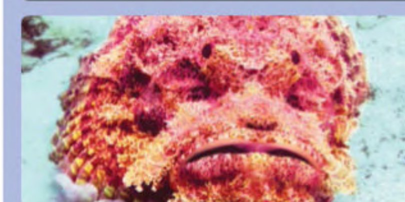


BOX JELLYFISH
Found in the waters of northern Australia, the box jellyfish has one of the most deadly venoms in the world. It attacks both the heart and nervous systems.

MOST PAINFUL VENOM

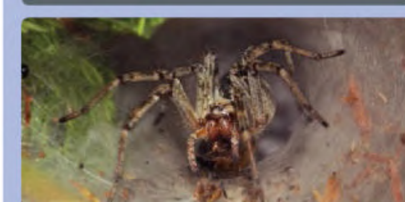
BLACK MAMBA
A native of eastern Africa, this long, highly venomous snake (actually brown in colour) can inject a whole bunch of nasty neurotoxins and cardiotoxins.

AFRICA'S MOST VENOMOUS SNAKE



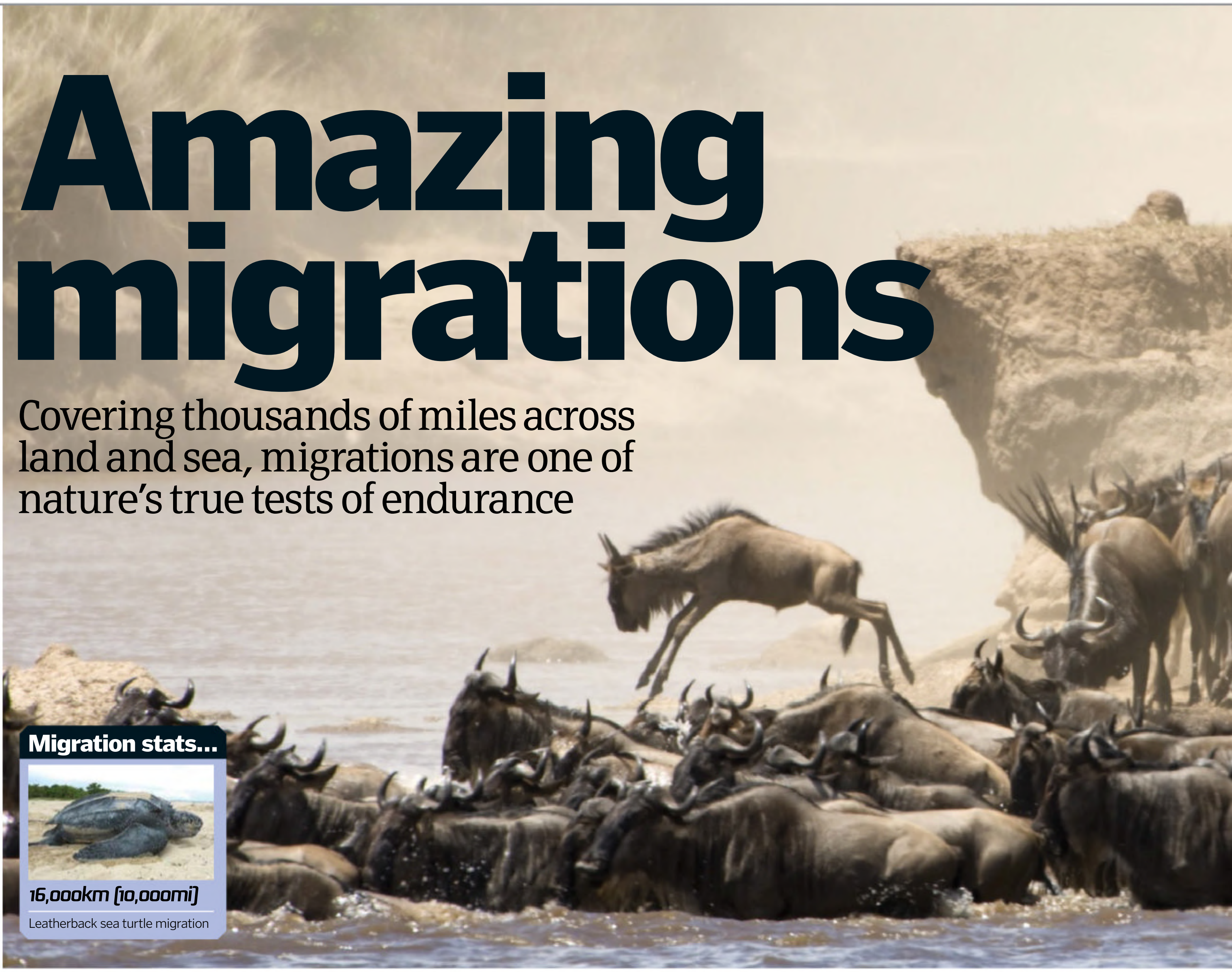
STONEFISH
Not to be mistaken for a lump of coral, the stonefish delivers powerful neurotoxins from its dorsal spines; in fact, some think it's the most venomous fish in the world.

MOST VENOMOUS FISH



FUNNEL-WEB SPIDER
Unlike most other venomous spiders, the venom of the male funnel-web is more deadly than that of the female. These arachnids have super-powerful fangs.

AUSTRALIA'S MOST FEARED



Amazing migrations

Covering thousands of miles across land and sea, migrations are one of nature's true tests of endurance

Migration stats...

16,000km (10,000mi)

Leatherback sea turtle migration

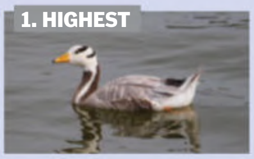
For some species, a migration is a habitual journey every year, but for others it is the never-ending voyage of a lifetime. The key element that links every type of migration is the instinct to survive.

Animals will move location in order to position themselves in the best place for their needs. This could be a move with the seasons to escape the cold weather, like the swallows that leave UK shores for the balmier African climate each winter. Similarly, some animals will move where the food goes, or for other instincts such as to breed. Others will make the journey to safety to give birth, like humpback whales that migrate to calving grounds in the winter, and some migrate to raise young, escape overcrowding or to fulfil a biological need like moulting. Whatever the reason for such a journey, necessity is at the core.

But how do they know where to go and when to leave? Each species has its own cues. For example, birds that leave the UK in winter can tell it's time to migrate when the days start to shorten and the nights get chillier. These seasonal cues also help them find their way. Visual clues, such as the position of the Sun, with other sensory clues like scent and sound of their destination alongside detection of Earth's magnetic field help all kinds of animals to navigate.

Animals can survive such journeys by fattening up in preparation, travelling in large groups and by hitching a lift on currents and winds. Migration is closely linked to seasonal changes and weather patterns. When things go wrong, this can affect the rest of the ecosystem, which relies on the migrating species' arrival. For example, due to climate change, some bird species are migrating earlier and departing later. This means that when they arrive too early there is not enough food to go around, and so their chicks suffer as a result. In turn, there are fewer of these birds for their predators to eat, and so on as the effect ripples through the ecosystem.

1. HIGHEST



Bar-headed goose
These geese can reach 6,300m (20,669ft) in altitude on their mammoth migration over the Himalayas.

2. LONGEST

Blue whale
At over 30m (98ft) long, the blue whale is naturally the longest migrating animal on Earth, as it's the biggest animal in history.

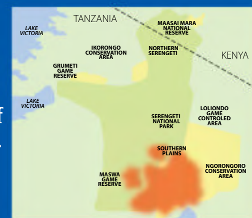
3. LARGEST

Plankton
The daily vertical migration of plankton from deep water to the surface is the largest migration on Earth in terms of biomass.

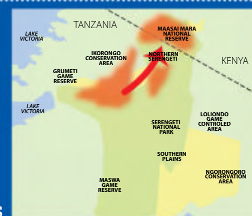
DID YOU KNOW? *Every autumn, millions of red crabs migrate to spawn at the coast of Christmas Island in the Indian Ocean*

The Serengeti's great migration

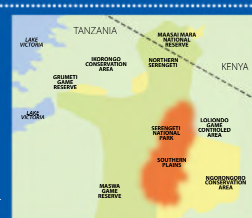
Year on year, huge herds of wildebeest, zebra, gazelle, eland and impala migrate around the Serengeti in search of fresh water sources and lush grazing areas



The herds spend January to March spread out and grazing the lush short-grass plains of the South Serengeti. The females calf in two to three weeks around February and March before starting their long journey north through Seronera as they head toward the Western Corridor in April and May.



June sees the vast herds split, as some cross the Grumeti River and move into the Grumeti Reserve, while others choose to head north. Over the summer months the herds gradually reunite in the northern part of the Serengeti National Park and spread out over the border into Kenya's Maasai Mara.



The wildebeest spend October in the far north of the Serengeti and into Maasai Mara before heading south, down the eastern side of the Serengeti National Park. As December arrives, the herds are just in time for the rains and graze on the lush southern plains once more.

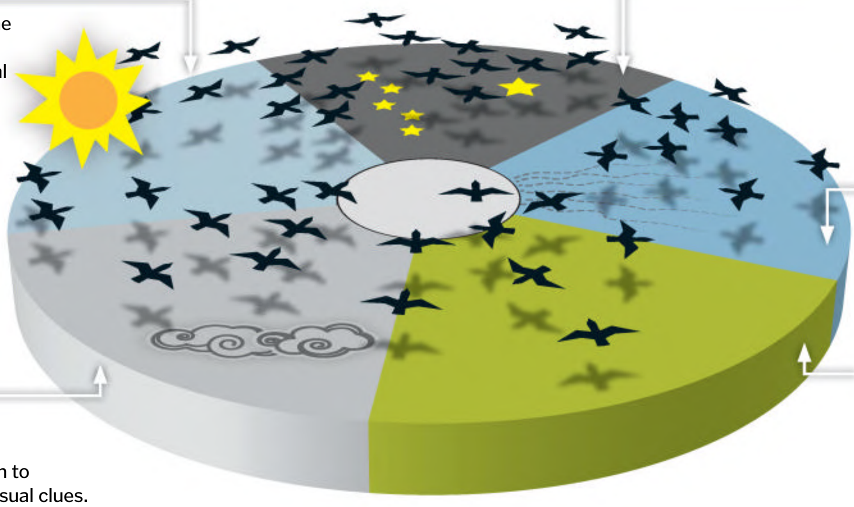
Migration stats…

2 million

Animals migrate across the Serengeti every year

How birds navigate

Birds sure don't need maps – they use incredible senses to find their way



Sun compass
Some birds, such as homing pigeons, use the Sun's position as a navigational cue. This is helped by their circadian rhythm (or 'internal clock') as the Sun tracks across the sky.

Star compass
Night migrations made by birds use the stars to find their way. This isn't an innate behaviour, so they birds must learn their north-south orientation by observing stars at a young age.

Odour map
A bird's sense of smell can put it on the right path. The scents of its home range can imprint a 'map' that can guide it back to the nest.

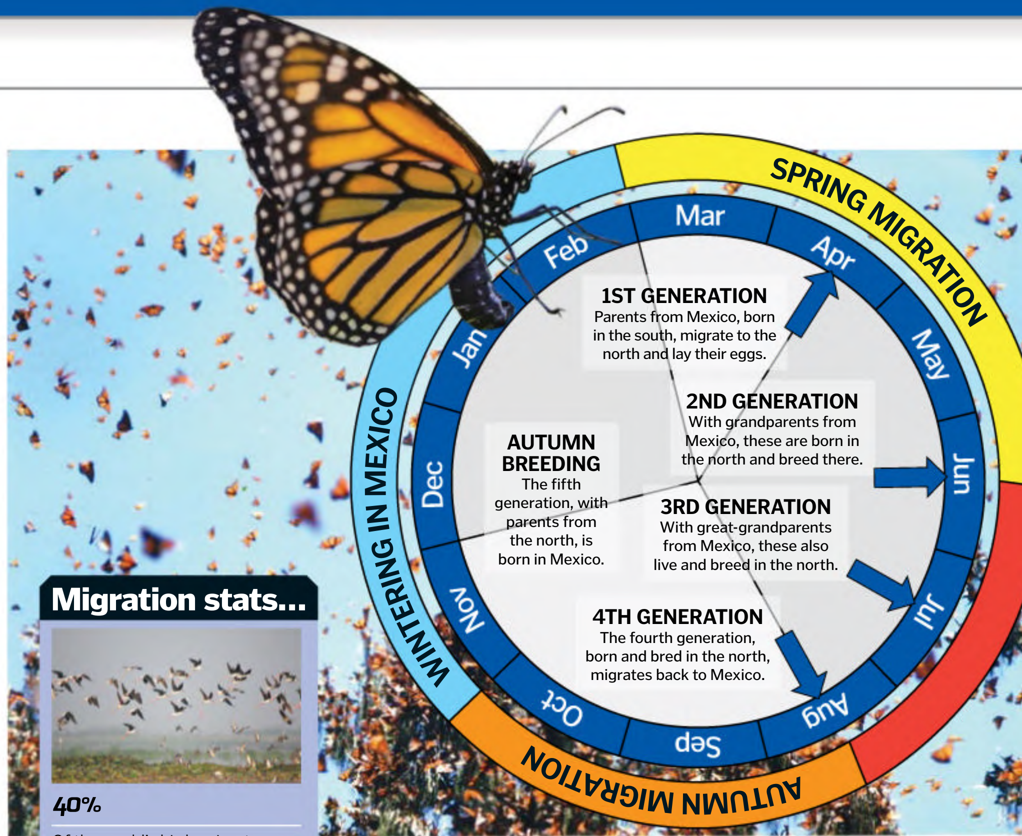
Magnetic compass
Migratory birds collect magnetic-field information through specialised receptors within their eyes. These receptors help them to distinguish north and south with no other visual clues.

Magnetic map
Another theory is that many birds may rely on Earth's magnetic field to find their way. The strength of this field increases the further away the bird gets from the equator.

Monarch butterfly

The monarch butterfly makes its home in the northern United States and Canada, but every year millions of them embark on a 4,828-kilometre (3,000-mile) journey south to the hills of central Mexico to avoid the harsh winter weather. Here they rest on tree branches in incredibly dense gatherings as they hibernate for four months.

What is incredible about this migration is that in summer, a monarch butterfly only lives up to six weeks. One generation migrates south, but it's that generation's grandchildren that migrate back north in the spring. Yet the butterflies always know where to go, sometimes even returning to the exact same trees their ancestors used.



Migration stats…

40%

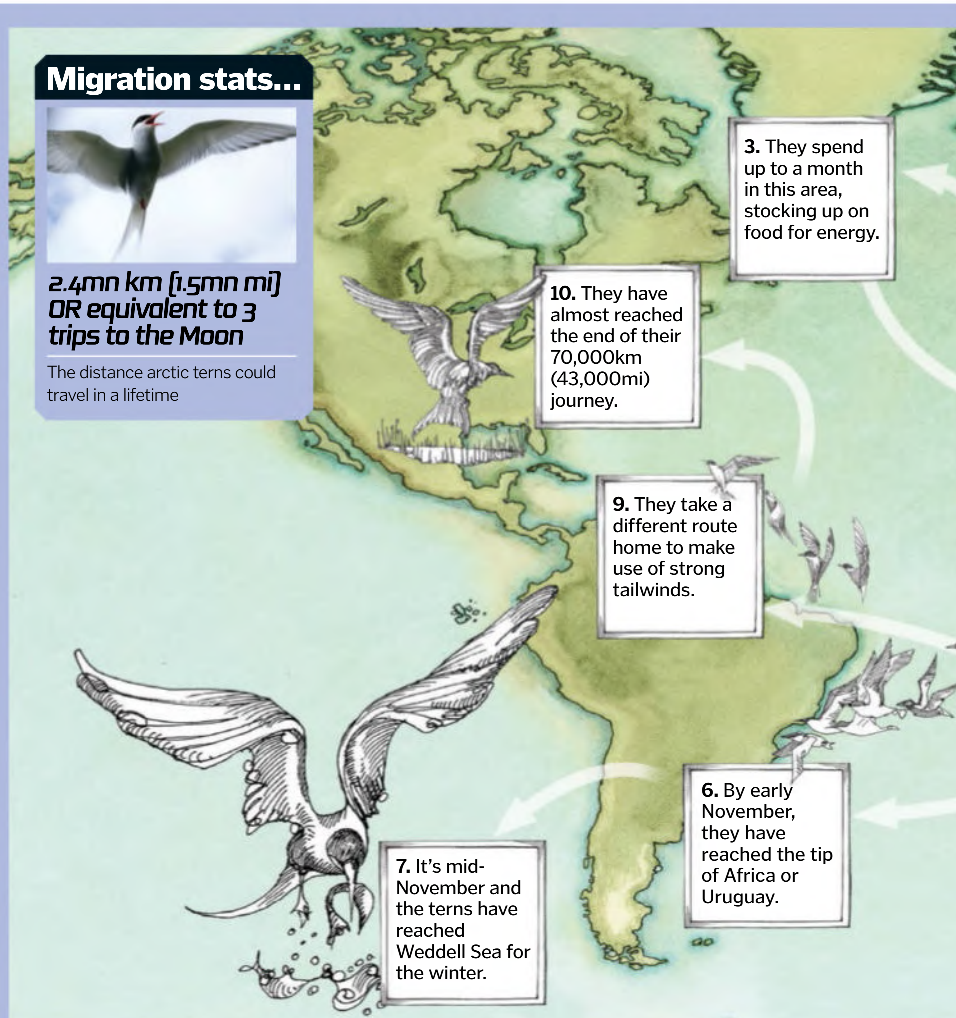
Of the world's birds migrate

Arctic tern

Every year, these little birds take to the wing to cover a mammoth distance, practically from pole to pole.

During the northern hemisphere summer, Arctic terns breed in colonies in Arctic and sub-Arctic regions of Europe, Asia and North America. 24-hour sunlight allows them to hunt and feed their chicks around the clock.

As the seasons begin to turn, these birds begin their flight south. They begin their 35,000-kilometre (21,750-mile) flight to the Southern Ocean where they will stay from November to March before returning to the Arctic to breed in the spring. This allows these birds access to 24-hour sunlight for eight months of the year!



Migration stats…

2.4mn km (1.5mn mi) OR equivalent to 3 trips to the Moon

The distance arctic terns could travel in a lifetime

RECORD BREAKERS
A LONG WAY BACK

4,800km

FURTHEST OVERLAND MIGRATION

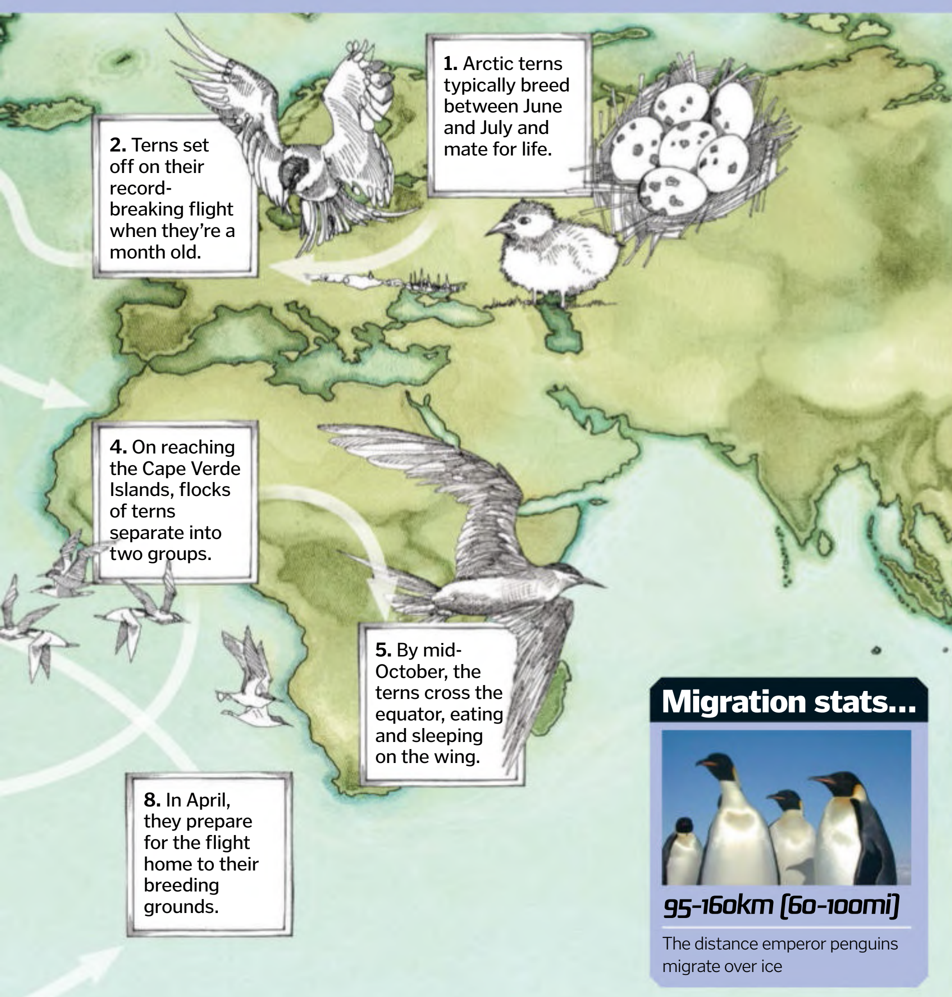
Porcupine caribou hold the record for their incredibly long migration of up to 4,800km (2,983mi) per year across the frozen tundra in North America.

DID YOU KNOW? *Wandering albatrosses circumnavigate the globe as they migrate after the breeding season*

Salmon

The salmon's story begins with eggs laid in shallow freshwater streams, miles inland. As the young fish hatch and grow, they move downstream until they reach a river mouth. These hardy fish adapt from living in fresh water to living in salt water and embark on an ocean-going journey as adult salmon to feed at sea.

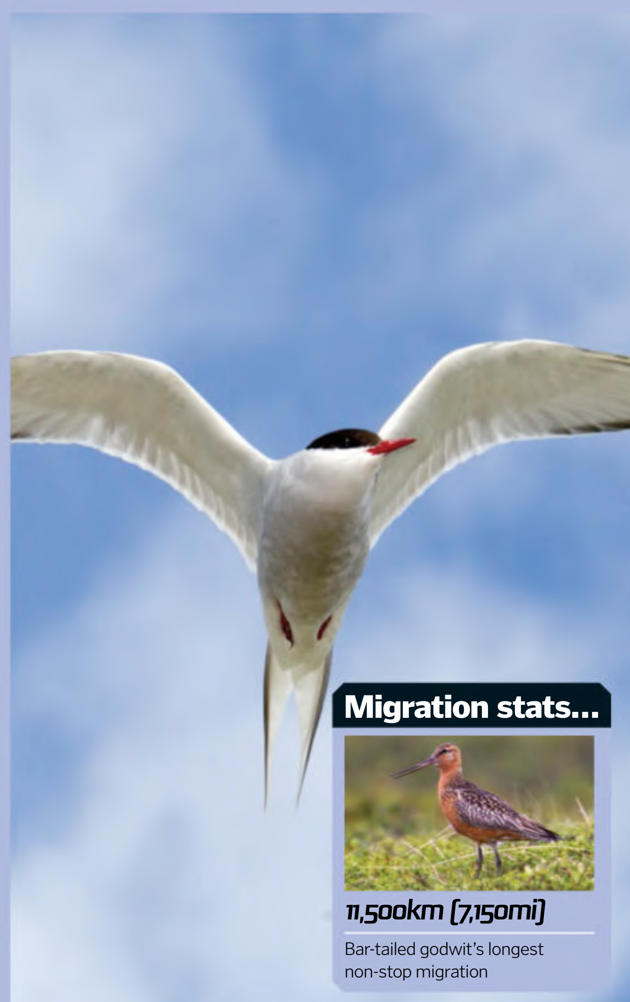
After a few years of fattening up, adult salmon make the staggering journey back to their home rivers to breed. They can home in on the exact location they were born using Earth's magnetic field, the imprint of their river's 'scent' and pheromones secreted into the water by other salmon.



Migration stats...

95-160km (60-100mi)

The distance emperor penguins migrate over ice



Migration stats...

11,500km (7,150mi)

Bar-tailed godwit's longest non-stop migration

Nature's satnavs

How do some creatures use the Earth's magnetic field to find their way around?

In order to navigate when the sky is cloudy, humans use compasses, originally made from the magnetic material lodestone, or magnetite. This iron oxide is the most magnetic naturally occurring substance on the planet. Interestingly, several animals on Earth have evolved internal compasses that use the same stuff.

This navigational adaptation is ancient and the ability to detect a magnetic field can be observed in life forms as simple as bacteria. Magnetotactic bacteria produce chains of magnetite, or a similar iron oxide – greigite. These chains rotate within Earth's magnetic field and because the micro-organisms are so light, they rotate with them, like a compass needle. Using their internal compasses, the bacteria are prevented from being carried away from the narrow zones where conditions are optimal for their survival.

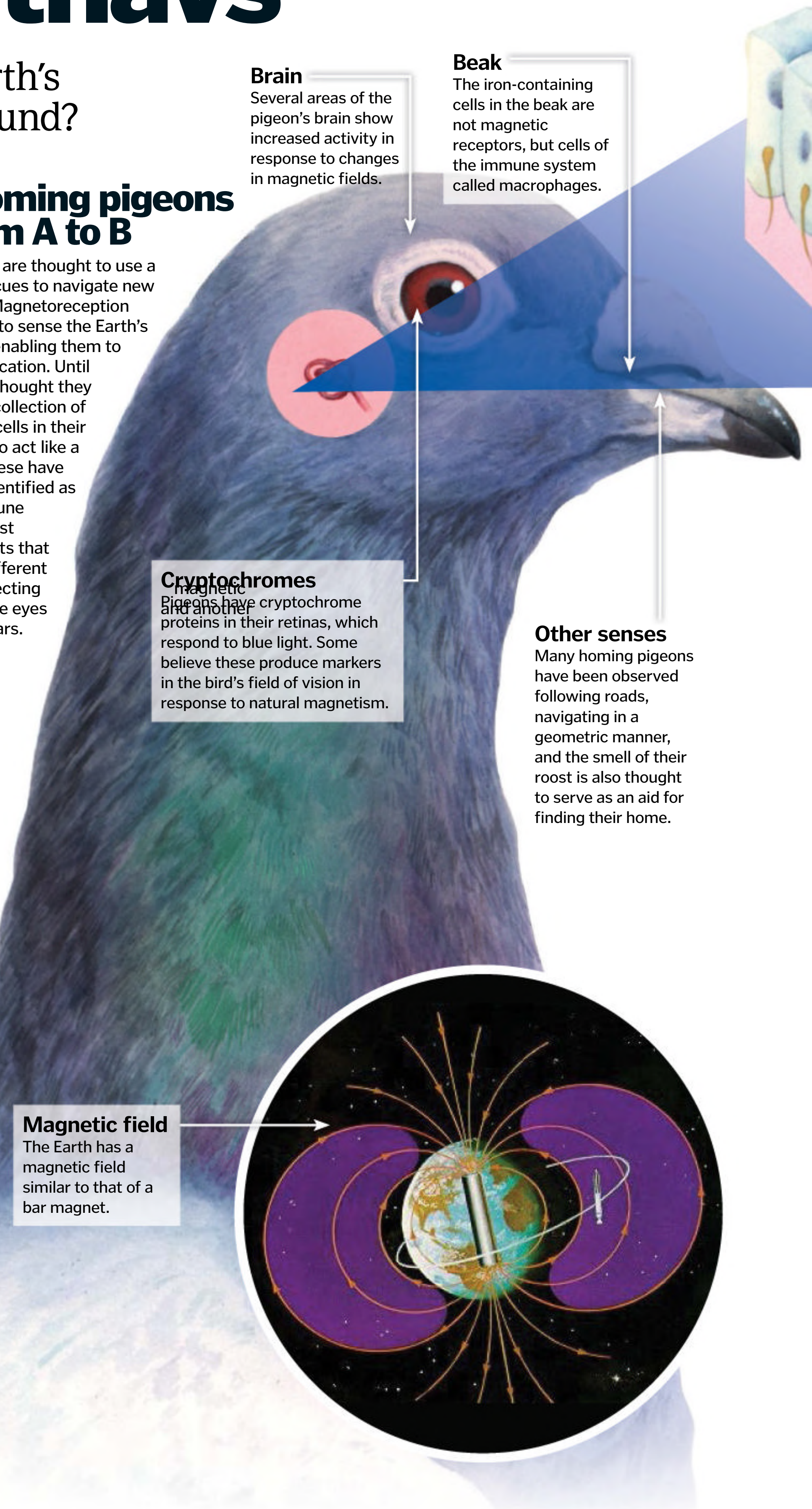
Magnetite is also found in larger organisms, like pigeons and fish, but instead of using it to turn like a compass needle, they incorporate the metal compound into nerve cells. Essentially this gives them a sixth sense for navigation, which they use with other cues like landmarks and the Sun's position to find their way around.

Magnetic metal is not the only way organisms detect magnetic fields; some use cryptochrome proteins, found in the eye, to 'see' magnetic fields. These cells, also used to regulate the sleep-wake cycle of circadian rhythm, respond to blue light and generate two spinning radicals – chemically reactive molecules. Earth's magnetic field alters the spin of these radicals, enabling the animal to establish its location.

Cartilaginous fish, including sharks and rays, can also pick up the Earth's magnetic field, but in a more indirect way. They have specialist organs known as the ampullae of Lorenzini on their face, which can detect electrical fields in the water. Oceanic currents are influenced by Earth's magnetic field and generate electrical signals, which can be picked up by the nerve cells, allowing the fish to orientate themselves.

How homing pigeons get from A to B

Homing pigeons are thought to use a combination of cues to navigate new environments. Magnetoreception allows the birds to sense the Earth's magnetic field, enabling them to estimate their location. Until recently, it was thought they did this using a collection of iron-containing cells in their beaks, thought to act like a compass, but these have recently been identified as cells of the immune system. The latest research suggests that there are two different systems for detecting magnetic fields – one in the eyes and one in the ears.



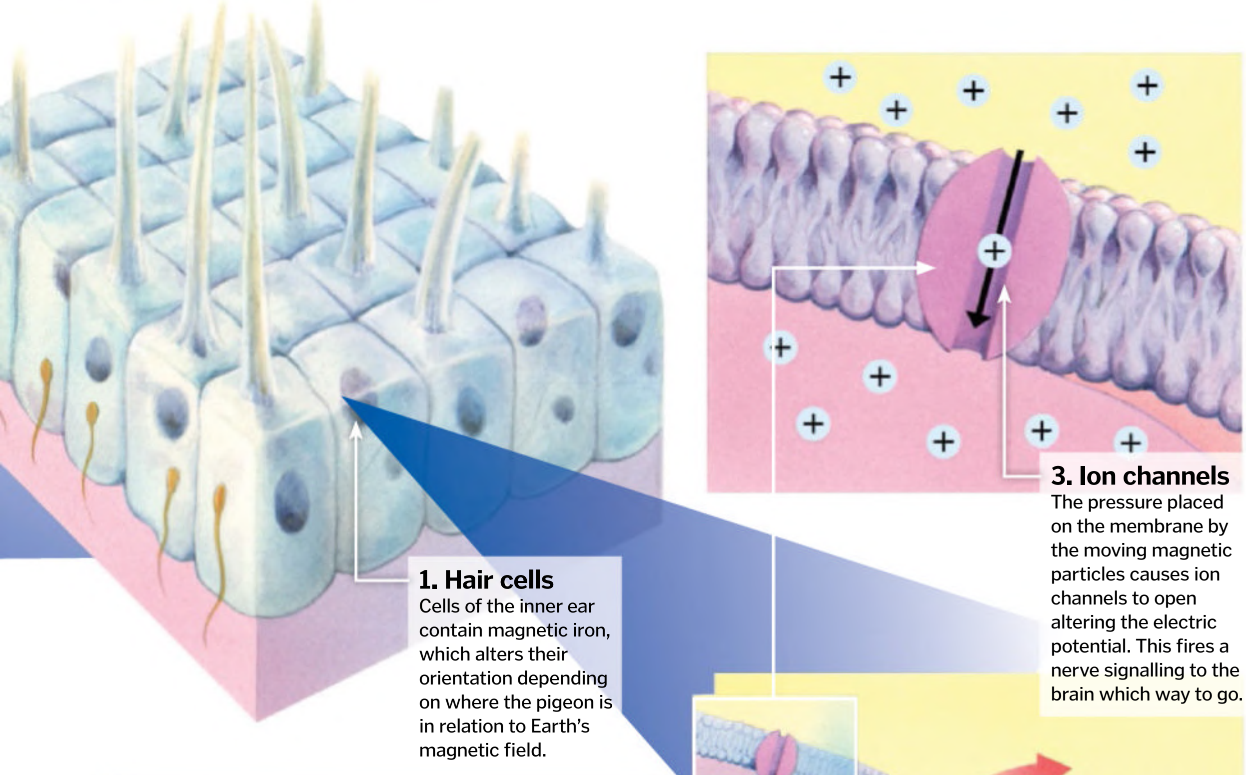
RECORD BREAKERS
PRICEY PIGEONS

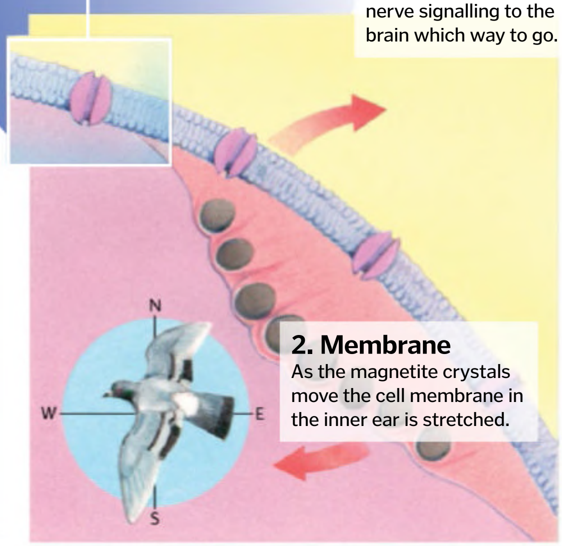
$400K

MOST EXPENSIVE RACING PIGEON

The natural ability of some racing pigeons to find their way home is so prized that one bird – fittingly named Bolt after the sprinter – was sold for $400,000 at auction in 2013.

DID YOU KNOW? *Magnetite is embedded in plastic to store info in magnetic storage devices, like floppy disks and hard drives*





Can people feel magnetic fields?

There is evidence that large mammals, even humans, might be sensitive to magnetic fields too. Magnetite has been detected in the bones of the human nose, and a magnetosensitive chryptochrome is found in the human eye. That said, our understanding of magnetoreception is not detailed enough to draw firm conclusions. Still, magnetic sensitivity has been experimented with in the body-modification community. This cosmetic technique uses a silicon-encased neodymium magnet implanted in the fingertip. Wearers can levitate paperclips and some report being able to feel the magnetic fields around electric wires and even being able to detect a break in the circuit.

Sharks use sense organs called ampullae of Lorenzini to detect electrical fields in the ocean, for hunting and navigation

Top five magnetic organisms

1 Magnetotactic bacteria

These micro critters use magnetic crystals to align themselves within the Earth's magnetic field like a compass needle. The entire creature rotates relative to the Earth. A meteorite from Mars has been claimed to contain fossilised magnetotactic bacteria (pictured above), though this has been fiercely contested.

2 Sea turtle

Landmarks in the sea are few and far between, so turtles use the Earth's magnetic field to navigate back to their favoured feeding grounds, following long, predictable routes every year.

3 Fruit fly

The laboratory fly, Drosophila melanogaster, has a cryptochrome able to detect a magnetic field. It is often used as a model to test the magnetoreceptor genes from other species.

4 Pigeon

Homing pigeons have iron spheres in the hair cells of their inner ears, allowing them to use the Earth's magnetic field to navigate.

5 Trout

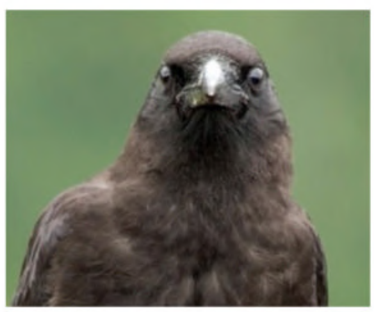
Around one in every 10,000 of the cells lining a trout's nose contains powerful magnetic material, which responds rapidly to changes in the external magnetic field.




THE WORLD'S SMARTEST ANIMALS

Discover fascinating facts about some of the most intelligent animals on Earth





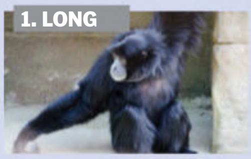

Although humans don't top the food chain, what we lack in physical ability we certainly make up for in mind. But that's not to say we're the only smart animals on the planet. Apes have long been considered our closest living relatives since we share over 90 per cent of their DNA, but we're also surprisingly similar in the intellectual stakes to other species too.

However, judging animal intelligence is not as easy as getting them to sit a multiple-choice exam. In fact, scientists have spent decades devising methods in order to weed out the brainless from the brainy. Researchers will spend years in the wild observing a species' natural behaviour in order to get a better insight into how they learn, solve problems and make decisions. Combining that with controlled lab testing methods, we're finally getting a better understanding of what animals are capable of.

Many animals, including domesticated pets, display cleverness and a desire to learn, but a small handful of species really outshine others when it comes to being truly intelligent. For example, the ability to memorise and recall past events in order to make decisions that will affect the present and future is found only in some of the very smartest animals on Earth. Join us in this feature as we uncover the facts about eight of the most intelligent creatures. From land mammals to marine life, you'll be surprised by how smart these animals really are and how similar they are to us.

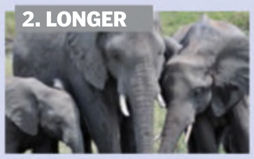
HEAD 2 HEAD
LONG-TERM MEMORY

1. LONG



Apes
These primates have a human-like long-term memory and are able to recall past experiences to help solve problems in their environment.

2. LONGER



Elephants
Elephants remember their relatives and are able to recognise skeletal remains of their peers long after they have died.

3. LONGEST

Dolphins
Dolphins have an impressive long-term memory that means they're able to recognise a call from a dolphin they have not had contact with for decades!

DID YOU KNOW? *Gorillas in the Republic of the Congo were observed using large sticks to test the depth of swamp water*

GREAT APE

Decision maker

Apes are not quite ready to take over the planet, but they are certainly among the most intelligent animals on Earth. In particular, chimpanzees have been subject to numerous research projects over the years to discover more about their intellectual similarities to humans. Observations have shown these brainiacs are capable of solving complex problems, are adept at decision making and will even make and use tools in the wild to help forage for food. They also have an impressive memory and are able to recognise other chimps and humans they have not seen for several years. In captivity, chimps have been taught to communicate and convey ideas using sign language and lexigrams.

99% *Chimp genes shared with humans*

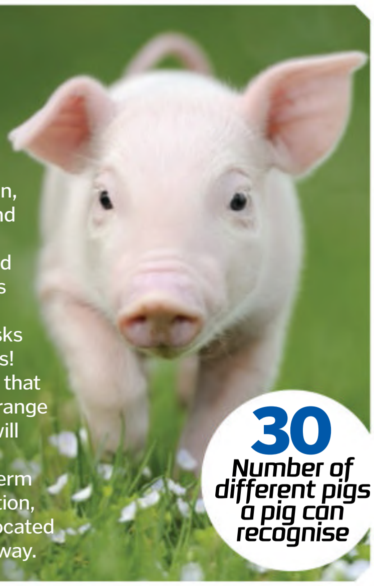
Talking apes

How sign language helps us communicate with apes

In 1967, a chimpanzee named Washoe became the subject of cognitive research. Allen and Beatrix Gardner aimed to discover whether chimps could master American sign language (ASL), after previous attempts to teach vocal languages to chimps had failed. To teach sign language to Washoe, they raised her in the same way as a human child and avoided verbal communication. Washoe eventually mastered around 130 signs and she also passed her skills onto her son Loulis. Since the experiment, many other chimps have been taught to use sign language and lexigrams as a way of communicating with humans.

PIG

Fast learner



Pigs are one of the most misunderstood species on Earth. Despite their reputation, these smart swines are clean animals and have proven through various scientific studies to be as smart as a three-year-old child! They are impressively fast learners who can respond to their own name, as well as be trained to perform various tasks and tricks, including playing video games!

Pigs are also incredibly social animals that communicate with one another using a range of different grunts and squeals – sows will even sing to their young when nursing. What's more, they have excellent long-term memory and a very good sense of direction, so are able to memorise where food is located and how to get home even from miles away.

30 *Number of different pigs a pig can recognise*

RAT

Logical thinkers

Rats are highly intelligent and have been used in scientific research for decades due to their learning ability. They have poor eyesight but are natural problem solvers with an excellent memory that enables them to navigate a route to food without ever forgetting the way. They are also very social and bond quickly with their own kind and humans, and can be trained to perform tricks as well as learn to respond to their own names when called. Gambian pouched rats have even been trained to successfully detect land mines in Africa using their heightened sense of smell.

2g *The weight of an average rat brain*

Observation and scientific research have been key to unearthing some fascinating facts about the animals we share our planet with. For centuries, scientists have sought to learn more about animal intelligence in order to determine how we differ as a species. As humans we're set apart from others in the animal kingdom thanks to our advanced thought processes. We're able to retrieve and combine knowledge and information in order to continually gain a new understanding of the world around us, which means we're adept to complex problem solving and can adapt quickly to new surroundings. Although it's been proven that we're all wired differently, we do share some intellectual similarities with many animals and not just our closest living relative, the chimpanzee.

Studying animal intelligence is no simple task, however. It's known scientifically as animal cognition – the study of the mental capacity of animals. Cognition is a term used to describe all mental abilities related to knowledge and takes into account things such as: attention, memory, judgement, comprehension, reasoning, problem solving, decision-making and language. In order to test an animal's cognition, researchers look for evidence comparable to a human's mental process when observing a species. Intelligence is largely evident in animals that display natural decision-making and problem solving abilities

CROW

Cunning planner

7
The number crows can count up to

Crows are by no means bird-brained; they are in fact cunning and innovative animals that have adapted expertly to their environment. In urban towns and cities, for instance, crows have been observed positioning nuts on the road and waiting for passing cars to crack their tough shells, they'll even wait for a red light before retrieving the snack! What's more, they have a fantastic memory and have been proven to remember human faces and even hold grudges. Crows will also communicate and play tricks on one another in order to hide food they plan to store.

ELEPHANT

Giant genius

Elephants are said to never forget. While that may be true, their long-term memory is not the only thing that makes these gentle giants so clever. Scientific observations have proved elephants are also cultured, self-aware and adept to solving problems. In fact, they will use tools in their environment to help them reach food and even coordinate their efforts. Recent research has also shown that elephants are able to tell some human languages apart, and they are able to grasp a person's age, gender and whether they're a threat based on their voice. Elephants in captivity have also displayed an interest in music and some even engage in art with a clear understanding of colour!

160
Number of tactile and visual signals used by elephants

5 TOP FACTS OUTSMARTING HUMANS

Direction
1 While we rely on sat-navs on long journeys, some animals can do so with no assistance. Homing pigeons can identify their geographical position by sensing the Earth's magnetic field!

Smell
2 Most animals have a better sense of smell than us. Elephants can recognise the scent of up to 30 absent family members and can work out their rough location based on the tracks left behind.

Memory
3 Chimps can outsmart us when it comes to memory games, as they have a photographic memory. In tests, young chimps could beat human adults at recalling a sequence of numbers.

Reproduction
4 A species of Amazonian ants have developed the ability to reproduce via cloning, which means the number of females able to reproduce each generation is doubled.

Hearing
5 Luckily we don't rely solely on our hearing sense to survive. Animals such as owls can pinpoint the position of sound sources in the dark night in less than 0.01 of a second.

DID YOU KNOW? *Octopuses sometimes use coconut shells as a shield to hide from potential predators*

DOLPHIN

Creative

It's no secret that dolphins are the most intelligent animals in the ocean. Like humans, they are self-aware and learn as individuals who can then educate others based on their own experiences. Passing knowledge between generations means dolphins create certain behaviours unique within their social groups. They are also creative thinkers and especially so when it comes to play and foraging for food. In the wild, dolphins have been known to partake in games of catch using things found in their environment, such as seaweed. They also have a strong memory and a sophisticated language that helps them to communicate with one another.

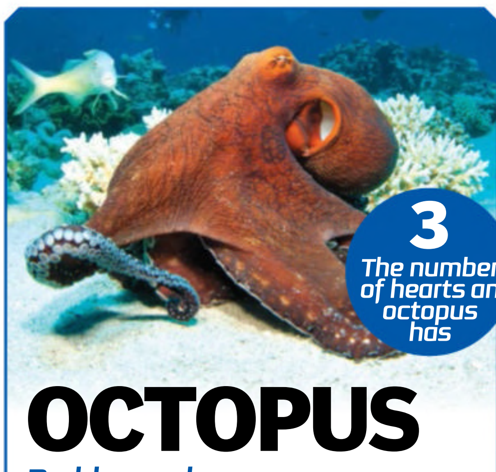
30 YEARS *Dolphins can remember each other after decades apart*

285 *Number of squirrel species*

SQUIRREL

Deceiving stasher

These clever critters are pretty deceptive when it comes to protecting their stash of food and will fool potential thieves by pretending to hide food when they know they're being watched. Squirrels also have an impressive memory recall and are able to plan ahead for the winter months by concealing food around the forest that they can locate months later. What's more, squirrels have been scientifically proven to learn behaviours from others, which makes them pretty smart. Squirrels in California have even been observed covering themselves in the scent of rattlesnakes to ward off predators.



3 *The number of hearts an octopus has*

OCTOPUS

Problem solver

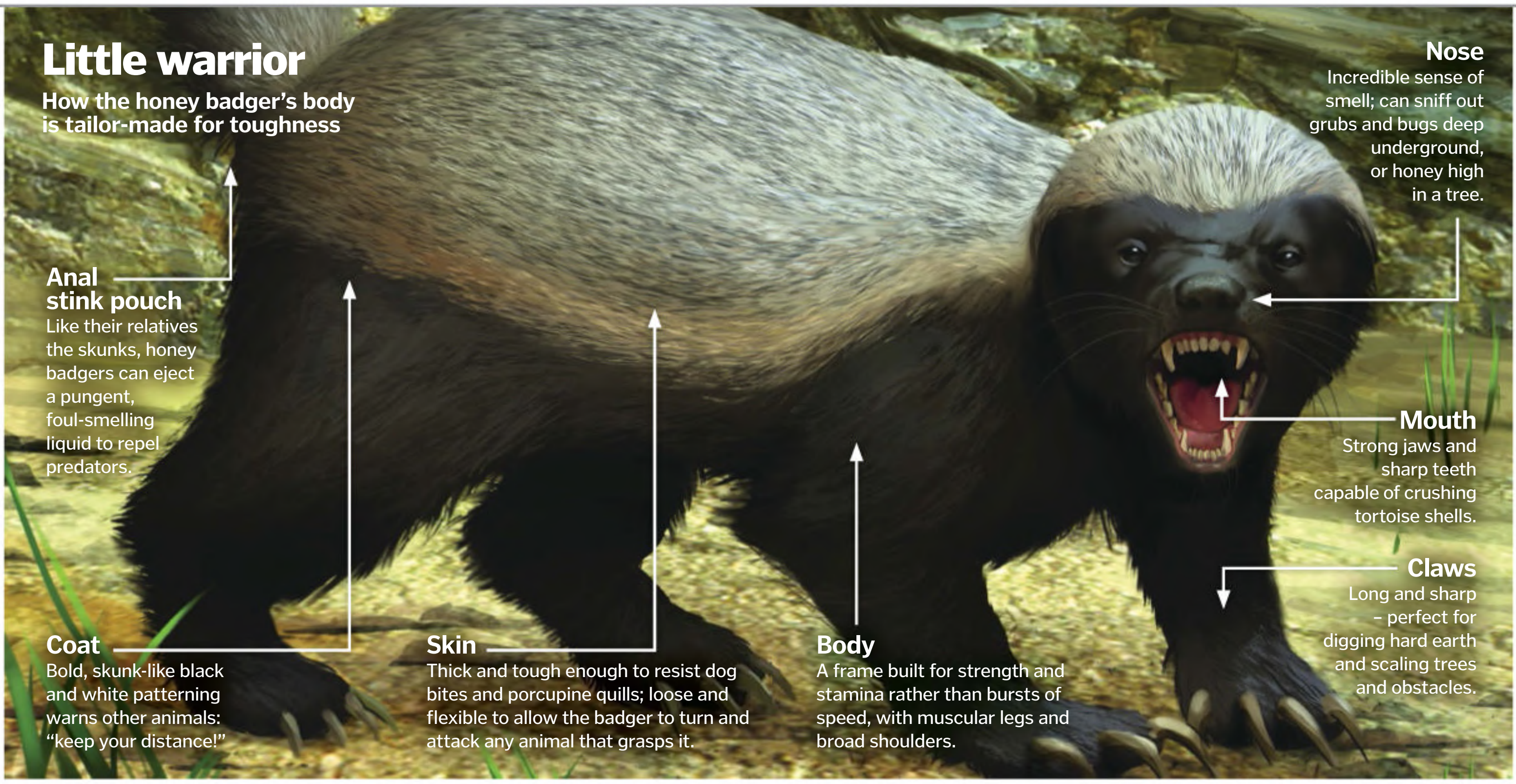
Octopuses are pretty skilled problem solvers. For many years, these flexible invertebrates were overlooked when it came to intelligence, however, scientific research has proven them to be quite astute. In fact, octopuses have both short and long-term memory and have been trained in experiments to tell the difference between shapes and patterns. They are also able to problem solve their way out of confined spaces, navigate through mazes and skilfully open jars that contain food.

in the wild, for example: when searching for food, avoiding predators, navigating their environment and seeking shelter. Many other factors are also taken into account when researching animal intelligence, especially in a lab environment. These include animal conditioning and learning, natural behaviour, ecology and even psychology.

Self-awareness in animals is also considered a good indication of intelligence. In humans self-awareness is described as a conscious knowledge of your own feelings, character and how others may perceive you. Naturally, this is hard to test in animals, as there's no direct way to measure their emotions. Scientists therefore perform what's known as the mirror test. The mirror test gauges an animal's self-awareness by determining whether the animal is able to recognise its own reflection in the mirror as an image of itself. To measure this successfully the animal is first marked by a coloured dye; if the animal reacts in a way that shows it's aware that the dye is located on itself rather than on its reflection, the animal is considered to be self-aware. Very few animals have actually passed the test but species that have include chimps, orangutans, dolphins and elephants.

Animals tend to learn largely by conditioning as they form an association between an action and reward, such as food. This is evident in the wild, as an animal will seek resources in ways that have been successful before. This type of positive reinforcement can also be replicated in lab conditions in order to determine if new behaviours, that are not necessarily natural to the animal in the wild, can be learnt.

Young animals that are raised within a family group, such as dolphins and elephants, also learn and replicate behaviours that they witness. This is known as observational learning, and for animals that have unique cultures it's a way that skills, such as using tools, are passed down to younger generations. Interestingly, dolphins are also known to be able to teach others based on their own personal experiences. For example, a bottlenose dolphin that spent three weeks in captivity was trained to perform a tail-walk trick. Once released back into the wild it's believed to have passed this knowledge on to the other wild dolphins in its pod.



The fearless honey badger

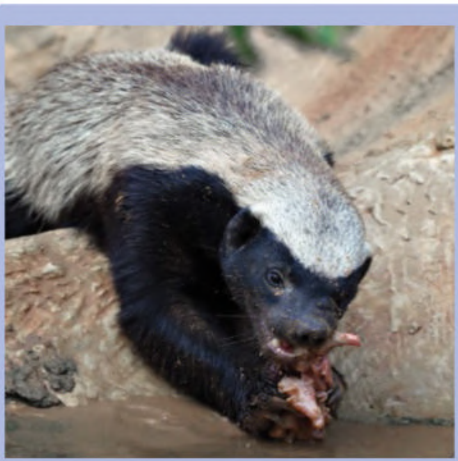
Hyenas, lions and snakes know better than to mess with the ruthless honey badger!

When you think of badgers, you probably imagine shy, snuffling woodland creatures with striped faces. Brace yourself, because the honey badger – despite its sweet name – is a whole different mouthful of teeth. In fact, it holds the official Guinness Book of World Records title for most fearless animal in the world!

Despite their name, honey badgers actually have more in common with weasels than they do with the other badger species. Around one metre (3.3 feet) in length and 30 centimetres (12 inches) tall, their bodies are squat, stocky and incredibly strong, and they move with a self-assured trot. They're nocturnal and generally solitary, and a large brain-to-body size ratio makes them master problem solvers.

Honey badgers are also ferocious fighters, all rattling snarls and vicious lunges. They don't think twice about giving attitude to hyenas – animals five times their weight, with jaws more powerful than a lion's – and are reported to go for the scrotum. One account even tells of a trio of honey badgers teaming up to chase a group of seven lions from their kill.

It may sound like the honey badger has a death wish, but this crazy little critter has every reason to be so bold. Virtually no predator can get the better of it, thanks to its secret weapon: its rubbery skin. At over half a centimetre (0.2 inches) thick, it is almost impenetrable to sharp objects, including spears, scorpion stings, and porcupine spines. Because the skin hangs loose around its muscular frame, a caught honey badger is able to twist right around and sink its vicious teeth and claws into its attacker's face. It can take a fully-grown leopard an hour to kill one of these tenacious little beasts!



What's on the menu?

Literally everything. Honey badgers are eating machines with high metabolisms, meaning they're constantly on the lookout for food. As their name suggests, they have a penchant for honeycomb; in particular the protein-rich bee larvae, which they will climb trees and shrug off hundreds of stings to secure.

As much as half of a honey badger's diet is made up of venomous snakes like puff adders. Even if they get bitten in battle, the relentless attackers are seemingly resistant to snake venom and apparently able to sleep off its effects in just a short time.

They also enjoy eating rodents, reptiles, birds, insects, small mammals, carrion and trash, and will just as soon scavenge as hunt. Where they cross paths with human residences, honey badgers will rifle through bins and ransack homes and kitchens, earning them the title 'masters of mayhem'.

5 TOP FACTS HIBERNATION

Cold-blooded animals
1 Some reptile species hibernate during the winter and will only wake when temperatures rise. The wood frog's body temperature can drop to a freezing -6°C (21°F) during hibernation.

Length of hibernation
2 The number of months an animal hibernates varies depending on the species and their environment; some will hibernate for five to eight months.

Brown fat
3 Most mammals that hibernate have a layer of brown fat that isn't burned for energy when they're in a sleep-like state. It actually helps to generate some heat to keep them warm.

Surprising hibernators
4 Some species of fish and even birds are known to hibernate, or at least enter a similar state of reduced activity. The fat-tailed dwarf lemur is the only known primate that can hibernate.

Waking early
5 Waking a hibernating animal during winter can kill it, as rousing from hibernation and re-entering it takes up a lot of energy, which means it winter reserves will deplete quicker.

DID YOU KNOW? *Alpine marmots are profound hibernators. They can remain in a sleep-like state for up to 200 days!*

Hibernation

Discover why animals go without food or water for months at a time

Winter in the wild can be extreme. Low temperatures and a scarce amount of food make it difficult for many animals to survive. Some will migrate south during the winter months, but certain species of mammals, rodents and reptiles simply bed down and hibernate until spring instead.

Hibernation is an extremely effective survival strategy that suspends the animal's body functions and metabolism so it can preserve energy. This state of suspended animation will allow its body temperature to drop and its breathing and heart rate to slow down. A chipmunk's heart rate can drop from over 200 to just five beats per minute during hibernation, and fat-tailed dwarf lemurs will only take a breath once every 20 minutes!

Hibernation is triggered by seasonal changes within the animal's habitat. Hibernating species are sensitive to alterations in their environment and can therefore predict the onset of winter. They also produce a hormone called hibernation-specific protein, which prompts the physiological changes needed to conserve energy while in a sleep-like state.

Prior to hibernating, many animals will eat excessively over the summer months in order to build up a reserve of fat. For instance, bears can consume up to 20,000 calories a day. Some species that hibernate even store imperishable food within their den and wake for short periods during hibernation to eat.

Once spring arrives and the temperatures begin to climb once again, the hibernating animal will start to rouse. The length of hibernation varies depending on the species, individual animals and even the weather patterns that year.

What's the difference between hibernation and sleep?

Hibernation is a much longer process than sleep, and the animal will go through physiological changes that, although similar to those that occur during sleep, are much more extreme. For instance, warm-blooded animals that hibernate turn almost cold-blooded as their body temperature can drop significantly. Their metabolism, breathing and heart rate also slow down dramatically, and they can remain motionless in a coma-like state for days at a time. Waking from hibernation is also a much longer, gradual process when compared to waking from sleep.

Sleep itself is also considered more of a mental process, as changes occur to brain activity. On the other hand, hibernating animals have shown brain waves that resemble wakeful brain activity, although they are suppressed. Once an animal wakes from hibernation they will still require a lot of sleep in order to recuperate from the long slumber. In fact, it can take weeks for some animals to recover from several months of hibernation.

Anatomy of a bear in hibernation

A hibernating bear's body is anything but idle – here are some of its key functions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