EARTHQUAKES

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2017 YEAR OF RISK

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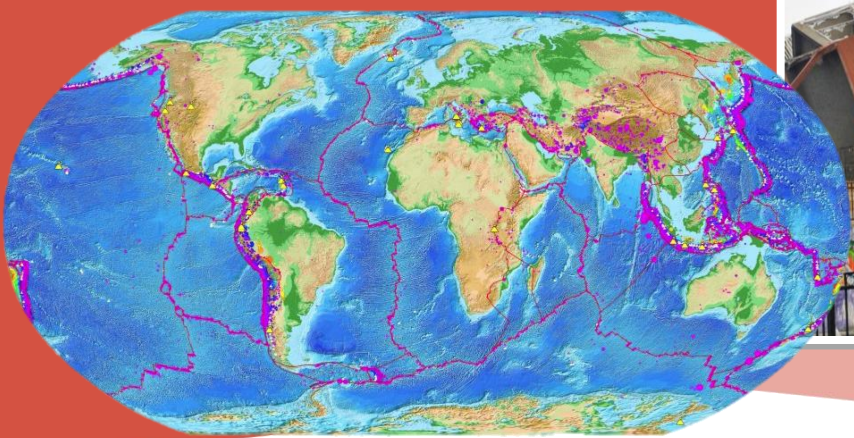

Left: Tectonic plates of Earth, circles denote earthquakes > magnitude 5.
Above: Earthquake damage, Chile, 2010 (Claudio Núñez, Flickr)

More than 500,000 times a year, the Earth's crust shakes. Many of these earthquakes are minor but others can cause devastation and kill thousands, mostly under collapsing buildings and landslides.

By studying earthquakes, geoscientists can help save lives – warning those at risk, showing people how to prepare and protect themselves, and advising on the construction of buildings.

Why do earthquakes happen?

Most earthquakes occur in the areas around the edges of moving **tectonic plates**. As two plates collide or scrape past each other, stress builds up like a compressed spring. The stress is released when the plates suddenly move, either by one plate sliding below, or grinding past, another. When the plates move, waves of energy, known as **seismic waves**, travel through the Earth and shake the surface. People who study earthquakes are called **seismologists.**

Seismogram from the 2011 Tohoku Earthquake in Japan (USGS)

Hazards of earthquakes

Hazard and Risk - it is important in seismology to know the difference between a hazard and a risk. A **hazard** is a dangerous natural event. **Risks** are the consequences of that hazard on people. An earthquake in Antarctica might create all three of the hazards listed below but would pose no risk to people.

Aftershocks - In the days and weeks after an earthquake, further earthquakes known as **aftershocks** can make it dangerous for rescuers to enter damaged buildings. Damage to roads and telephone lines also slows down rescue efforts.

Liquefaction - Almost all soils contain water but when the ground shakes, this water can separate, turning solid ground into quicksand. This liquefaction can sink infrastructure, with particular damage to roads, making it harder for rescuers to reach effected areas.

Tsunamis - If an earthquake occurs at sea it can trigger a wave called a **tsunami**. These can cross oceans and devastate coastal regions far from the original earthquake. **Tsunami Warning Systems** in the Pacific and Indian Oceans monitor water levels and alert communities at risk.

The damage that an earthquake can cause depends not only on magnitude of the quake but also the depth at which the quake originates, the duration of shaking, local geology and infrastructure.

Measuring Earthquakes

Earthquakes are detected using instruments called **seismometers.** These measure the shaking from seismic waves and plot them as a **seismogram**. Although the well-known Richter scale is still in popular use, scientists now use **Magnitude Scales** to measure the energy released by earthquakes. This is a logarithmic scale, which means that for each increase on the scale by one, the energy released actually goes up by about 30 times!

The 12-point **Modified Mercalli Scale** (right) is a qualitative way of measuring the damage caused by earthquakes. It uses shaking and damage reports to describe earthquake impacts.

Index	Description
I	**Earthquake not felt**: only detected by seismometers.
III	**Weak:** vibrations feel like a passing truck.
V-VI	**Felt by all**: houses shake, windows break, furniture moves. Equivalent to 5 on the **Moment Magnitude Scale**
VII	**Damage** to poorly built structures; walls & chimneys crack
VIII-IX	**Major damage**. Most people unable to stand. Buildings partially collapse and shift off their foundations. Soil liquefaction can cause buildings or cars to sink into the ground or fall over.
X-XI	**Severe damage**. Few masonry buildings remain standing. Rails bent, bridges destroyed & damage to gas or water mains can cause fires or floods. Ground fracturing and landslides common.
XII	**Damage total**. Waves seen in the ground surface, objects thrown into the air.

Modified Mercalli Scale

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Major Earthquakes of the last 50 years

Year	Location	Magnitude (Moment Magnitude)	Deaths	Cost (million US$)
1970	**Peru (Chimbote)**	7.9	67,000	550
1976	**China (Tangshan)**	7.6	290,000	5,600
1985	**Mexico (Mexico City)**	8.3	10,000	4,000
1994	**USA (Los Angeles)**	7.1	61	44,000
1995	**Japan (Kobe)**	6.8	6,348	200,000
1999	**Turkey (Kocaeli)**	7.6	19,118	20,000
2001	**India (Gujarat)**	7.7	19,727	<5,000
2003	**Iran (Bam)**	6.6	26,271	1,000
2004	**Indonesia (Sumatra)**	9.1	230,000	15,000
2010	**Haiti (Port-au-Prince)**	7.0	230,000	14,000
2010	**Chile (Concepcion)**	8.8	432	30,000
2011	**New Zealand (Christchurch)**	6.3	161	11,000
2011	**Japan (Tohoku)**	9.0	>10,000	199,000
2012	**Italy (Emilia)**	6.1	27	15,800
2015	**Nepal (Gorkha)**	7.8	8,964	10,000

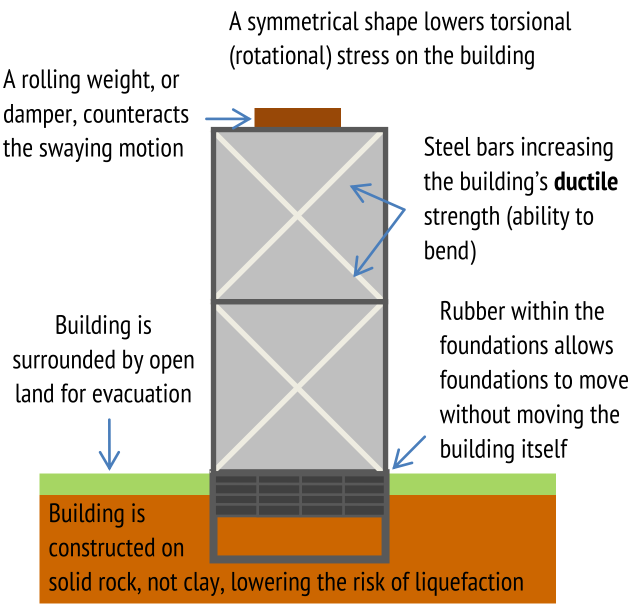
Buildings damaged by ground liquefaction, Niigata, Japan 1964

Tsunami flooding, Indonesia 2004

Protecting against earthquakes

The type of boundary that a region sits on has a big impact on how well it can protect itself against earthquakes. Boundaries between oceanic and continental plates are narrower than continent – continent plate boundaries, allowing countries to prepare only in the regions where earthquakes are most likely. Pacific countries, like Chile, can prepare for earthquakes in cities that have suffered from them in the past, confident that they will reoccur in similar places. By contrast, the continent – continent boundary in Iran has a wide earthquake region, leaving people unsure of where the next earthquake will hit.

Early Warning Systems are commonly used in developed countries. When an earthquake occurs, the first seismometer to record it sends out a warning which can give cities between a second and a few minutes before the seismic waves reach them, depending on how far away the earthquake strikes. This may not sound like much but it is enough time for buses and trains to be stopped and gas and electricity lines to be turned off, which can prevent fires and therefore save lives.



Ways in which buildings can be designed to reduce damage from an earthquake

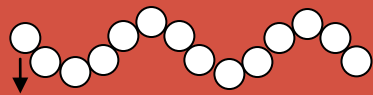
Seismologists help work on earthquake mitigation - reducing the damaging effects of earthquakes. Building collapse is a common cause of death during an earthquake but buildings can be designed to withstand violent shaking. For expensive buildings, it is possible to create a scaled down model and test it on a shake table, simulating how it might react to a real earthquake. Education is the best way to reduce life loss. Teaching people how to react to an earthquake, telling them where to go and providing emergency ration kits all contribute to survival rates.

P, S and Surface waves

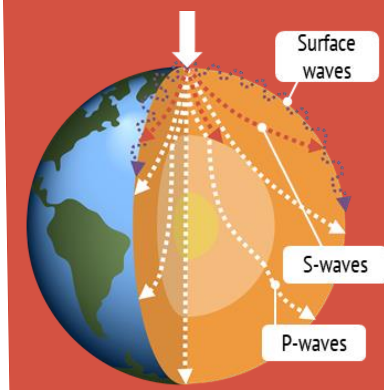
When an earthquake strikes, the ground vibrates. The vibrations occur as seismic waves, radiating out from a central point – the **focus**. The waves travel through rocks in three ways.

Primary waves are **longitudinal**; they push particles forward in a straight line. These are the fastest waves.

Secondary waves are **transverse**; the vibrations are at right angles to the movement of the particles.



Surface waves travel across Earth's surface and are the vibrations that we feel.



The speed of P and S waves is determined by the density of the material they are moving through. In liquids, S waves don't travel at all. This is very useful as it allows us to work out the inner structure of the Earth. The density difference can also help us find things underground.

FIND OUT MORE...

Plate Tectonics interactive website
www.geolsoc.org.uk/plate-tectonics
Earthquake education resources
www.geolsoc.org.uk/earthquakes

FLOODING

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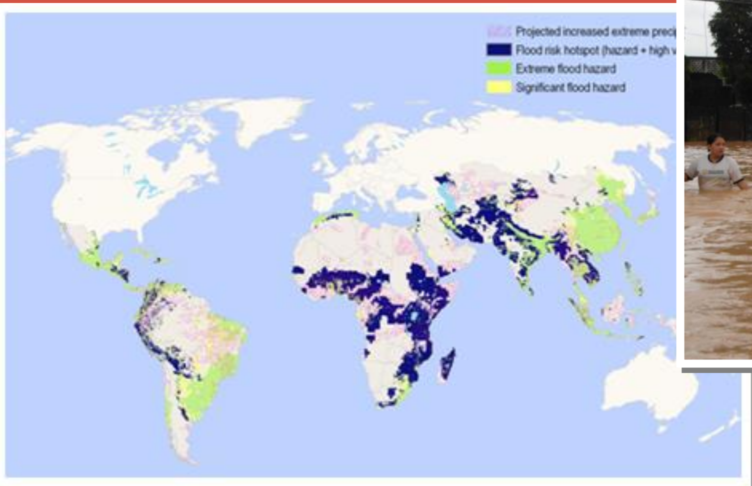

Image Right: Flooding in the Philippines, 2007
Image Left: "Humanitarian Implications of Climate Change: Mapping Emerging Trends and Risk Hotspots" Copyright © 2009 CARE International. Used by Permission.

Flooding – an overflow of a large amount of water beyond its normal confines – can take many forms.

River flooding is usually the result of heavy and/or widespread rainfall, or sometimes melting snow. But blockages such as fallen trees, undergrowth or rubbish can increase the risk of river flooding.

Coastal flooding is often due to extreme weather such as storms, tropical cyclones and/or high tides. Tidal surges can also flood estuaries, which are also at risk from high river flows upstream.

Groundwater flooding occurs when the water level under the ground exceeds normal levels and reaches the surface – usually after prolonged rainfall. The permeability of the local geology is the major control.

Inadequate drainage systems can result in **urban flooding,** if rainwater is unable to drain to ponds, rivers or sewerage systems.

Flash floods can be caused by heavy rainfall, or catastrophic events such as the collapse of dams, landslides, earthquakes or volcanoes. Areas with steep slopes, heavy rain, a massive melting of snow, or the failure of flood or drainage systems can lead to the sudden release of water that quickly becomes very deep. This can carry away people, bridges, etc.

Climate change and flooding

Although there has always been flooding, evidence suggests a correlation between global climate change and flooding. Because warmer air can hold more water, rainfall events are likely to be stronger. Rainfall volume is likely to increase by 1-2% per degree of warming, and rising sea levels put more coastal areas at risk. In addition, changes in atmospheric circulation are likely to cause more extreme weather events, which are often difficult to predict.

DID YOU KNOW?

'Deluge myths' are widespread in many cultures. Some scientists believe there may be a historical basis for the bible's story of Noah's Ark, with a catastrophic rise in the level of the Black Sea at around 5600 BC. As well as Noah's Ark, other deluge myths have their origins in the Black Sea area, which may stem from the same event. Scientists are undecided as to whether the flood would have been large enough to have such an influence on culture.

FLOODING

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Significant UK floods

Date	Major features
2012	The insurance industry paid claims totaling over £1.19 billion when a series of low pressure systems brought heavy rain to most of the UK from April right into the winter. Freak weather included destructive thunderstorms and severe hailstones in the Midlands in June; river floods, flash floods and groundwater flooding due to saturated ground; and landslides that led to major rail disruption.
May – July 2007	The wettest May – July for 250 years led to extensive flooding over England and Wales, with Yorkshire worst hit. More than 55,000 homes and businesses were affected.
August 2004	A flash flood, triggered by heavy rain over 8 hours, affected Boscastle and Crackington Haven in Cornwall.
15 August 1952	The greatest loss of life from a UK flood in living memory, when a flash flood killed 34 people in Lynmouth, Devon. A 9m high wall of water swept down narrow valleys into the town.

DID YOU KNOW?

Following the North Sea floods of 1953, which killed over 18,000 people in the Netherlands, the Dutch Regional Water Authorities have developed some of the best flood defences in the world. The aim is to safeguard vulnerable areas from a 1 in 10,000 year event through a network of sluices, locks and barriers. Other measures include river widening and building floating homes.

Flooding in the UK

Floods are a significant natural hazard in the UK. According to the Environment Agency, the UK average for homes at risk of surface water, river and tidal flooding in 2013 is one in six.

Global flooding

Flooding accounts for about 40% of all national disasters. According to a 2012 report, in the previous 18 months, destructive floods had occurred in Pakistan, Australia, Brazil, Japan, the Philippines, S Africa, Sri Lanka, Thailand and the USA. Almost the entire population of Bangladesh lives in a flood-prone area, and most of Holland is also at risk.

With a growing urban population, urban flooding is an increasing problem, particularly in unplanned developments. Rio de Janeiro hit the headlines several times in 2010/11 as heavy rains triggered floods and mudslides that, in the January 2011 event alone, killed over 800 people. There is a debate about the role of climate change, but no doubt that poor urban planning was also to blame.

Flood prediction?

It is often possible to predict flooding using weather forecasting and information about local geology.

In flood plains, geoscientists use technology such as satellite imaging and remote sensing to monitor alluvial deposits and produce risk maps. In extreme circumstances, flood warnings will be followed by evacuation.

Flood defences

In **floodplains**, soft measures include changing farming practice, tree planting, or encouraging a 'managed retreat' of the flood plain to its natural environment.

Where needed, engineering can raise the natural flood banks to form 'levees', or reroute the main channel.

Dams can help regulate flow and reduce downstream risk. At river mouths, flood barriers such as the Thames Barrier can protect upstream areas.

In **coastal areas**, natural defences such as mangroves and wetlands can help with flood defence.

Engineering approaches such as seawalls and levees can protect seafronts, whilst groynes, breakwaters and artificial headlands encourage sediment deposition on the beach and give protection from storm waves.

Oosterscheldekering sea wall, the Netherlands

GROUNDWATER

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BBC TERRIFIC SCIENTIFIC

This factsheet was written for teachers and a general audience. A factsheet for primary school students aged 9-11 is also available on the website:

www.geolsoc.org.uk/factsheets

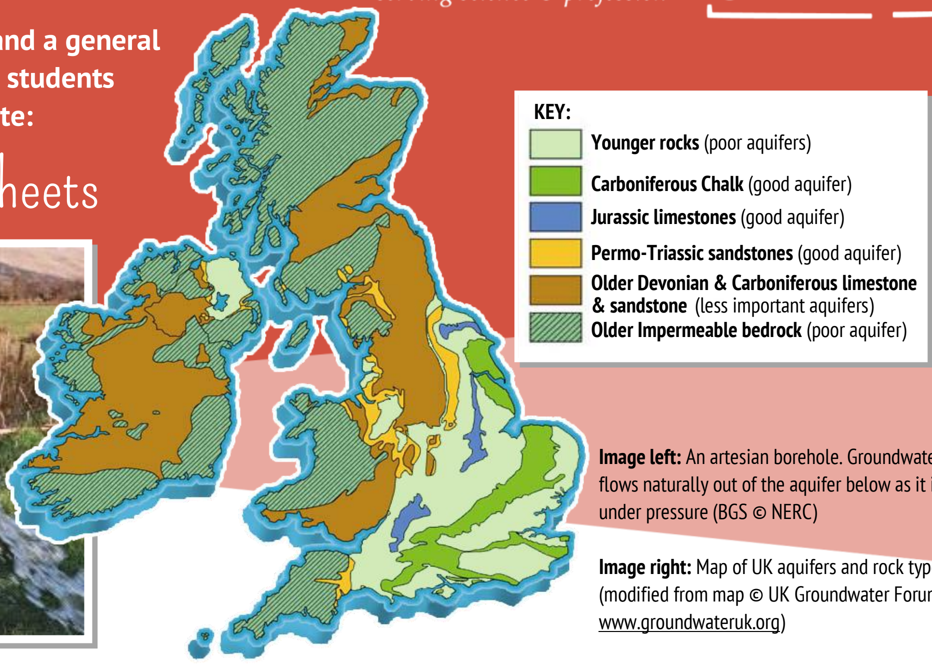


Image left: An artesian borehole. Groundwater flows naturally out of the aquifer below as it is under pressure (BGS © NERC)

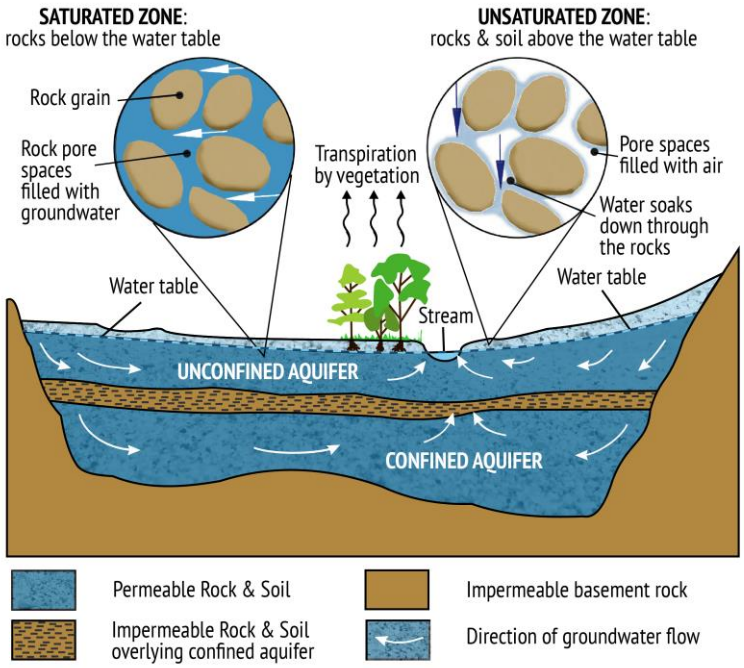
Image right: Map of UK aquifers and rock type (modified from map © UK Groundwater Forum: www.groundwateruk.org)

Maintaining a supply of drinking water to every tap in the United Kingdom is a huge challenge. Water hidden underground, or groundwater, is vital to this process in many regions of the UK, but can also cause flooding.

After rainwater falls it filters down beneath the surface through soil and into the rocks beneath. If these rocks contain pore spaces and fractures, they act like a sponge and water collects in them below the **water table** as groundwater. This water is in the **saturated zone**. From there it moves through the rocks (often very slowly) until it resurfaces as a spring or flows into rivers, lakes or the sea.

Cross section view of an aquifer

(Modified from diagrams © UK Groundwater Forum and USGS / Wikimedia Commons)



Aquifers and UK water

Rocks containing groundwater that can be usefully extracted are called **aquifers**. A good aquifer needs cracks and gaps to store water (known as **porosity**), which must also be connected so water can pass through (known as **permeability**). Some rock types, such as **sandstone**, **limestone** and **chalk**, often have high porosity and high permeability so make good aquifers. Other rock types, such as **granite**, usually have low porosity and low permeability so make poor aquifers.

An aquifer is described as **confined** if it has an overlying **impermeable** rock layer through which water cannot pass, or **unconfined** if the layer above is permeable.

Groundwater is a vital source of drinking water in many parts of the UK and around the world. The locations of the main UK aquifers, shown in the map above, determine the source of drinking water. About 35% of all public water supplies in England and Wales come from groundwater.

- In areas with good aquifers, such as much of South East England, groundwater is the main public water supply.
- In other areas, the aquifers are smaller and used less. For example, around 7% of public water supply in Scotland and Northern Ireland comes from groundwater. These areas have plentiful **surface water** in rivers, lakes and reservoirs.

DID YOU KNOW?

The average person in the UK uses about 3,400 litres of water every day (about 10 large fish tanks). Some of this is 'direct use' such as drinking or washing, but most is 'hidden use' in things like food production or manufacturing goods we use. Growing a single apple takes around 70 litres of water. Producing a glass of milk takes 200 litres!

GROUNDWATER

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Groundwater Flooding: why do areas away from rivers flood?

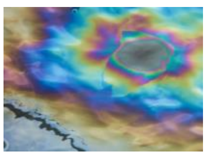
In very wet weather, rivers rise and overflow their banks, causing **surface flooding**. However, areas far from a river can also flood when the water table rises above the surface causing **groundwater flooding**. This most commonly occurs after heavy rain adds more water than usual to the aquifers, but can be made worse by changes in groundwater use. Water soaks into the ground slowly, so groundwater flooding can come as a surprise, some time after the rainfall that caused it. Surface floodwater drains away quickly but groundwater may take much longer.

Groundwater flooding in Oxfordshire (BGS © NERC 2007)

Types of groundwater flooding	
Clearwater flooding	Extended periods of wet weather cause the water table in an area to rise. When the water table in an unconfined aquifer rises above the surface, groundwater flooding occurs.
Flooding related to rising rivers	Small areas of sediments, often connected to rivers, can act as aquifers. After heavy rainfall, river levels rise and the connected groundwater rises to the surface quickly. This causes flooding away from the river.
Changes in groundwater use	In parts of the UK the water table level depends on how much groundwater is used. When industrial activity decreases dramatically and less water is used, the water table can rise quickly. This flooding is therefore unrelated to recent rainfall.

Groundwater contamination

Groundwater is less easily contaminated than surface water. Natural contamination can occur but pollution is mostly caused by human activities. Some pollutants are harmful to living things (including humans) and cleaning up pollution can be extremely costly, both financially and in terms of energy use.
The table below shows some of the types of groundwater pollution caused by human activities.

How do pollutants get into groundwater?		Effects of pollution	
Pesticides, fertilisers & agricultural waste	Chemicals added to farmland to kill pests or fertilise the soil, as well as animal waste, are washed into water courses and aquifers after rainfall.	Pesticides can cause serious problems including cancer. Fertilisers and animal waste in surface waters can trigger processes leading to low oxygen (**eutrophication**) which kills fish.	
Landfill sites used to bury rubbish	Landfills must have impermeable liners. If these leak then liquid from rotting waste (**leachate**) can seep into groundwater.	Leachate can be acidic and may contain hydrocarbons, heavy metals, and other toxic substances harmful to humans.	
Oil-based products	Underground storage tanks (such as those at petrol stations) may rupture and release their contents into groundwater.	Many oil-based chemicals can cause cancer in humans.	

Groundwater around the world

Most of the liquid fresh water on Earth is groundwater (some fresh water is frozen in the polar ice caps). It can be a very convenient source of water because:

- Aquifers have enormous storage capacity – more than any man-made reservoir
- Groundwater is less easily contaminated than surface water, so is generally safer.
- It can be extracted close to areas of population with minimal infrastructure.

Many parts of the world rely on groundwater for their water supply, particularly areas without much surface water. In desert regions, storing water in surface reservoirs is not practical as they evaporate quickly. Many cities worldwide depend on groundwater. In 1998, **Mexico City** used 3.2 billion litres of groundwater a day, enough to fill six of the world's largest oil tankers!

Over-reliance on groundwater can be a problem when not enough is replaced by rainfall, leading to **groundwater drought**. Some countries are reducing their use of groundwater. One example is **Saudi Arabia** where about half of public water is supplied by removing salt from seawater (**desalination**).

Desalination Plant, United Arab Emirates
© Ryan Lackey / Flickr

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Hard and soft water: www.geolsoc.org.uk/waterhardness

MINERAL RESOURCES

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Images (left to right):
Giant gypsum crystals, Naica, Mexico © Alexander Van Driessche / Wikimedia
Biotite mica in thin section under a microscope © Strekeisen / Wikimedia
Kaolin ('china clay') quarry at Wheal Martyn, Cornwall © Martin Addison / Flickr

Why do we extract minerals? The answer is simple: if you can't grow it, you have to mine it! Some minerals are prized for their beauty as gemstones, but many others have more important hidden uses. Almost everything in the modern world uses minerals or their by-products in some way.

Rock, mineral or chemical element?

A mineral is a naturally occurring substance, with a particular chemical formula and crystal structure.

Chemical elements are atoms with specific properties. **Minerals** are made up of one or more different elements, and **rocks** are composed of one or more different minerals.

We can extract certain minerals from rocks and separate out chemical elements from them. In the United Kingdom, the average person benefits from the use of about **10 tonnes** of minerals and metals every year.

Minerals in your diet

The human body needs a number of **essential 'minerals'** to function, which must be taken in through our diets. Calcium, iodine and iron are needed in the largest quantities, with 16 others in smaller amounts:

Essential dietary 'minerals':			
calcium	iodine		iron
beta-carotene	boron	chromium	cobalt
copper	magnesium	manganese	molybdenum
nickel	phosphorus	potassium	selenium
silicon	sodium chloride	sulphur	zinc

Most of these are actually chemical elements, apart from **beta-carotene** (an organic pigment found in plants) and **sodium chloride** or salt (the only mineral listed above). However, we call them 'minerals' because the body will only accept them combined with other elements in food or drink. For example, we cannot consume **sodium** metal by itself as it would react violently with water in the body, so it is consumed as sodium chloride (salt).

Industrial and Construction Minerals

Fuels and metal ores are not the only geological materials we extract for their commercial value. The others are known as Industrial and Construction Minerals. Hundreds of these are extracted for an enormous range of uses, some of which can be surprising:

- You thought **paper** was made entirely from wood? Not so - it contains a clay mineral, **kaolin**, as a 'filler' and to make it white.
- The world communicates through crystals! **Quartz** is commonly used in microphones and telephones as **piezoelectric crystals** that convert sound into electrical signals.

Quartz © Didier Descouens / Wikimedia

Fluorite © Carles Millan / Wikimedia

Wolframite © Alchemist-hp / Wikimedia

DID YOU KNOW?

There are over **5,000** known minerals. Many of these are extremely rare and some occur in a single location on Earth.

The entire global supply of some of the rarest (such as 'hazenite' and 'fingerite') would fit into a thimble, less than 50 grams. By comparison, we may think of gold as rare, but humans mine about 3,000 tonnes of it every year.

MINERAL RESOURCES

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Minerals in 'green energy' technology

Renewable energy technology uses a variety of chemical elements sourced from minerals:

Technology		Some chemical elements used	Where do we get them?
'Solar' (Photovoltaic) panels		• tellurium, selenium • indium, cadmium • gallium	By-products of copper mining By-products of zinc mining A by-product of aluminium mining
Wind turbines		• neodymium (one of the rare earth elements*)	Neodymium occurs most commonly in the minerals **monazite** and **bastnäsite**, with other rare earth elements*.
Steam turbines used in Geothermal Energy		• nickel • titanium • ruthenium • rhenium	We commonly mine for nickel and titanium. Rhenium and ruthenium are very rare and are by-products of copper and platinum mining.
Water turbines used in Hydroelectric Energy		• chromium • nickel	Chromium is usually produced from the mineral **chromite.**
Energy storage (batteries)		• lithium	Lithium has two different sources: • Mining for the minerals **spodumene** & **lepidolite** • Extraction from brine pools by electrolysis (mostly in the Andes).

Steam turbine image © Siemens Pressebild / Christian Kuhna / Wikimedia

*Rare earth elements are a group of metallic chemical elements with similar properties.

Artisanal mining and conflicts

High value minerals are locally abundant in some developing countries, leading to small-scale subsistence mining, often using hand tools. While often illegal, this '**artisanal mining**' makes a significant contribution to local economies, but has sometimes been used to fund armed conflicts. Civil wars in Sierra Leone, Liberia and Angola were heavily financed by 'blood diamonds'. The Democratic Republic of the Congo has been hardest-hit, with conflict minerals including **gold**, **cassiterite** (for tin), **wolframite** (for tungsten) and '**coltan**' (for niobium and tantalum).

Image: Artisanal miners at a tantalum mine, Democratic Republic of the Congo © U.S. GAO

What is being done?

Some countries, such as the USA, have passed laws forcing companies to declare the origin of the minerals in their products. Voluntary schemes to increase accountability and traceability of minerals have also been introduced. Several charitable organisations campaign against the use of conflict minerals, including **Amnesty International** and **FairPhone**, which produces a 'responsibly sourced' smartphone. Organisations such as the **Alliance for Responsible Mining** work to improve the safety and welfare of miners, strengthen environmental protection and eliminate child labour.

What minerals do we produce in the UK?

Despite a long mining heritage, the UK currently has few metal mines. Important exceptions are the Hemerdon/ Drakelands Tungsten-Tin Mine in Devon and mining for precious metals near Omagh, Northern Ireland.

The UK mostly produces construction minerals including **sand**, **gravel** and crushed rock **aggregates**, as well as **limestone**, **clay**, **slate** and other minerals. These are relatively cheap to extract from quarries. They are mainly used domestically for building and construction, as well as for manufacturing processes in agriculture and the chemical industry.

Nevertheless, the UK does export some minerals, and is the world's third largest producer of the mineral **kaolin** or 'china clay'. This is extracted from two sites in Devon and Cornwall, and mostly used in the paper and ceramics industries. **Potash** is currently produced in North East England for use as crop fertilizer, with future plans to open one of the largest potash mines in the world in North Yorkshire.

Image: Boulby Potash Mine, North Yorkshire © Michael Jagger / geograph.org.uk

VOLCANOES

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2017 YEAR OF RISK

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Image left: degassing of Colima, Mexico. Tom Hodgkinson
Image center: eruption of Sarychev, Russia
Image right: Etna, Italy. Alastair Hodgetts

A volcano is a rupture in the Earth's crust which allows magma and gas to escape from beneath the surface. When magma reaches the surface of the Earth, it is called lava. Over many eruptions, the layers of volcanic materials, like lava, ash and pumice, build up, forming a volcano.

How do volcanoes form?

Volcanoes can form in a number of different ways but in all cases, they form where there is partially molten rock, **magma**, below the surface of the Earth. This magma then either rises through natural cracks in the crust or gets stuck underground where the pressure rises until it erupts explosively.

At **convergent plate boundaries,** plates move towards each other. The denser of the two plates then sinks under the other. Inside the Earth, the denser plate becomes incredibly hot and loses of all its water. The water enters the mantle, lowering the melting temperature of the mantle rocks. This allows the rocks to melt, producing magma.

At **divergent plate boundaries,** plates move away from each other. As they move apart, a crack is created and pressure is lowered. This decrease in pressure lowers the melting temperature of mantle rocks. This newly molten magma is then erupted at the surface, most commonly under the sea.

In the middle of plates, we can sometimes find volcanoes, like Kilauea in Hawaii. These volcanic areas are called **hot spots** and are fed by **plumes** of hot, partially molten rock that rises from the mantle.

Fissure eruption of mantle plume material at the Hawaiian hot spot.

Types of eruption

How explosive an eruption is depends on two main factors: how much **silica** (SiO_2) and how many bubbles of **gas** there is in the magma. Silica increases the **viscosity** of magma (makes it less runny) which traps bubbles of gas in the magma, increasing pressure and therefore leading to a more explosive eruption.

Effusive

Effusive eruptions occur when magma has low silica content and therefore low viscosity. They usually cause few hazards the gas emissions from larger eruptions can affect climate. Effusive eruptions form **shield volcanoes**, which are typically large, round, low lying structures. Effusive volcanoes do not produce ash so the volcano is just made of lava. These eruptions take place at divergent plate boundaries and in the middle of plates.

Explosive

Volcanoes with high silica and gas content are explosive. They are very hazardous, producing **ash** (small fragments of broken rock), **pyroclastic density currents** (hot clouds of gas and rocks that flow down the sides of the volcano) and **lahars** (cement-like mixtures of water and hot ash). Explosive eruptions create **composite volcanoes**, built up of repeated layers of ash and lava over multiple eruptions. These eruptions take place at convergent plate boundaries.

DID YOU KNOW?

The 1815 eruption of Tambora, Indonesia, was one of the largest in recorded history. One of the main products of the eruption was Sulphur dioxide (SO_2), which acts as a short term global coolant. So many millions of tons of SO_2 were released during the eruption that global temperatures fell by 0.5°C. This led to 1816 being known as the 'Year without Summer'.

VOLCANOES

www.geolsoc.org.uk/volcanoes

2017 YEAR OF RISK

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Explosivity

Volcanic eruptions are classified on a logarithmic scale called the Volcanic Explosivity Index (VEI), which is scaled from 0 to 8.

VEI	Volume of erupted material (km^3)	Height of ash cloud (km)	Example
0	< 0.0001	< 0.1	Kilauea, Hawaii (ongoing since 1975)
1	> 0.0001	0.1 - 1	Nyiragongo, Democratic Republic of Congo (2002)
2	> 0.001	1 - 5	Stromboli, Italy (ongoing since Roman times)
3	> 0.01	3 - 15	Nevado del Ruiz, Colombia (1985)
4	> 0.1	> 10	Eyjafjallajökull, Iceland (2010)
5	> 1	> 10	Mount St Helens, USA (1980)
6	> 10	> 20	Pinatubo, Indonesia (1991)
7	> 100	> 20	Tambora, Indonesia (1815)
8	> 1000	> 20	Yellowstone, USA (630,000 years ago)

Can we predict an eruption?

An eruption is caused by the movement of magma underground. All methods of prediction, therefore, are designed to detect magma movement.

Rising magma can cause **ground deformation**, where parts of the volcano bulge or recede. **Global Positioning Systems** and **tilt meters**, which measure the angle of slope on a volcano's flank, can both pick up changes in ground level.

Movements underground can cause minor **earthquakes** as space is made to accommodate new material. Earthquakes are measured using **seismometers**; an increase in the frequency of quakes may mean that an eruption is imminent!

All magma contains gas. When magma rises, the pressure on it decreases, allowing more gas to escape. By measuring changing gas emissions at volcanic vents, volcanologists can tell when magma has risen.

A common cosmetic tool, pumice stone comes from the top of volcanoes; the holes are empty gas bubbles.

Volcanoes and people

Around the world, many millions of people live on or near volcanoes. Many do so because they have no choice, and the hazard posed by a dormant volcano is negligible, until it reawakens. Although prediction has improved greatly in recent years, volcanoes can still erupt with little to no warning. When a volcano starts to ramp up to an eruption, evacuation may be the only way to save the lives of those in harm's way; but evacuation may disrupt communities, damage livelihoods and cause misery to those affected.

A volcanologist measures gas release from an effusive volcanic eruption

There are some reasons why people might choose to live near volcanoes: volcanic materials such as ash are full of nutrients and, once broken down, they can act as a natural fertilizer (the land around Naples is intensively cultivated because of the rich soils produced by Mount Vesuvius); lava is also a good building material; the heat produced by volcanoes can be used to produce geothermal energy and the beauty of volcanic landscapes can create a great deal of wealth through tourism.

Volcanic Hazards

Lava the molten rock that flows from volcanoes isn't a particularly dangerous hazard. Generally speaking, even low viscosity, basaltic magma will only travel at 1 km/h on a gentle slope.

Ash: fragments of broken lava are thrown high into the air and can travel around the globe. Ash particles are toxic and sharp; breathing in ash can kill animals and humans. When mixed with water, ash becomes very heavy and collapses roofs.

Pyroclastic Density Currents: dense clouds of hot gas and rock that can reach 900°C and travel at 700 km/h on steep slopes. They are a major hazard that poses serious risk to people.

Lahars: when ash mixes with water, it creates a cement-like slurry that flows downhill. Lahars can be up to 70°C and can be activated by heavy rainfall months after an eruption. They can ruin fertile land and destroy villages.

Earthquakes: as magma rises through the Earth's surface, it can cause the ground to deform. This movement can cause earthquakes and, if underwater, **tsunamis**.

Gas: volcanoes produce large quantities of gas, such as SO_2 and CO_2, which can cause suffocation.

Mount Fuji, Japan. A famously stunning volcano, it attracts 300,000 climbers every summer.

WATER RESOURCES

This factsheet was written for teachers and a general audience. A factsheet for primary school students aged 9-11 is also available on the website:

www.geolsoc.org.uk/factsheets

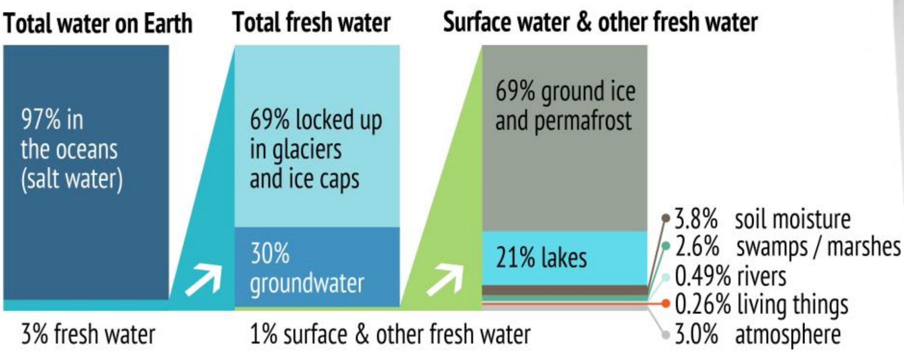
Left:
Akosombo dam, Ghana (© ZSM, Wikimedia Commons)

Fresh water is needed for every part of our lives, from drinking water to farming and industry. Access to clean water is becoming increasingly difficult for millions around the world. With a growing population and changing climate, new discoveries and responsible management of water resources is more important than ever.

Where is water found on Earth?

Although much of the world's surface is covered with water, only 3% of Earth's water is fresh water, and only about a third of this is liquid. Some of this is **surface water** in rivers and lakes. However most is **groundwater**, or water which filters down into the ground after rainfall and is held in cracks and pore spaces within underground rocks below the **water table**.

For one in three people, groundwater is the only source of water. Groundwater can be extracted using wells or boreholes, and in places flows out naturally at the surface as springs.
The diagram below shows the distribution of Earth's water resources.



The distribution of Earth's water resources. Percentages are rounded so may not add up to 100. (Adapted from diagram © USGS / Wikimedia Commons)

How do we use water?

Humans use the Earth's freshwater for three main purposes:

- 70% **Agriculture**
- 22% **Industrial processes** (including energy production)
- 8% **Domestic purposes** (including sanitation)

These proportions vary dramatically in different parts of the world. For example, in North America and Europe, about 50% of all freshwater is used for industrial processes. In Asia 85% of all water resources are used in agriculture.

DID YOU KNOW?

- About 9% of the global population, or **650 million** people, lack access to safe drinking water, mainly due to poverty.
- One approach that some water-stressed countries have invested in is removing the salt from seawater (**desalination**), for example in desert areas like the Middle East. Even the United Kingdom has a desalination plant; the Beckton plant in East London can produce 150 million litres of fresh water a day in times of severe drought.

WATER RESOURCES

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Exploring for groundwater

Hydrogeologists can find groundwater in all sorts of areas, including beneath deserts. Rocks containing groundwater which can be extracted are known as **aquifers**. Some rocks make better aquifers than others, and finding them isn't as simple as just digging a well. A range of methods are used to understand and predict groundwater.

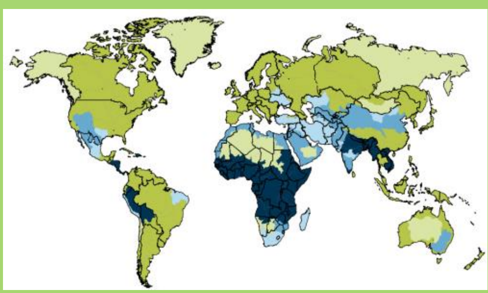
Drilling a groundwater borehole in Ethiopia (© UNICEF Ethiopia 2016 / Ayene / Flickr)

Exploration methods

Interpretation of satellite/ aerial photographs & maps	Hydrogeologists study aerial photos together with maps of rivers, land height and geology. These are used to identify potential aquifer rocks which could store groundwater, areas where rainwater flows into an aquifer (**catchment areas**), and geological features such as faults and folds that could influence aquifer quality.
Borehole drilling	The only way to test if the groundwater can be exploited is to drill boreholes and try to pump water out (pumping tests). These provide direct data about the aquifer, such as information on rock pore spaces and fractures, and whether these are connected to allow water to flow. Samples can also be taken to test groundwater quality.
Groundwater modelling	Once they already have some information about the groundwater in an area, hydrogeologists build complex computer models to simulate how it might behave. This helps predict the best borehole locations, how much water can be used and if there is a risk of pollution.

Groundwater recharge and fossil groundwater

Groundwater levels change over time. To make sure the groundwater doesn't dry up, hydrogeologists use information on the regional climate, water cycle and geology to estimate how quickly the aquifer fills up with water after rain, (the **recharge rate**). Recharge can take anything from days to many years. In some areas the groundwater was recharged thousands of years ago, when the climate was wetter. Known as **fossil groundwater**, once that groundwater is used up, it will not be replenished. In these areas groundwater is viewed as a **non-renewable resource.**



Water stress (light blue) & Economic water scarcity (dark blue) around the world. Light green areas have no data. (© WWAP 2012)

Water scarcity around the world

Many parts of the world suffer from **water stress**, where the water supply in an area is less than the needs of the people living there. Large parts of the world, such as central Africa and parts of Latin America and Southern Asia, also suffer from **economic water scarcity**. This means that there is insufficient money or infrastructure to extract water and provide it to the population.

Poor access to safe water is rarely due to just a lack of rainfall. Drought may temporarily reduce the area's water resources, but long-term water issues are usually related to other factors. For example:

- The population may increase rapidly so more people need water
- There could be a lack of water resource management, infrastructure or exploration
- The water supplies could be polluted, for example by poor sewage treatment
- Climate change leads to dry areas becoming even drier (**desertification**)

Goal 6 of the United Nation's Sustainable Development Goals aims to ensure access to water and sanitation for all by tackling the above issues.

The world's largest aquifer

Groundwater aquifers can be truly vast. The world's largest aquifer is the **Great Artesian Basin** in Australia. It covers 1.7 million square km, equivalent to about a quarter of the entire country, or 7 times the area of the UK.

The Great Artesian Basin, Australia (©Tentotwo, Wikimedia Commons)

The Great Artesian Basin is also the deepest aquifer in the world. The sandstone layers holding the groundwater extend to depths of 3 km in places, but elsewhere they outcrop at the surface and water flows out at springs.

Crucially, this is the only source of freshwater for the majority of inland Australia. As a result, groundwater pollution can cause problems for the millions of people living in this water-stressed area. Recently, the hydraulic fracturing ('fracking') industry was accused of polluting and over-using groundwater in the Basin while exploiting coal seams for natural gas.

FIND OUT MORE...

- **Find out more about aquifers, groundwater flooding and where UK water supplies come from:** www.geolsoc.org.uk/factsheets
- **Read our factsheet on hard and soft water:** www.geolsoc.org.uk/waterhardness