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Geology for Society

A report by The Geological Society of London
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Why does geology matter?

Geology is the study of the Earth's structure and history. It underpins the provision of resources to the UK's population and industry, delivers a wide range of essential services, and helps us understand how we can live more sustainably on our planet, thanks to our strong skills base, education and research.

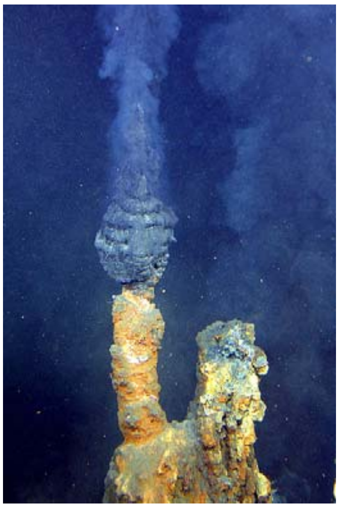
Image of the Earth taken by the crew of Apollo 17. Photo credit: ©NASA

Geology (sometimes referred to more broadly as Earth science or geoscience) is the study of our planet's structure, and the processes which have shaped it throughout its long history – and which continue to do so. It underpins the provision of most of the **resources** on which the UK's population and industry depend, including **energy, minerals**, **water** and **food**. A wide range of vital services depend on geology, including management of the **waste** we produce; ground engineering for the construction of **buildings, roads, dams, tunnels** and other large infrastructure projects; and remediation of a wide range of environmental problems, including **land contaminated by industrial use**. The work of geologists to understand natural disasters and **hazards** is essential for preparedness and mitigation of their effects. The safeguarding of clean, available drinking water and the provision of varied **ecosystem services** depends on an understanding of both the underlying geology and its multitudinous interactions with surface processes. The future security of the UK's energy supply relies heavily on geological skills in a wide range of contexts, from resource extraction to renewable energy and use of the subsurface to store carbon dioxide and radioactive waste.

Evidence of the interaction between **environmental change** and the evolution of life over hundreds of millions of years gives geologists a valuable perspective on the changes that humans are now causing by burning fossil fuels and our wider impacts on the environment. Geologists will also play a vital role in **abating carbon emissions** from burning fossil fuels by putting them back where they came from – underground. Just as we are starting to understand more fully the impact we are having on our planet, resources are becoming scarcer, and humankind more numerous. As we seek to live more sustainably and equitably, geologists are developing a more holistic view of resource use, the wastes and by-products produced, and our complex interactions with the subsurface, land, sea, air and life, which together form the Earth system.

Understanding and provision of all of these resources and services depend on highly skilled and trained geologists across academia and industry, building on development of strong geoscience skills through school and higher education. The UK has an excellent geological research base, which is fundamental to understanding Earth processes and future environmental challenges. Sustained investment in geoscience skills and research will fuel economic growth and allow the UK to play a leading role in tackling global challenges.

A black smoker known as 'the brothers' in the Kermadec arc, New Zealand. Black smokers collect rich metallic sulfide deposits which can be mined. Photo credit: © NOAA (National Oceanic and Atmospheric Administration)



Geology for the economy

Geology plays an essential role in many areas of the economy. Economic growth and sustainability, as well as societal well-being, will require reliable supplies of energy and mineral resources, a dependable supply of clean water and the secure and sustainable production of food. All this will be contingent on sustained investment in technology, infrastructure, education and skills development.

Locating and extracting geological resources are vital to the UK's GDP, tax revenues and economic growth. The use of raw materials for industrial and consumer products and processes, and of fossil fuels for energy, underpin our prosperity and are major contributors to the economy in their own right. The extraction of oil, gas, coal and construction and industrial minerals in the UK generated £38bn in 2011 – about 12% of non-service GDP – with the industries dependent on these resources contributing even more. Since 1970, North Sea oil and gas alone has earned the country £3000bn, about half of which went to the UK government in tax. Energy and mineral companies constitute a significant part of the FTSE 100 share index - oil and gas about £287bn, and mining £219bn (as at March 2013).

Philippine stock market board. Photo credit: Wikimedia Commons.

A thorough evaluation of demand, supply and costs (both financial and environmental) of these commodities is essential to effective economic planning and decision-making. Commodity reports produced by the British Geological Survey play an important part in meeting this national need. The EU has identified a list of critical mineral raw materials, whose supply may act as a 'bottleneck', restricting economic growth. For example, Rare Earth Elements (REEs) are in growing demand due to their use in high-tech applications including plasma screens, medical imaging and low-carbon technologies such as wind turbines and hybrid vehicles.

Our future is one in which resources are constrained, and the impacts of extracting and using them more keenly felt. An increasing global population rightly expects greater prosperity and more equitable access to resources, putting additional pressure in particular on the already stressed water-energy-food nexus. The challenge of secure and sustainable supply of water and energy is exacerbated by climate change. Increased stress to their supply will have significant repercussions both for domestic supply and for energy- and water-intensive industries such as mining and construction.

Uranium ore from Australia. Uranium ore is an essential raw material for nuclear power plants. Photo credit: Wikimedia Commons.

All these challenges may challenge the economic status quo. But they also present opportunities for innovation to support future economic stability and growth. With sustained investment in infrastructure, research and skills development, and the creation of the right environment to nurture innovation, the UK can become a world leader in high-tech and environmental technologies and their application. Radioactive waste management and carbon capture and storage (CCS) will need to be developed across the world as we aim to decarbonise our energy system, presenting opportunities for development of domestic technologies, skills and expertise, so that ultimately they can be exported overseas. Our highly developed research and higher education sector also positions the UK ideally to play a leading role in the global knowledge economy.

Energy

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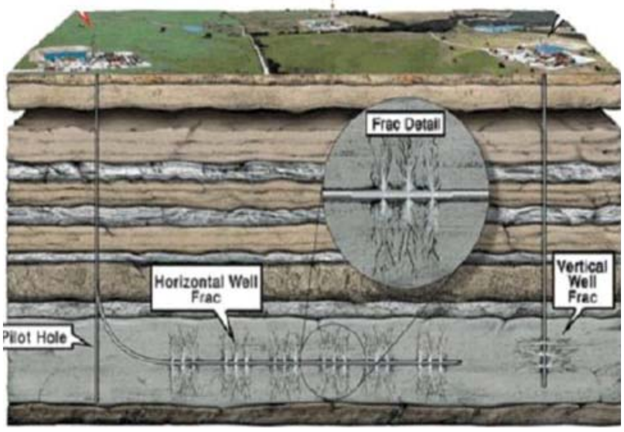
The need for transition to a low-carbon economy is urgent. However, as we manage this change, we will continue to be dependent for many more years on fossil fuels. Geoscience skills are essential at every step of the energy cycle, from the location of energy resources through to their safe, reliable extraction and use, and the subsequent disposal or recycling of wastes.

In meeting its future energy needs, the UK faces a triple challenge: to drastically reduce CO_2 emissions in order to avoid dangerous climate change; to ensure security of supply; and to deliver energy affordably to industry and consumers.

Fossil fuels

Fossil fuels will continue to make up an important part of the UK's energy mix over the next few decades at least. The UK has reaped enormous benefits from North Sea oil and gas in recent decades. Significant offshore resources remain – their successful extraction depends on continuing to develop our geological understanding and extractive technologies. We are also starting to understand better the extent of the UK's onshore resources of **unconventional fossil fuels**, such as shale gas, shale oil and coal bed methane, which have the potential to make a significant contribution to our energy mix if we choose to extract them. If we do not develop our domestic fossil fuel resources, we will become more dependent on imported fuel, which may adversely affect our energy security. Much of our electricity is still generated from burning domestic and imported coal.



Schematic representation of shale gas operations. Most shale gas plays are at 2km to 5km depth, with drinking water aquifers within the first few hundred metres below the surface. Image credit: © B J Services.

Shale gas

Hydrocarbons (oil and gas) are formed from organic matter deposited millions of years ago in layers of sedimentary rocks, which was then subjected to heat and pressure. In 'conventional' reservoirs, oil and gas have migrated from where they were formed, to become trapped by an impermeable bounding layer. When gas is instead formed and retained in impermeable shale and cannot migrate, it cannot be extracted using conventional drilling techniques (and is hence referred to as an 'unconventional' resource).

It is now possible to extract shale gas economically, using horizontal drilling and hydraulic fracturing ('fracking'), in which water, sand and small quantities of added chemicals are used to open up fractures in the rock, allowing the gas to flow more freely. Geological expertise is vital to locate shale gas resources, and to understand and manage possible risks linked with their extraction, such as induced seismicity or aquifer contamination due to poor well construction.

Carbon capture and storage (CCS)

As the significant role played by fossil fuels in our energy mix is set to continue in the medium term, urgent action is required to avoid dangerous climate change as a result of the CO_2 released when they are burnt. CCS has the potential to achieve this objective, if implemented at sufficient scale, by capturing this CO_2 and trapping it safely underground.

Geologists are already working on siting and technical development of suitable storage sites. North Sea oil and gas reservoirs nearing the end of their life are prime candidates as locations for carbon storage, and this potential storage capacity represents a further valuable resource for the UK, especially if existing infrastructure can be repurposed. Geologists will also be key to long term implementation, and monitoring of CO_2 leakage and sub-surface deformation. Promising new research is currently underway into novel geological settings for carbon storage.

Other energy sources

Renewables are set to play an increasingly important role in the energy mix, as we move towards a decarbonised economy.

A thorough understanding of the surrounding and underlying geology is important for the siting and construction of many forms of renewable energy generation; in particular wind farms, dams and geothermal and tidal energy sources.

Many of the raw materials required for renewable energy technologies, including wind turbines, hybrid motors and solar panels, include critical raw materials such as the Rare Earth Elements, all of which rely on geological research and skilled personnel to locate and extract safely.

Nuclear power is likely to constitute an important part of the future energy mix. It depends on a reliable source of uranium, extracted from economically recoverable uranium ore – again, a process dependent on geological expertise. We will need to ensure the safe long-term management of radioactive waste from our existing nuclear power stations, even if no more are built. In common with most other countries with nuclear power capacity, the UK Government's policy is to dispose of this waste in a geological disposal facility.

Geothermal pool, Rotorua, New Zealand. Photo credit: Wikimedia Commons.

Geological disposal of radioactive waste

Geological disposal involves isolating waste in an underground repository constructed in a suitable rock formation, typically at a depth of 200 to 1000m, to ensure that no harmful quantities of radioactivity reach the surface environment. It is a multi-barrier approach, with packaged wastes placed in engineered and backfilled tunnels, and the geosphere providing an additional barrier, to keep radionuclides trapped for tens of thousands of years. Various geological settings can be suitable, including granite, clay and salt. The siting process in the UK is based on community voluntarism. Geologists will play many vital roles in characterising potential sites and implementing a repository.

Geothermal energy

There is scope in the UK for greater use of ground source heat, heat sinks and (in some locations) high-temperature geothermal sources. With heat supply accounting for 44% of final energy consumed in the UK, ground source heat pumps are gaining popularity, particularly in rural areas. Integrated heating systems for modern building developments using ground source heat and cooling can deliver reductions in CO_2 emissions of up to 10%. Development of these resources requires the expertise of geologists to locate and test for viable geothermal capacity, and understanding of the sub-surface to design and engineer the necessary infrastructure.

Water

A secure, high quality supply of fresh water is vital to human health and well-being. Geologists help meet this need, in the UK and globally, through their understanding of water movement and aquifer behaviour, as well as identifying and mitigating water contamination.

Water security

Fresh water on the land's surface exists as part of a wider system encompassing groundwater, oceans, water in the atmosphere and water stored as ice.

Approximately one third of public water supplies in England and Wales, 6% in Northern Ireland and 3% in Scotland come from groundwater - an important but fragile resource that needs careful management. The remainder comes from surface water from lakes and rivers, collected in reservoirs.

Groundwater levels vary depending on local rainfall, rate of infiltration (the rate at which the ground is able to absorb it) and the volume of abstraction (removal for use). In some locations, groundwater is effectively a non-renewable source of fresh water, due to the time required for aquifer recharge (replenishment), which can vary from seasonal timescales to many millennia.

Water quality and the water cycle

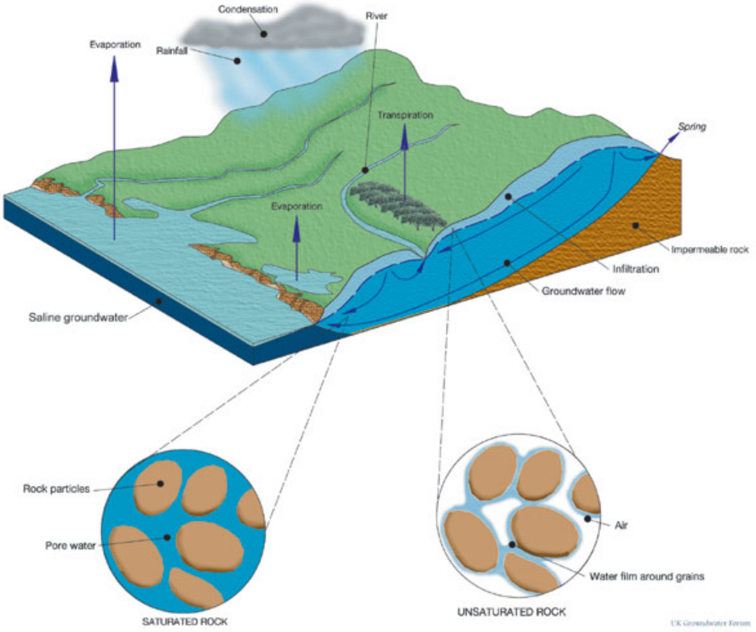
Water can be naturally contaminated but is at greater risk of pollution from human activities. Much pollution comes from diffuse sources such as the application of pesticides and fertilizers to agricultural land. Rain falling on this land picks up pollutants from the surface of the soil and drains into watercourses or into underlying aquifers. There are also many point sources of pollution, such as leaks of chemicals at industrial sites, from sewage systems or from landfill sites.

Contamination can build up slowly and have long residence times, due to slow rates of groundwater infiltration, recharge and migration. Remediation of contamination can be expensive, financially and in terms of energy use. To minimise future clean-up costs and provide clean water, is it vital to understand both groundwater behaviour and the geochemical cycles of potential contaminants.

What is groundwater?

Groundwater is water which filters downwards through the ground to below the water table, where it is held in porous rocks. This water is in the 'saturated zone'. It flows through the ground (often very slowly) until it reaches a point of discharge such as a spring, a river or the sea.

Geological formations that contain groundwater which can be extracted are called **aquifers**, and are an important source of drinking water in the UK and internationally. However, not all water in aquifers is fresh – it can be highly saline. The porosity and permeability of a rock formation affect how much water can be stored and its ability to flow, and hence how good an aquifer the formation is.



Groundwater in the Hydrological Cycle. Image credit: UK Groundwater Forum.

The water-energy nexus

The energy sector demands high volumes of water for many of its core processes. Resource extraction, the transport of fuels, energy transformation and power plants account for around 35% of water use globally. By 2050, water consumption to generate electricity is forecast to more than double. The current trend in diversification of energy sources, including use of alternative fuels, will often require increasingly water-intensive processes. Extraction of oil from oil sands requires up to 20 times more water than conventional drilling, for example, while biofuels can consume thousands of times more water than conventional fossil fuels due to extensive irrigation.

At the same time, energy is needed to produce and deliver clean water. It is essential at every stage of the supply chain, including pumping ground water, surface water treatment, transport and domestic water heating. Energy use for water treatment is set to increase with the addition of treatment technologies and purification measures, particularly if energy-intensive desalination increases in response to reduced fresh water availability. Water companies in the UK report increases of over 60% in electricity usage since 1990 due to advanced water treatment and increased connection rates, and conservative estimates predict increases of a further 60-100% over 15 years in order to meet water quality guidelines.

Impact of environmental change

The well-documented **drought** in the UK early in 2012 raised questions over the security of UK water supplies. There was concern regarding the groundwater level of aquifers in the UK, the majority of which fell significantly below average. The drought was eventually alleviated by unusually wet weather in the spring and summer of 2012, but threats to the UK's water security are likely to grow. Globally, this threat is already critical. Increasingly erratic weather patterns put at risk aquifer recharge and water supplies. Low groundwater levels coupled with slow recharge could have very serious effects on future water security, even in the UK. Climate change is expected to have a multiplier effect, and extreme weather may compromise economic activity and national infrastructure.

Geological expertise

An understanding of local hydrogeology and environmental conditions is essential to managing water supply and quality. Hydrogeologists and other geoscientists investigate and map the subsurface in order to model and understand the movement of water, and to quantify and characterise aquifer resources. Seasonal and long-term groundwater monitoring can help predict and manage periods of aquifer depletion due to low rainfall. This information can then be used to design strategic drought, flooding and water provision plans.

Wastewater treatment system and Akosombo dam in Ghana illustrating the interdependence of water and energy. Photo credits: Wikimedia Commons.

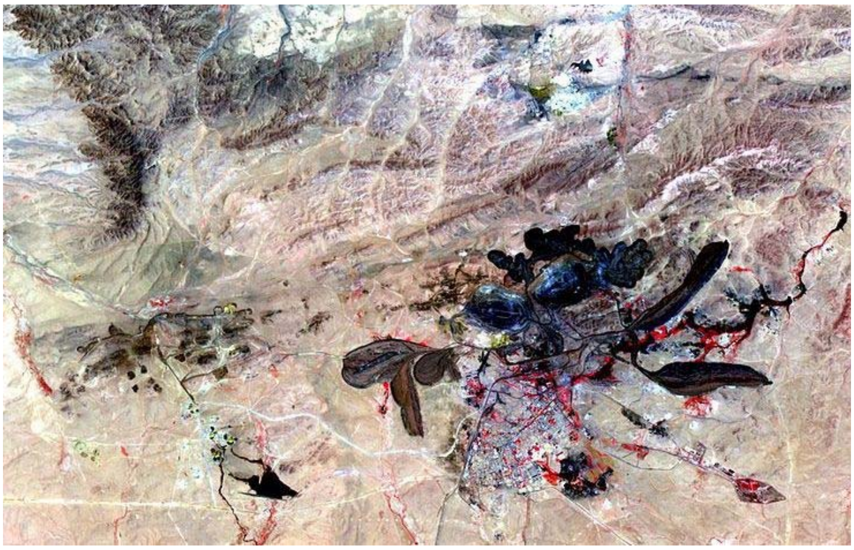
Mineral resources

Modern industry, technology and consumer products require a vast array of minerals, both abundant and rare. Their extraction and trade forms a major part of our national and global economy. As the population and demand for resources grow, innovative technologies are required to locate and extract minerals and to use them more efficiently.

Resources

The minerals industry supplies a wide range of resources. These include construction materials such as natural and crushed rock aggregate and sands; phosphates and potash for fertilisers; many minerals with specific industrial applications such as fluorspar (used in optical equipment) and barytes (used in drilling fluids for oil and gas extraction); and minerals from which metals of all kinds are extracted.

Some mineral resources are relatively abundant, and are extracted and used in large quantities, such as aggregates and some metals including copper, nickel, aluminium and iron. Others, while used in much smaller quantities, are nonetheless in sufficient supply to meet global demand. However, in the case of some economically or strategically important minerals, there is a risk that supply may be insufficient to meet demand in the short to medium term, generally due to economic and political factors rather than limited geological abundance. These are known as **'critical' raw materials**. There is no definitive list, but the EU has identified 14 critical mineral resources. They include two groups of metallic elements – the Rare Earth Elements (REE) and the Platinum Group Metals (PGM). There is also concern about future supply of phosphates and potash, which are used in large quantities for fertiliser production.



Bayan Obo Mine, Inner Mongolia, China - one of the largest rare earth deposits in the world. Photo credit: Wikimedia Commons.

Rare Earth Elements

The Rare Earth Elements (REE) are a group of seventeen metallic elements: the fifteen lanthanides, with atomic numbers 57 to 71, together with Yttrium and Scandium. Their use in high-tech applications such as plasma screens, electronics, medical imaging and low carbon technologies including wind turbines and hybrid vehicles has led global demand to increase by more than 50% in the last decade, and this is expected to rise further. A June 2010 study by the European Union identified the REE collectively on its list of 14 critical mineral resources. China currently dominates global production of REE, and most other large deposits are located outside Europe - principally in China, the CIS (in Russia, Kyrgyzstan and Kazakhstan), the USA and Australia.

Geological scarcity in absolute terms is not likely to be a problem, and increased REE prices and global concerns over security of supply have driven efforts to start up large mining operations outside China. But the technical, financial, environmental and regulatory challenges which must be overcome make establishing new REE mines a long and expensive process. This could lead to demand outstripping supply over the next few years, and may act as a constraint on the development and deployment of low carbon technologies which depend on REE.

The UK mineral sector

Mineral extraction in the UK played a major part in our industrial development and economic growth. Most minerals are no longer extracted on a large scale in the UK, although we continue to produce significant amounts of aggregate and rock salt, for instance. Some new metalliferous mining operations are also coming on stream, such as at Hemerdon in Devon where tungsten mining operations are expected to restart in 2014. Many global mining companies have a significant UK presence and are traded on the London Stock Exchange.

Hemerdon tungsten and tin mine, Devon. Photo credit: Wikimedia Commons.

Only very small quantities of the critical minerals used in the UK are produced within the EU. Production of specific mineral resources is often dominated by one or two countries (the Democratic Republic of Congo in the case of cobalt, for example), and this can put security of supply to the UK and other EU countries potentially at risk. Overall China, Russia, Australia and the US are the largest producers of minerals.

The UK's world-renowned work on mineral deposits research and exploration, across academia and industry, supports the global search for new economic deposits and the assessment of known resources. The sea floor is considered by some to be a potentially significant future source of metals, including several identified as critical materials. Innovative research looking at whole resource cycles may also lead to economic extraction of metals from wastes produced by industrial processes, and reworking of historic mining wastes to recover minerals that were not extracted initially. Product design can also be improved to 'close the loop' through recycling and reduced dispersal of materials (so called 'cradle-to-cradle design'). Energy efficiency and reduction of environmental impacts of resource use are also driving research in this area.

Feeding a growing population

Without geology, there would be no agriculture. Plant crops depend on good quality soil (consisting of weathered rock together with organic matter, water and gases) as a growing medium. They also require geological nutrients. Global population growth is putting increasing pressure on food resources. The supply of phosphates and potash used in fertilisers is coming under ever greater pressure, at a time of increasing tension between food, energy and water security and environmental change.

The global growth in high levels of fertiliser use has led to high demand and concerns about the future security of supply of phosphates and potash. A few countries supply most of the world's phosphates, with China the largest producer. Even fewer supply potash. Continuous use of phosphorus (in contrast to potash) can also have damaging effects on the environment due to phosphates leaching into rivers, causing eutrophication.

Agriculture in Brazil. Photo credit: Wikimedia Commons.

Engineering the future

Understanding ground conditions and how buildings, infrastructure and people interact with their geological environment is essential to assuring public safety and well-being, delivering value for money and meeting the challenges of living with environmental change.

The built environment

Engineering geology involves the application of geological principles and specialisms alongside relevant engineering disciplines, in a wide range of contexts. The construction sector employs large numbers of engineering geologists, along with hydrogeologists, environmental geologists and others, to understand ground conditions and the wider geological setting, and how this will interact with elements of the built environment, including buildings, roads, railways, dams, tunnels, pipelines and cables. A fundamental part of this work is to plan for the impacts of environmental change, to remediate contamination of land especially if it has previously been used for industrial activity, and to assess and manage the effects of geological hazards of all kinds, from earthquakes to landslides and the swelling and shrinking of clay.

Underestimating the importance of such work in major projects, or failing to carry it out properly, is often the cause of very significant additional cost and time overruns. Identifying and effectively managing ground-related problems is also essential to ensure public health and safety, quality of our built environment and fitness for purpose. High professional standards must be defined and upheld by geologists, engineers and others involved, for the public benefit. Geotechnical risk can affect all those involved in construction, including the client (which may ultimately be government, especially for national infrastructure projects), the designer, the constructor and the general public.

Geologists will also play an essential role in infrastructure development as we move to a low carbon economy, for example in siting tidal barrages and wind turbines, and carrying out seismic hazard analysis in planning for new nuclear power stations.

The British Geological Survey National Geological Model

Due to our rich geological resource base and industrial past, the subsurface of the UK and the surrounding waters has been extensively explored and mapped, ever since the making of William Smith's 1815 map – the first national geological map in the world. As we increasingly make competing demands on the subsurface and our search for resources becomes more sophisticated, innovation in mapping and modelling the geosphere is imperative.

The British Geological Survey National Geological Model project builds on its legacy of traditional two-dimensional mapping, over a million borehole records from drilling and site investigation work, and a wide range of other extensive datasets. The aim of the project is to construct an accurate, multi-scalar, geospatial model of subsurface rocks and sediments across the UK and offshore. A major step towards achieving this was the December 2012 release of GB3D – a three-dimensional map of the UK constructed from myriad intersecting cross-sections, free to download and interrogate online.

GB3D National Bedrock Fence Diagram. Image Credit: BGS

The National Geological Model will be of great practical value to hydrogeologists, engineering geologists and others working across a wide range of contexts, including modelling of groundwater systems to help meet demand for fresh water and anticipate drought and flooding; and nationally important infrastructure projects such as the siting and construction of a geological disposal facility for nuclear waste.

Urban geology – engineering tomorrow's cities

An ever-growing proportion of the world's population lives in increasingly large and complex cities. The work of geologists in managing multiple concurrent (and sometimes competing) uses of the surface and subsurface will be particularly important in urban areas if the cities of the future are to be sustainable.

The Tottenham Court Road Crossrail construction site.
Photo credit: Wikimedia Commons.

Space is at a premium, and the subsurface is used intensively for transport, construction and the delivery of resources and services. The supply of water and energy and the disposal of waste present particular challenges in large cities, as well as opportunities for innovation. The built environment must be designed to maximise energy efficiency, and manage (and make use of) the 'urban heat island' effect. Large scale underground transport infrastructure projects, such as Crossrail in London, are technically demanding and depend on the skills of a wide variety of engineers and scientists, including engineering geologists and hydrogeologists. As the complexity of the ground becomes better understood and new technologies are developed, in some instances it may be possible to extract geological resources including minerals, groundwater and energy in urban environments.

Environmental policy-making in the UK is dominated by an 'ecosystems services' approach (see page 13). It is important to remember that ecosystems, the environment and interactions between different parts of natural and human systems are not restricted to rural areas. The subsurface and abiotic aspects of ecosystems are fundamental, in both rural and urban settings.

Using the subsurface

Geologists are involved in a wide range of uses of the subsurface, many of which are mentioned in this document. These uses include the extraction of energy, water and mineral resources; use of pore space in rock to contain injected CO_2 or natural gas stored in geological formations; disposal of radioactive waste, landfill and other waste disposal; foundations and basements of buildings; and accommodating transport infrastructure, cables and pipes.

As we turn to the geosphere to provide an ever-greater variety of services, these need to be carefully planned. Any given volume of the ground may be required to perform several different functions, consecutively or concurrently. There may sometimes be competition for underground space between functions which are not readily compatible. Geologists can advise on these matters, but decisions about how we use the geosphere are ultimately political and economic.

Environmental health

Centuries of industrial and urban development in the UK have left their mark on our land, water and atmosphere. Pollution can spread and interact across the geosphere, biosphere, atmosphere and hydrosphere, all of which are interconnected.

Land and water quality

Around 300,000 hectares of land in England and Wales, 80,000 hectares in Scotland and 22,000 hectares in Northern Ireland are thought to have been contaminated as a result of past industrial activities. To make such brownfield sites suitable for redevelopment requires investigation and remediation. Sites may be cleaned up voluntarily by the site owners, through the planning system during development or, for the most heavily contaminated sites, through regulation.

When designing remediation schemes, it is important to consider how they may be affected by future environmental change. In situ remediation techniques such as permeable reactive barriers and contaminant encapsulation may no longer be stable, as increased erosion, drought or flood water inundation can result in release of contaminants into the environment.

High quality soil and water is essential for secure and sustainable food supply. Soil also acts as an important sink for atmospheric carbon, and records past and present environmental change, making it a vital tool in the understanding of such change. Protecting and improving our waterways, oceans and drinking water depends on a good understanding of the behaviour and interaction of water, soil, rock and the atmosphere at the surface, and the subsurface geology.

Our industrial legacy and its effect on land quality

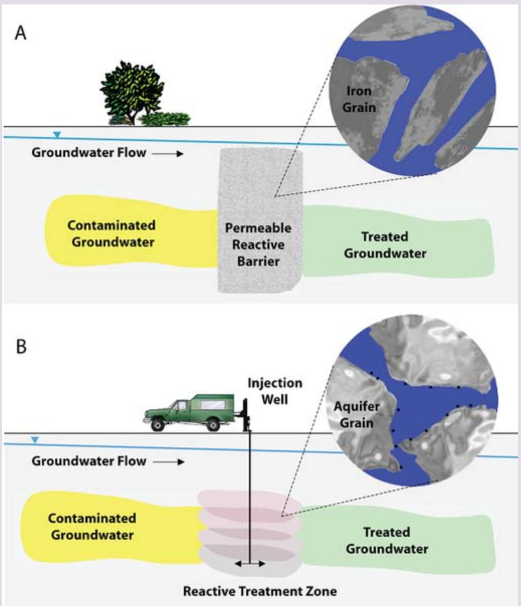
Remediation and management of contaminated land can be complex and expensive, especially if there is a legacy of unregulated disposal of waste and contaminated materials. Work done by the British Geological Survey to characterise the soil geochemistry of five indicative elements in the London area highlights the complexity of industrial soil contamination. Long term sustainable remediation of the UK's contaminated land requires innovative engineering and management approaches and safe disposal of contaminants, underpinned by sound geological understanding.

Chemical dumping in Wakefield. Photo credit: Wikimedia Commons.

Groundwater remediation

Geology acts as a primary control on the quality of surface water and groundwater. Remediation of contaminated groundwater comes in a variety of forms, including physical barriers, chemical remediation and – usually the most economical – natural attenuation. Engineered solutions depend on knowledge of ground behaviour and strength, and the use of materials such as adsorbents and oxidants requires an understanding of the rock and water geochemistry. Natural attenuation methods rely on naturally occurring physical, chemical and biological processes to break down contaminants as they flow through the subsurface. Their use depends on a good understanding of the ground's chemistry and hydrogeology.

In addition to improving the efficiency of remediation work, a good understanding of the subsurface geology can save a great deal of time and money spent on engineering and implementation.



Permeable Reactive Barrier. Image credit: Wikimedia Commons.

Valuing and protecting our environment

Environmental policy and management based on an 'ecosystems services' approach depends on taking a truly holistic view of ecosystems and the environment. The importance of geology and the geosphere to environmental protection and ecosystem service provision are all too often overlooked – in fact they shape our landscape, interact with the atmosphere and hydrosphere, and sustain living systems.

Geosystem services

A wide range of ecosystem services – ways in which we derive societal and economic benefit from the environment – depend on the geosphere, and can collectively be termed 'geosystem services'. They include:

- vital **provisioning services** such as the supply of energy, water, mineral resources and the ground on or in which our urban and transport infrastructure is built
- **regulating services** such as potential storage capacity for radioactive waste and CO_2 and natural buffering of atmospheric CO_2 sequestered in soils
- **supporting services** which underpin ecosystems, including geochemical cycles, and the effect of geomorphology on habitat fragmentation and between-community disparity, essential to biodiversity
- enjoyment and appreciation of landscape and other **cultural services**

The UK's rich geological heritage and diversity is a valuable resource in terms of education, tourism and quality of life. It is vital that geologically important sites are adequately protected, for instance through designation as Sites of Special Scientific Interest (SSSIs).

The buffering functions performed by the geosphere, hydrosphere and atmosphere are of huge environmental value, and are only starting to be properly understood. The capacity of natural systems to withstand change depends in part on the critical loads of pollutants which they can absorb. They are likely to become increasingly stressed as atmospheric CO_2 levels increase, global temperatures rise, and oceans become more acidic due to dissolved CO_2. Coral reefs, which host vast numbers of species in some of the world's most biologically diverse ecosystems and provide ecosystem services such as tourism, fishing and coastal protection, are particularly vulnerable to changes in ocean chemistry, and are already deteriorating rapidly.

Marine Conservation Zones

Marine Conservation Zones (MCZs), and Marine Protected Areas in Scotland, provide a potential basis for a holistic approach to marine ecosystems and environmental processes. The effectiveness of this approach is at risk if only biotic aspects of marine ecosystems are considered, neglecting abiotic elements and the interactions of the land's surface and subsurface with the sea and the life it sustains.

Sediments are transported in and out of estuaries by the tides and currents, carrying with them pollutants, and interacting with seawater chemistry. Fishing can cause disturbance to the sea floor, disrupting ecosystems. The construction of coastal defences can change current patterns and resultant sediment distribution. Nutrient cycling as a supporting service is dependent on geochemical interactions between various components of the marine/fluvial system – the bedrock, superficial sediments, biota, the water column and the atmosphere.

Durdle Door Coastline. Photo credit: Wikimedia Commons.

Geohazards

Geohazards, such as earthquakes, volcanic eruptions, landslides and tsunamis, can have devastating effects on populations, economies and landscapes around the world. Understanding and effectively communicating the risks, impacts and mitigation of these hazards is essential for reducing human suffering.

Earthquakes

The impact of earthquakes depends not only on their magnitude and depth, but on human factors – population density, level of development, preparedness and education. Far more deaths were caused by the 2010 Haiti earthquake, for instance, than by some much bigger earthquakes. A large earthquake near a megacity in a developing country could be more devastating still. The most effective ways to reduce the human impact of earthquakes are to reduce poverty; to improve education, civil preparedness and infrastructure; and to design and construct new buildings to withstand their effects. Retrofitting old buildings is possible, but far more expensive.

Probabilistic forecasting of the likelihood of earthquakes happening in a particular area over a period of time has improved greatly in recent decades as a result of geological research. However, it is not currently possible to make deterministic predictions of exactly when and where earthquakes will happen, and most geologists do not believe this to be a realistic prospect.

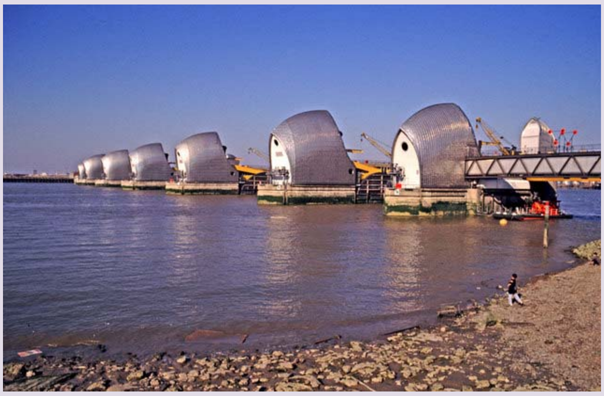
The UK generally experiences only very minor earthquakes, but global vulnerability to earthquake hazards has important implications for international trade, development and aid.

President Barack Obama visiting earthquake damage in L'Aquila in Italy. Photo credit: Wikimedia Commons

UK geohazards

Although we do not think of Britain as experiencing large scale geological hazards, less dramatic ones result in costs of between £0.5bn and £1bn each year, as well as occasional injury or loss of life.

Most significant is the swelling and shrinking of clay formations, which can damage buildings and infrastructure. Other relatively common natural geological hazards include landslides, sinkhole formation by the dissolution of more soluble rocks, and the presence of weak and compressible ground. The geological record also shows that the UK has experienced significant tsunamis in the recent past, and this could happen again.



Thames Flood Barrier – built to prevent the floodplain and eastern Greater London from being flooded by high tides and storm surges. Photo credit: Wikimedia Commons.

There are also 'anthropogenic geohazards' caused by human activities such as ground contamination, mineral extraction and waste disposal. We are experiencing increasing levels of weather-related hazards such as flooding, including groundwater flooding. The 2012-2013 flooding events seen across the UK resulted in insurance claims of over £1bn. Geologists have an essential role to play in advising on the construction of flood defences, understanding and managing natural defences, and ensuring land use is planned effectively.

Landslides

Landslides are relatively common in the UK, and can have a significant impact on the economy. They may be becoming more frequent as our climate changes. Initial figures suggest there was a five-fold increase in the number of landslides between June 2012 and June 2013, following exceptional levels of rainfall in 2012.

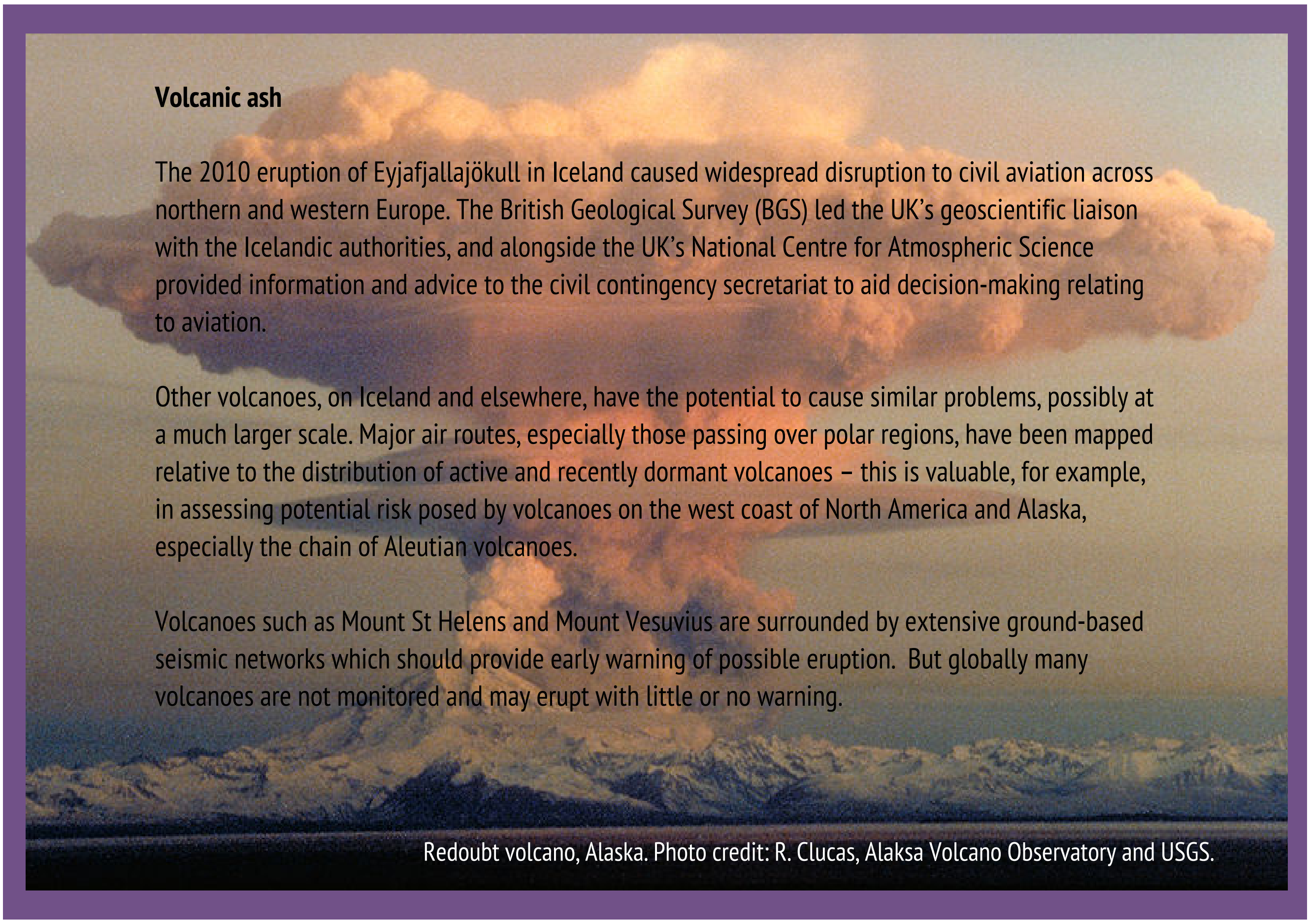
Landslides do not occur only as a result of factors such as heavy rainfall and erosion. They can also be triggered by other geohazards, and by human activities such as mining, deforestation and land use change. Landslides are responsible for about 15% of all tsunamis worldwide.

Volcanoes

An estimated 500 million people globally live close enough to active volcanoes to be affected when they erupt. Many cities have developed on the fertile land often found in the vicinity of volcanoes. Active volcanoes which may affect large populations include Mount Vesuvius near Naples and Popocatepetl near Mexico City.

Every effort should be made to minimise casualties from volcanic eruptions, but in fact these have been relatively modest (around 300,000 in the last 200 years) compared to some other natural hazards. Nonetheless, economic losses, damage to infrastructure and societal disruption can be considerable.

As with tsunamis, volcanoes can also have affects on communities much further away, where the perceived risk may be low as the hazard is ‘out of sight, out of mind’. The modern globalised world is vulnerable to very large volcanic events, making the study of their return periods and environmental impacts a topic of active research in volcanology.



Volcanic ash

The 2010 eruption of Eyjafjallajökull in Iceland caused widespread disruption to civil aviation across northern and western Europe. The British Geological Survey (BGS) led the UK’s geoscientific liaison with the Icelandic authorities, and alongside the UK’s National Centre for Atmospheric Science provided information and advice to the civil contingency secretariat to aid decision-making relating to aviation.

Other volcanoes, on Iceland and elsewhere, have the potential to cause similar problems, possibly at a much larger scale. Major air routes, especially those passing over polar regions, have been mapped relative to the distribution of active and recently dormant volcanoes – this is valuable, for example, in assessing potential risk posed by volcanoes on the west coast of North America and Alaska, especially the chain of Aleutian volcanoes.

Volcanoes such as Mount St Helens and Mount Vesuvius are surrounded by extensive ground-based seismic networks which should provide early warning of possible eruption. But globally many volcanoes are not monitored and may erupt with little or no warning.

Redoubt volcano, Alaska. Photo credit: R. Clucas, Alaksa Volcano Observatory and USGS.

Climate change

The geological record contains abundant evidence of the ways in which Earth's climate has changed in the past. That evidence is highly relevant to understanding how it may change in the future, and the likely impacts of anthropogenic carbon emissions.

Geological evidence of past climate change

Over at least the last 200 million years, the fossil and sedimentary record shows that the Earth has undergone many fluctuations in climate, from warmer than the present climate to much colder, on many different timescales. As well as cyclical variation caused by factors such as variation in the Earth's orbit and in solar activity, there have been instances of rapid climate change associated with increases in atmospheric carbon, such as the Paleocene-Eocene Thermal Maximum (PETM) 55 million years ago.

Evidence of past climate change is preserved in a wide range of geological settings, including marine and lake sediments, ice sheets, fossil corals, stalagmites and fossil tree rings. Advances in field observation, laboratory techniques and numerical modelling allow geologists to show, with increasing confidence, how and why climate has changed in the past. This baseline of knowledge about the past provides an essential context for estimating likely changes in the future.

Melting at the perimeter of an ice sheet in Greenland.
Photo Credit: Michael Studinger, NASA GSFC, 2008.

Lessons for the future

Based on records of past climate change, geologists are increasingly confident that CO_2 is a major modifier of the climate system. The evidence confirms the basic physical principle that adding large amounts of greenhouse gases such as CO_2 to the atmosphere causes temperatures to rise. It also shows that this is likely to result in higher sea levels, increased ocean acidity, decreased oxygen levels in seawater, and significant changes in weather patterns.

Life on Earth has survived major changes to the climate in the past, but these have caused mass extinctions and major redistribution of species. The impact of relatively small increases of a few degrees in global temperatures on modern human society is expected to be enormous.

The exact causes of past instances of rapid climate change are the subject of continuing research, but it is likely that the trigger for such events was geological in origin – for example, a period of intense volcanic activity. The rapid rises in atmospheric CO_2 in the last few decades cannot be attributed to any such geological cause. Over 500 billion tonnes of carbon (hence over 1,850 billion tonnes of CO_2) have been added to the atmosphere as a result of human activities since 1750, some 65% of that being from the burning of fossil fuels, and at the present rate of increase, atmospheric CO_2 may reach 600 parts per million (ppm) by the end of this century – a value that appears not to have been typical for at least 24 million years.

Geologists have a vital role to play, not just in helping to improve our understanding of climate change, but in reducing future CO_2 emissions (through development of CCS and alternative energy sources, for instance), and adapting to the consequences of future climate change.

The Anthropocene

Human activity has had dramatic impacts on landscape, the subsurface and Earth systems, driving significant atmospheric, chemical, physical and biological changes. Are these changes sufficiently significant and permanent to mark the beginning of a new geological epoch – the Anthropocene?

Anthropogenic change

The International Commission on Stratigraphy (ICS), which defines the International Geologic Time Scale and sets global standards for classifying geological time, is currently considering whether to define a new geological epoch – the 'human epoch' or Anthropocene – to recognise the extent of the impact we have had on our planet. Some stratigraphers suggest the Industrial Revolution as the starting point of the Anthropocene, recognising that the effects of the 1,850 billion tonnes of CO_2 which humankind has released into the atmosphere since that date may extend over geologically appreciable timescales. Others argue that lasting human impacts on the planet can be dated earlier, to the development of farming and sedentary cultures around 8,000 years ago. Whatever date is identified, the development of human society has been responsible for significant reshaping of the land and landscapes through a wide variety of processes including agriculture, construction, canalisation of rivers, deforestation, urban growth and industrialisation.

We have also left a potentially indelible mark of contamination and pollution in the air, on the land's surface, in the oceans and waterways and in the subsurface. Telling markers include lead pollution, which is produced primarily by smelters, metal processing and incineration, and is now being found to have reached remote locations such as polar ice caps and peat bogs as far back as Greco-Roman times. As well as the widespread burning of fossil fuels, the Industrial Revolution brought considerable levels of contamination from mining, smelting and the spread of pollutants as a result of other industrial activity and waste disposal.

Air Pollution: Smoke rising from a plant tower. Photo credit: Wikimedia Commons.

The British Geological Survey is currently undertaking work to investigate the range, type, scale and magnitude of anthropogenic influences on land use and Earth system processes, their impacts and their geological significance. These combined changes and their impacts on the chemistry, biology and geomorphology of the surface, subsurface, oceans and atmosphere could help to demarcate the Anthropocene and its unique environmental signature.

Does it matter?

Whether or not the ICS concludes that the Anthropocene satisfies the definition of a new geological epoch, the term has rapidly gained currency, both in the geological community and more widely. It expresses the idea that the cumulative and combined impacts of humankind on our planet, including but not limited to climate change, may persist over geological timescales, and this may be helpful in framing our response to these changes.

The future

With the global population estimated to reach nine billion by 2045, there will be increased pressure on resources, the environment and the shallow subsurface, particularly in built-up areas where the subsurface is in high demand and infrastructure is complex. Living in the Anthropocene will present unprecedented challenges to societies and governments across the world.

Communicating geology: time, uncertainty and risk

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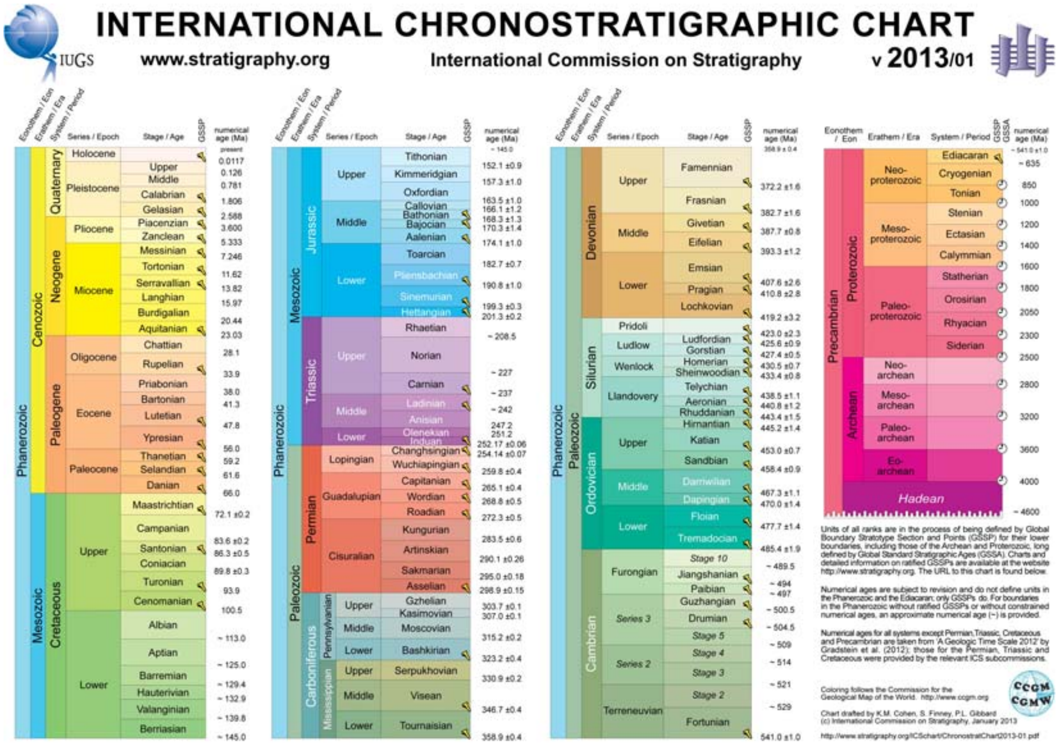
Geological issues are increasingly prominent in the everyday lives of people across the UK – and professional geoscientists have to learn to communicate their science better, to enable the wider population to participate in informed debate.

From decision-making about onshore extraction of shale gas and other hydrocarbons, to subsurface injection of water to generate geothermal power and the deep storage of carbon and radioactive waste, geology underlies some of the key questions which communities across the UK will face as we seek to meet future resource needs, grow the economy, understand technical risks and their social impacts, and ensure that regulation and governance of technology protect public and environmental health and well-being. Along with the complex scientific and technical challenges that implementing these technologies will bring, to most people the geological subsurface is an unknown realm. If the public are to engage in informed debate and decision-making about such technologies, it is important for professional geoscientists to develop effective strategies to communicate effectively what they know and do, and to understand what the public knows and what concerns them.

Some of the fundamental well-established ideas and knowledge which geologists use (and may take for granted) are unfamiliar to most people. Geologists may see their appreciation of immensely long **time** periods as giving them a privileged understanding of the planet and the processes which have shaped it. But this may also lead them to take a very different view of time from non-geologists. To most people, for instance, 100,000 years may seem a very long time to rely on the geosphere to contain radioactive waste – but to a geologist, this is a very short period. This may reduce rather than enhance public confidence and trust in the expertise and professional judgment of geologists advising on radioactive waste disposal, unless they work hard to understand public perspectives and concerns.

Similarly, geologists are often comfortable dealing with **uncertainty** and with incomplete data – and may view their ability to work in this way as a core element of their expertise. Communicating openly and effectively the ways in which geologists work with incomplete data, seek to constrain uncertainty and make **probabilistic assessments**, for example of **resources** and of **risk** from natural hazards, is essential if these attributes are to be recognised as having value rather than simply being expressions of ignorance.



Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Numerical ages for all systems except Permian, Triassic, Cretaceous and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012); those for the Permian, Triassic and Cretaceous were provided by the relevant ICS subcommissions.

Coloring follows the Commission for the Geological Map of the World. http://www.ccgm.org

Chart drafted by K.M. Cohen, S. Finney, P.L. Gibbard
(c) International Commission on Stratigraphy, January 2013

http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01.pdf

The International Chronostraigraphic Chart depicting geological time to the last 4.6 billion years. Available to download at http://www.stratigraphy.org/index.php/ics-chart-timescale

Image credit: International Commission on Stratigraphy.

Geology for the future

21st century society faces unprecedented challenges in meeting the resource needs of a growing global population which aspires to higher living standards, while learning to live more sustainably on our planet. Ensuring a skilled geoscience workforce and a strong research base will help equip us to address these challenges, and is vital if the UK is to be internationally competitive.

Education

Geology is vital to people's lives. However, it is not a core subject in the school curriculum in its own right, and is not taught at the majority of schools. It is therefore essential that young people are taught about key processes and concepts in Earth science within mainstream science subjects (chemistry, physics and biology) and geography, to equip them as well-informed 21st century citizens able to engage in debate about the great challenges facing humankind. The school curriculum across the nations of the UK should reflect this. Ensuring that all students have a basic grounding in Earth science is also necessary to stimulate the next generation of geologists, who will have a fundamental role in addressing these challenges. High quality careers advice is also vital, so that students are aware of the wide range of possible careers in geology, and understand how the subjects they choose to study at each stage of their school education may later restrict the programmes of university study (and hence career options) available to them.

In many sectors of industry, most employers seeking to recruit geoscientists require applicants to have a taught applied MSc in a relevant specialism such as petroleum geology, engineering geology, hydrogeology or geophysics. Public funding to support taught MSc programmes has historically delivered through the Research Councils, but in recent years this has been withdrawn. Industry already funds many MSc students, and any assumption that potential employers (especially SMEs) will also backfill the funding previously provided by government appears to be misplaced. Together with lack of access to student loans for MSc students and real or perceived restrictions on overseas students coming to the UK, this risks the supply of trained personnel in some key areas. It also jeopardises the viability of MSc programmes, some of which are already closing down, risking the UK's national capability and competitiveness.

Research

Economic competitiveness and our ability to meet future challenges will also depend on sustaining the UK's highly regarded geoscience research base. It is essential that we continue to support excellent curiosity-driven research, as well as needs-driven research, not least so that society is as prepared as possible to respond to 'unknown unknowns' – novel future risks and emergencies which we have not yet anticipated. Maintaining and developing our research base will require us to look after all stages of the 'skills pipeline', and to invest in sustained research funding so that young researchers can build stable careers.

Assuring professional standards for public benefit

The Geological Society of London awards the professional designation of Chartered Geologist (CGeol) to practitioners with a high level of education, professional competence in their field and a commitment to professional ethics. The Society is also licensed to award the title of Chartered Scientist (CSci) by the Science Council, and that of European Geologist (EurGeo) by the European Federation of Geologists. With partner bodies, it maintains the Register of Ground Engineering Professionals (RoGEP) and the Specialist in Land Condition (SiLC) scheme. As well as being qualifications valued by individuals and their employers, all these designations provide assurance to others that individuals' work, on which public safety and well-being often depends, will be carried out competently, professionally and ethically.

The Society also accredits undergraduate and MSc degree programmes, ensuring that they foster core skills and knowledge of value to future employers, and the in-house professional training schemes provided by employers.

The Geological Society of London

The Geological Society
serving science & profession

The Geological Society is the UK's learned and professional body for geoscience, with more than 11,000 Fellows (members) worldwide. The Fellowship encompasses those working in industry, academia and government with a broad range of perspectives on policy-relevant science, and the Society is a leading communicator of this science to government bodies, those in education, and non-technical audiences. The Geological Society is a global leader in Earth science publishing, and is renowned for its cutting edge research conferences. It also holds one of the world's most important geological libraries. For more information about the Society and its activities, visit **www.geolsoc.org.uk**.

You can find policy documents, articles, audio-visual resources and more relating to the topics covered in this report at our online Geology for Society portal at **www.geolsoc.org.uk/geology-for-society** - or refer to the list below to find resources relating to a particular topic.

Geology for the economy	**www.geolsoc.org.uk/economy**
Energy	**www.geolsoc.org.uk/energy**
• Shale Gas	**www.geolsoc.org.uk/shalegas**
• Carbon Capture and Storage	**www.geolsoc.org.uk/ccs**
• Radioactive Waste	www.**geolsoc.org.uk/radioactivewaste**
Water	**www.geolsoc.org.uk/water**
• Groundwater	**www.geolsoc.org.uk/groundwater**
Mineral Resources	**www.geolsoc.org.uk/minerals**
• Rare Earth Elements	**www.geolsoc.org.uk/ree**
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