Earth Science

Big idea (age 11-14)
EDE: Dynamic Earth

What's the big idea?

The rocks and landscape around us appear unchanging and permanent, but careful observation can detect the effects of weathering and erosion on exposed rocks, and the laying down of sediments that in the right conditions can be changed into new rock. Longer term processes transform rocks deep underground and bring fresh rock to the surface. Understanding the dynamic Earth helps us to identify and utilise resources it contains and to find ways to build a sustainable and environmentally stable future.

Key concepts

The big idea is developed through a series of **key concepts** at age 11-14, which have been organised into teaching topics as follows:

Topic EDE1 **Earth's resources**	Topic EDE2 **Physical weathering and erosion**	Topic EDE3 **Rock changes**
Key concepts: 1.1 What's in a rock? 1.2 Inside the Earth 1.3 Making rock by heating	Key concepts: 2.1 Physical weathering and erosion	Key concepts: 3.1 Making rock by pressure and cementing 3.2 Making fossil fuels

The numbering gives some guidance about teaching order based on research evidence on learning pathways and effective sequencing of ideas. However, the teaching order can be tailored for different classes as appropriate.

Guidance notes

A large and useful collection of activities for teaching about Earth science, supported by the Geologists' Association, can be found on the website: https://www.earthlearningidea.com/

Learning progression

The science story associated with the big idea develops from age 5 to age 16, and could be summarised as follows:

Science story at age 5-11

Everyday materials

Objects are made from a variety of different materials, including wood, plastic, glass, metal, water and rock.

Materials can be described as hard or soft, stretchy or stiff, shiny or dull, rough or smooth, bendy or not bendy, waterproof or not waterproof, absorbent or not absorbent, opaque or transparent. Materials can be grouped according to their properties. The physical properties of a material make it suitable for particular purposes and unsuitable for others.

Rocks

There are many types of rock. Rocks have different colours, some are smooth and others are rough. Some rocks are more difficult to scratch than other rocks. Different rocks of the same size can be lighter or heavier than each other.

Rocks may contain grains that are stuck together, or crystals. Some rocks contain observable fragments of shells or fossils within their structure. When some rocks are rubbed together tiny fragments break off. Soil is a mixture of rock fragments and organic matter, which is the remains of living things.

Fossils

There are different types of fossil. Some fossils are plants, or the bones of animals, that have been turned into stone and are made from minerals once dissolved in water. This process can take millions of years. Some other fossils show the imprints of shells or even footprints that were buried and filled by a sediment that later turned into rock.

The fossils we find today were formed over very long periods of time and show evidence of living things that lived a long time ago, but the process of making new fossils continues even today.

Science story at age 11-14

Resources from the Earth

Important raw materials that can be used as a source of new materials and chemical substances include:

- Rocks – which are used as aggregate and building stone and to make cement, pottery and glass as well as many chemicals including acids and alkalis.
- Minerals – from which metals can be extracted.
- Fossil fuels (coal, crude oil and natural gas) – which are the main source of fuels, plastic and other chemicals.

Types of rock

Rocks are made of one or more types of mineral or of fragments of rocks and fossils, and may also include organic remains. Minerals can consist of elements or of compounds. Like other substances, a mineral has a definite chemical composition, crystalline structure and physical properties. An example of a mineral is calcite which consists of the substance called calcium carbonate. One type of rock formed almost entirely of calcite fragments is limestone. Another rock made predominantly of calcite is marble which consists of interlocking calcite crystals formed during metamorphosis.

Sedimentary rocks are made from small particles cemented together. Igneous and metamorphic rocks are made of interlocking crystals. The crystals in igneous rocks, which formed from cooling magma, have random orientation, whilst the crystals in most metamorphic rocks are aligned by the pressure that formed them. Clues like these can be used to tell the different types of rock apart.

The structure and composition of the Earth

Chemically, the Earth can be divided into three main layers: core, mantle and the crust.

The inner part of the core is solid while the outer core is liquid. The core is thought to be made up mainly of an alloy made of iron atoms and nickel atoms.

The mantle is solid rock but its outer part is hot enough to flow very, very slowly (averaging around 2 cm per year) as it is near to its melting temperature.

The crust is the outermost layer of the Earth and is made from solid rocks that are chemically different to the rocks in the mantle. The oceanic crust is around 7 km thick. The continental crust averages 35 km thick and because it is less dense than the oceanic crust it is more buoyant and forms continents at a higher level than the ocean crust.

Tectonic plates are very large plates of strong, rigid rock about 125 km thick that form the surface of the Earth. They form a layer called the lithosphere that consists of both the crust and the upper mantle. The upper mantle makes up the most of the thickness of each tectonic plate.

Directly below a tectonic plate is solid rock that is hot enough to flow. A good analogy is ice that is solid, but can flow downhill in glaciers. This rock allows the tectonic plate above it to move very, very slowly over the rest of the mantle. Heating from the Earth's core can move tectonic plates a few centimetres each year.

When tectonic plates are pushed together some rocks are carried down into the mantle while other rocks are deformed into mountain chains by folding. The compression causes faulting and metamorphism whilst the rock carried into the mantle partially melts, and the magma rises forming intrusive rocks and volcanic eruptions.

Formation of igneous rocks

Igneous rocks form when liquid magmas cool and crystallise. Magmas form underground by the partial melting of pre-existing rocks. These magmas may rise to the surface and erupt in volcanoes as extrusive igneous rocks. The magma flows from volcanoes as lava which cools quickly giving rise to rocks with very small crystals. Basalt is an example of dark-coloured solidified lava, composed of fine-grained crystals rich in iron and magnesium atoms.

Magma gives rise to intrusive igneous rocks if it does not reach the surface of the Earth but cools more slowly underground. This produces rocks with larger crystals such as pale coloured silica-rich granite, a common intrusive igneous rock. The chemical composition of a particular magma determines the type of rock that it forms. The quicker the magma cools, the smaller the crystals in that rock.

As igneous and metamorphic rocks are made of interlocking crystals, they usually have no pore spaces and are impermeable and tough. In contrast, sedimentary rocks are usually permeable and weaker.

Weathering and erosion

Various surface processes slowly break down and remove rocks. These processes are called weathering and erosion. Weathering is the chemical breakdown and physical break up of rocks by biological, chemical and physical processes. Erosion is the removal of solid material, often weakened by weathering.

A range of physical processes contributes to weathering by breaking up rocks; these include temperature changes, water freezing and thawing and the growth of mineral salts by evaporation.

Rock weakened by weathering can be eroded by gravity, moving water, wind or moving ice, which carry away the pieces of rock to be deposited somewhere else.

Formation of sedimentary rock

Weathering and erosion of exposed rocks lead to the formation of sediments. Over long periods of time these sediments can build up into thick layers. The pressure on the buried sediments compacts the rock, changing mud to mudstone, for example. Crystals may form from water flowing through the tiny pore spaces between the grains of the rock, helping to cement them together. These processes give rise to sedimentary rocks such as sandstone. Other sedimentary rocks, such as limestone and chalk (a very fine-grained limestone), form when shells and other remains of living organisms build up on the sea bed becoming compacted and cemented.

Sedimentary rocks contain clues showing how they formed. For example the shape of sand grains and the layering of sandstone can show if the sand was laid down in wind-formed dunes in a desert or was washed down streams into a lake or sea. Fossils in sedimentary rocks give clues about the ages of the rocks and the environments in which they were laid down.

Heat and pressure can convert sedimentary and igneous rocks into metamorphic rocks without melting them. Metamorphic rocks are crystalline. The size and arrangement of the crystals in this type of rock depends on how it was formed. Slate, for example, was formed by the action of very high pressures on mudstone. Marble consists of larger crystals of calcium carbonate. It is a metamorphic rock formed by the effect of heat and pressure on limestone.

Rock changes

The ‘rock cycle’ *does not* describe a sequence of changes that happens to a particular rock over its lifetime. Instead, it is a model that geologists use to link together all the processes that cause rocks to be changed from one form to another.

Rocks in higher areas are weathered and eroded and the sediments are deposited in lower areas. The energy driving this process comes from the Sun through the water cycle. As sediments are buried, they can become sedimentary rocks. When these are involved in the mountain building caused by plate movements, they can be changed into metamorphic rocks by high temperature and pressure. More intense heating can cause rocks to partially melt to form magma which can form intrusive or extrusive igneous rock as it cools. The Earth’s internal energy sustains the movement of tectonic plates, causing mountain-building and igneous and metamorphic rocks to form.

The timescales of rock cycle processes vary from seconds (e.g. rock fall) to millions of years (e.g. mountain-building).

Formation of fossil fuels

Coal is a sedimentary rock formed from thick plant deposits that have been buried and compressed, releasing natural gas in the process. When muds are laid down in the sea, they often contain the remains of plankton. As they are buried and compressed they become heated and release crude oil which can become trapped, like natural gas, in rocks beneath the sea bed, as oil and gas reservoirs.

Science story at age 14-16

Extraction of metals

Metal substances are shiny when freshly cut and polished. They conduct electricity well. They are generally strong and bend and stretch without breaking. Most metals melt at high temperatures. They are also good conductors of thermal energy (heat).

Unreactive metals such as gold are found in the Earth as the metal itself, but most metals are found as metal compounds that require chemical reactions to extract the metal. The minerals that make up most rocks contain metal compounds, but these are not usually ores. A metal ore is a rock or mineral deposit that contains enough metal for potential commercial use. Some of these ores are abundant, but quantities of others are limited.

Many important metals can be found combined with oxygen in minerals. Examples are iron oxide and aluminium oxide. Other metals are combined with sulfur in compounds such as copper sulfide, zinc sulfide and lead sulfide. These metal sulfides can be converted to metal oxides by heating in air.

Metal substances (metals for short) are extracted from their oxides on a large scale by removing the oxygen atoms to leave the metal atoms. The oxygen atoms can be removed from some metal oxides, such as the oxides of zinc, iron, copper and lead, by heating them with the substance carbon, in the form of coke (made from coal) or charcoal. This process is called reduction. Heating iron oxide with carbon, for example, produces iron metal and carbon dioxide gas.

More reactive metals, such as sodium, magnesium and aluminium, combine so strongly with oxygen that the oxygen atoms cannot be removed using carbon. Another method has to be used to extract these metals.

A reactivity series puts the metals in order of their reactivity with oxygen. This shows how strongly the atoms of the metals hold onto oxygen atoms and so how easy or difficult it is to remove the oxygen atoms from their oxides.

Recycling

Recycling makes new materials from materials that have already been used. Crude oil, natural gas, metal ores and other resources are valuable; but they lose value if they end up as waste. Recycling is becoming increasingly important to avoid waste and to make sustainable use of the Earth's resources. Materials that are recycled on a large scale include metals, glass, cardboard and some plastics.

Carbon cycle

Carbon atoms are found in a range of substances in the natural environment. In the crust of the Earth carbon atoms are in calcium carbonate found as limestone, chalk and marble. Coal is a sedimentary rock composed mainly of carbon atoms. Combined with hydrogen atoms, carbon atoms are also found as hydrocarbons in crude oil and natural gas.

Living things depend on many different carbon compounds. Sugars, starch, fats, proteins, and DNA all exist because the molecules are based on chains and rings of carbon atoms.

The atmosphere is a mixture of substances in the gas state. The composition of the atmosphere is 78% nitrogen, 21% oxygen, 1% argon with 0.04% carbon dioxide and variable amounts of water vapour.

The carbon atoms in the environment do not stay in one place. The carbon cycle describes the stores of carbon atoms on Earth (substances containing carbon atoms) and the processes that move carbon atoms from one store to another.

A carbon atom that is part of a carbon dioxide molecule in the air, for example, can be taken in by a plant leaf and turned into sugars by photosynthesis. If an animal eats the plant the carbon atom may then return to the atmosphere as the animal breathes out the waste carbon dioxide from respiration. This is a relatively quick part of the carbon cycle. Much, much slower are the processes in the carbon cycle that lead to the formation of fossil fuels and calcium carbonate rocks. This long-term carbon cycle involves the release of carbon dioxide into the atmosphere from volcanoes which is then washed out by rain. When acidic rain reacts with silicate and carbonate minerals during rock weathering, soluble carbonates are produced that are then washed into a carbonate store (ocean sediments) by surface processes. Sediments formed in this way become subducted at convergent plate boundaries leading to CO_2 being released into the atmosphere once more, via volcanic activity.

Human activity has made a difference to the carbon cycle. Burning fossil fuels produces carbon dioxide gas and transfers carbon atoms into the atmosphere that were previously trapped underground. This has increased the concentration of carbon dioxide in the air over 200 years from 0.028% before the industrial revolution to 0.041% today.

The percentage of carbon dioxide in the air seems very small but it is very significant. Thousands of millions of tonnes of carbon atoms, as carbon dioxide, are released into the atmosphere each year by human activities. This matters because carbon dioxide is one of the substances in the atmosphere that keeps the Earth warm. It is a greenhouse gas which absorbs infrared radiation that would otherwise escape into space from the Earth. As the concentration of carbon dioxide in the atmosphere rises, the Earth gets warmer. This can change the average weather patterns in different parts of the world over many years – which is climate change.