Earth’s structure

Introduction

This topic explores the key concepts of Earth’s structure as they relate to:

- the structure of Earth
- movement of Earth’s crust
- earthquakes
- tsunamis
- volcanoes
- rocks.

Key concepts of Earth’s structure

The activities in this topic are designed to explore the following key concepts:

- Earth is made up of layers: the core, mantle and crust.
- Earth’s crust is divided into plates that move like bricks over freshly laid mortar.
- Earth’s plate movements are responsible for earthquakes, tsunamis and volcanoes.
- Earth’s plate movements are responsible for the creation of mountain ranges.
- Soils on Earth are the result of weathering of rocks.
- There are three main categories of rock: igneous, metamorphic and sedimentary.
- Igneous rocks are formed through the cooling of magma.
- Sedimentary rocks are formed through compaction of sediment over an extended period of time.
- Metamorphic rocks result through the transformation of other rocks by heat and pressure processes that occur below Earth’s surface.
- Minerals are the building blocks of rocks.

Students' alternative conceptions of Earth's structure

Research into students' ideas about this topic has identified the following non-scientific conceptions:

- The location of earthquakes is random.
- Continents don't move.
- Earth is molten, except for its crust.
- Most of the world's most spectacular scenery was created by cataclysmic events.
- An earthquake measuring 6.5 on the Richter scale is one time more powerful than an earthquake measuring 5.5.
- Rocks stay the same forever.
- Earthquakes cannot happen where I live.
- The biggest danger of a volcano such as Mount St Helens is the hot lava.
- Any crystal that scratches glass is a diamond.
- Rocks must be heavy.
- Soil must have always been in its present form.
- Mountains are created rapidly.
- Earth's gravitational attraction is drastically reduced on mountaintops.
- Boiling or burning radioactive material can reduce the radiation emanating from the material.
- All radioactivity is man-made.

Resources

Current volcanic activity—useful links: USGS

http://vulcan.wr.usgs.gov/News/current_activity_links.html
This US Geological Survey (USGS) site details current volcanic activity.

Earthquake Hazards Program—Northern California

http://quake.wr.usgs.gov/
US Geological Survey (USGS) information; latest quake information; maps and lists of recent earthquakes; what's new or interesting; hazards and preparedness.

Earthquakes

http://www.thetech.org/exhibits_events/online/quakes/
Everything you wanted to know about earthquakes, and more. This is the best site for clear explanations, with good graphics and animations.

The Mineral and Gemstone Kingdom

http://www.minerals.net/
Contains information on all types of gemstones and includes interesting facts about all minerals from A to Z.

Minerals Council of Australia

http://www.minerals.org.au/

Minerals Downunder

http://www.agso.gov.au/education/factsheet/
Fact sheets on gold, copper, silver and exploration techniques

Minerals Education Victoria

http://www.vicmins.com.au
A good resource for teachers and students.

Mountain Maker, Earth Shaker

http://www.pbs.org/wgbh/aso/tryit/tectonics/
Comprehensive site with facts, history and graphics relating to plate tectonics and continental drift. Includes an activity that allows you to manipulate tectonic plates.

National Earthquake Information Center

http://wwwneic.cr.usgs.gov/
Provides frequently asked questions and links to general earthquake information.

Plate tectonics: the cause of earthquakes

http://www.seismo.unr.edu/ftp/pub/louie/class/100/plate-tectonics.html
Concise, informative site that contains satellite pictures.

Project Atmosphere Australia Online

http://www.schools.ash.org.au/paa/
Contains trivia and facts related to volcanoes—takes you to various links.

Puzzles of the Earth

http://library.thinkquest.org/17701/high/structure/
Provides information about Earth's structure, plate tectonics, volcanoes, earthquakes and tsunamis.

Rock and Mineral Dictionary

http://www.enchantedlearning.com/geology/rocks/glossary/

Rocks and Minerals: Franklin Institute

http://www.fi.edu/tfi/units/rocks/
A comprehensive site from the Franklin Institute (USA).

Rocks and Minerals: Kentucky Geological Survey

http://www.uky.edu/KGS/coal/webrokmn/rocksmin.htm
Rocks and minerals.

This dynamic earth: the story of plate tectonics

http://pubs.usgs.gov/publications/text/dynamic.html
Comprehensive site that explains the history of plate tectonics theory and evidence for it.

USGS Volcano Hazards Program

http://volcanoes.usgs.gov/
Lists active and potentially active volcanoes; hazards of volcanoes.

Volcanoes online

http://library.thinkquest.org/17457/english.html
Covers plate tectonics and volcanoes, and has games, lesson plans, comics and links to related sites.

Volcanoes page: Michigan Technological University

http://www.geo.mtu.edu/volcanoes/
Public information about volcanoes. Provides current global volcanic activity among other things

Volcano types: USGS

http://vulcan.wr.usgs.gov/Glossary/VolcanoTypes/framework.html
Description and examples of types of volcanoes and how they are formed.

Volcano World

http://www.volcanoworld.org/
Describes itself as the Web’s premier source of volcano information. Sponsored by NASA, Volcano World has all you wanted to know about volcanoes, and more.

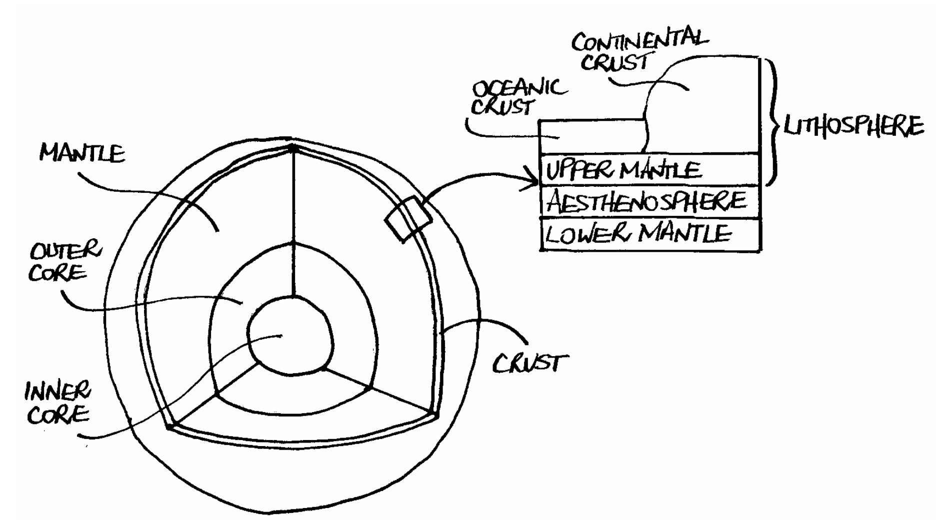
The structure of Earth

Earth’s inside structure is quite different to its hard, crusty shell. We sometimes get a glimpse of Earth’s interior through the action of active volcanoes. Earth’s rocky crust is by no means stationary and we regularly see evidence of crust movement in the form of earthquakes. Earthquakes in ocean regions produce destructive ocean waves called ‘tsunamis’.

The universal acceptance of plate tectonic theory is recognised as a major milestone in the earth sciences. It is comparable to the revolution caused by Darwin’s theory of evolution or Einstein’s theories about motion and gravity. Plate tectonics provide a framework for interpreting the composition, structure and internal processes of Earth on a global scale.

Earth is made of three concentric layers: the core, mantle and crust. Each layer has its own chemical composition and properties (see Figure 1).

FIGURE 1: INTERIOR STRUCTURE OF EARTH

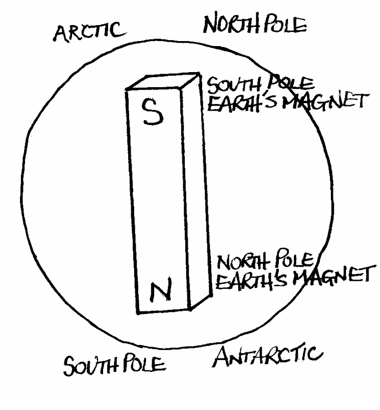


Core

The core has two layers: an inner core that is solid and an outer core that is liquid. The core is mostly iron, with some nickel and takes up 16% of Earth's total volume. The metallic core accounts for Earth's magnetic field. Earth behaves as though it has a simple straight bar magnet at its centre, with the 'south' pole just below Canada and the 'north' pole opposite, not quite coincident with the geographical poles (see Figure 2). A compass needle's 'north' pole points northwards; because 'unlike' poles attract, Earth's magnetic pole in the Arctic must be the opposite type, 'south'. It is thought that streams of liquid metal within the outer core, combined with Earth's rotation, cause the magnetism. The strength of the magnetism may change from decade to decade and, over the period of 500 000 years, the magnetism reverses completely. This means that over the next 500 000 years, compasses will point south!

Evidence of Earth's change in magnetic polarity (direction of north–south line of magnetism) is found in the rocks. Scientists have found that rocks within Earth's crust formed at different times. Within some rocks there are small particles of magnetite that are magnetic and, when the rocks were formed, these magnetite particles aligned themselves with Earth's magnetic field. As the rocks cooled, the direction of the particles' magnetic polarity was fixed. Therefore, by knowing the age of a rock and the magnetic polarity of the magnetite particles within it, we can determine the magnetic polarity and Earth's strength in times past.

FIGURE 2: EARTH AS A MAGNET



Mantle

The mantle is the thickest of Earth's layers and takes up 83% of Earth's volume. It extends down to about 2900 km from the crust to Earth's core and is largely composed of a dark, dense, igneous rock called 'peridotite', containing iron and magnesium. The mantle has three distinct layers: a lower, solid layer; the asthenosphere, which behaves plastically and flows slowly; and a solid upper layer. Partial melting within the asthenosphere generates magma (molten material), some of which rises to the surface because it is less dense than the surrounding material. The upper mantle and the crust make up the lithosphere, which is broken up into pieces called 'plates', which move over the asthenosphere. The interaction of these plates is responsible for earthquakes, volcanic eruptions and the formation of mountain ranges and ocean basins. The section on plate tectonic theory later in this topic explains the occurrence of these events further.

Crust

The Earth's crust is the outermost layer, consisting mainly of the chemical elements silicon and aluminium. The crust has two types: a continental crust that varies in thickness between 20 km and 90 km, and an oceanic crust that varies in thickness between 5 km and 10 km. The oceanic crust is denser than the continental crust.

The following activity provides a picture of the relative size of Earth's interior and atmospheric components.

ACTIVITY: FROM THE CENTRE OF EARTH TO OUTER SPACE

This activity creates a linear model to help you get some idea of the size of Earth, the thickness of its interior layers and the various layers of its atmosphere.

You will need:

- **a roll of toilet paper**
- **some Post-it notes.**

In this activity, 1 cm on the toilet paper represents a distance of 10 km. A sheet of toilet paper is about 11 cm long, so this represents a distance of 110 km.

Lay the toilet paper out on the floor. At one end of the paper place a label for the centre of Earth. Place labels along the paper according to the table below.

Layer of Earth	Distance (km)	Distance (sheets of toilet paper)
centre of Earth	0	0
edge of inner core	635	6
edge of outer core	2200	20.5
edge of mantle	2900	25
surface of Earth	2940	25 + 4 cm
edge of troposphere	2955	25 + 5.5 cm
edge of stratosphere	2990	25 + 9 cm
edge of ionosphere	3640	33
edge of exosphere	4290	39
outer space	> 4290	place next to last note

The space shuttle and the international space station orbit Earth at a height of about 700 km above Earth's surface. Are these spacecraft in outer space? I find it surprising that the thickness of Earth's crust and atmosphere are quite small in comparison to the size of Earth.

The temperature of the material in Earth's interior increases with depth, as the table below illustrates. Heat is transferred to Earth's surface by convection (liquid layers) and conduction (solid layers). Convection is where the hot material, in this case the liquid magma, moves from a lower layer to a higher one. Conduction is heat transfer where the actual hot material, in this case the rock, does not move. For example, conduction occurs along a metal bar if one end is held in a flame.

Section	Depth (km)	Temperature (°C)
upper mantle (top)	50	800
upper mantle (bottom)	1000	3300
lower mantle	2000	2225
mantle core boundary	2900	2500
centre	6371	3000

Movement of Earth's crust

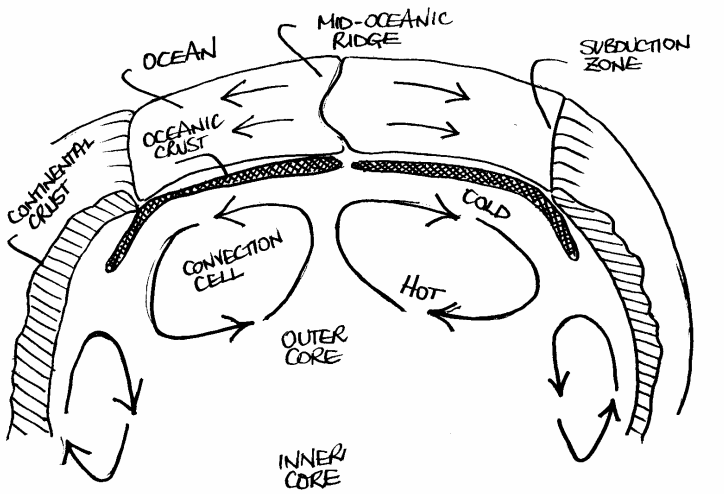
Plate tectonic theory

Plate tectonic theory is a theory developed in the 1910s by a German meteorologist, Alfred Wegener, who amassed a tremendous amount of geological, paleontological and climatological data that indicated continents moved through time. He proposed the hypothesis of 'continental drift' to explain his data. However, Wegener's theory was not accepted at the time because it could not account for a mechanism by which the huge continental masses move; evidence of a possible mechanism was not found until the 1950s and 1960s. Plate tectonic theory is now universally accepted. The significance of this theory is enormous when you consider that it can account for many seemingly unrelated geological features and events.

According to plate tectonic theory, the lithosphere is divided into about a dozen rigid sections, called 'plates', which move over the asthenosphere, the part of the mantle that behaves plastically and flows slowly (imagine bricks moving over freshly laid mortar). Refer to one of the websites listed in the section 'Resources' in this topic to view how Earth's surface divides into plates and why they are referred to as 'continental plates'.

The mechanism responsible for the movement of Earth's plates is thought to be convection cells within Earth's mantle. Convection cells are convection currents that occur when warm material from deep within Earth rises towards the surface, cools, and then, upon losing heat, descends back into the interior. Hot material rises because it is less dense (amount of material per volume) than the colder material. The cycle then begins again with hot material rising. This results in loops of moving material that form convection cells. The direction of the top of the convection current determines in which direction the overriding plate moves (see Figure 3).

FIGURE 3: CONVECTION CELLS BENEATH EARTH'S PLATES



Zones of volcanic activity, earthquake activity, mountain ranges and oceanic ridges mark plate boundaries. Along these boundaries, plates diverge, converge, or slide sideways past each other. Based on adjoining convection cells (see Figure 4) we can see how plates can sometimes converge and other times diverge (see Figure 4).

Divergent plate boundaries

Plates move apart as magma rises to the surface from the asthenosphere. These boundaries occur in the oceans at oceanic ridges. As the plates separate, the gap is continually being filled by magma (molten rock), which solidifies to form rock and then attaches to the moving plates. The phenomenon of sea-floor spreading occurs at different rates. For example, in the Atlantic the spreading is at a rate of 2 cm per year, whereas in the east Pacific the rate is 4 cm of new crust every year.

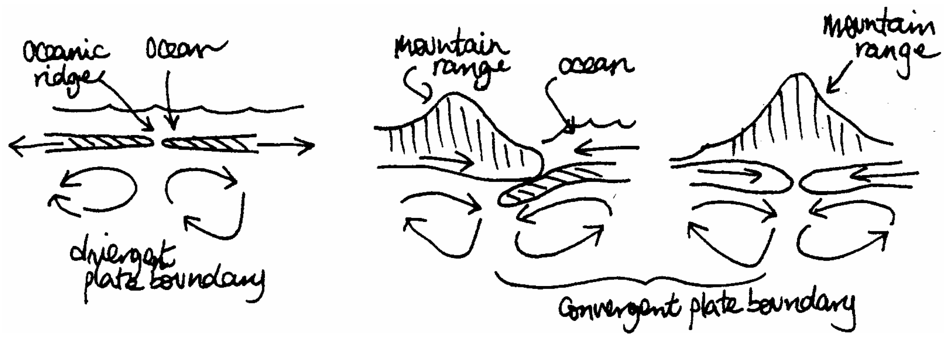
Convergent plate boundaries

One plate sinks beneath another plate (called 'subduction') along a subduction zone. The leading edges of the colliding plates may both be oceanic, or one plate may be oceanic (and will be the sinking plate) and the other continental, or both plates may be continental. Where oceanic plates collide, deep trenches in the ocean occur. As the plate descends it melts to generate magma. As this magma rises, it may erupt at Earth's surface, forming a chain of volcanoes. Where continental plates collide, mountain ranges such as the Himalayas arise. Mountain chains are also formed where one of the plates is continental and the other is oceanic.

Transform plate boundaries

Plates slide sideways past each other. The San Andreas Fault in California is a transform plate boundary separating the Pacific plate and North American plate. Sliding plates build up pressure in certain places, causing the sudden movement of plates to release the pressure. The sudden movements of plates are earthquakes.

FIGURE 4: PLATE BOUNDARIES



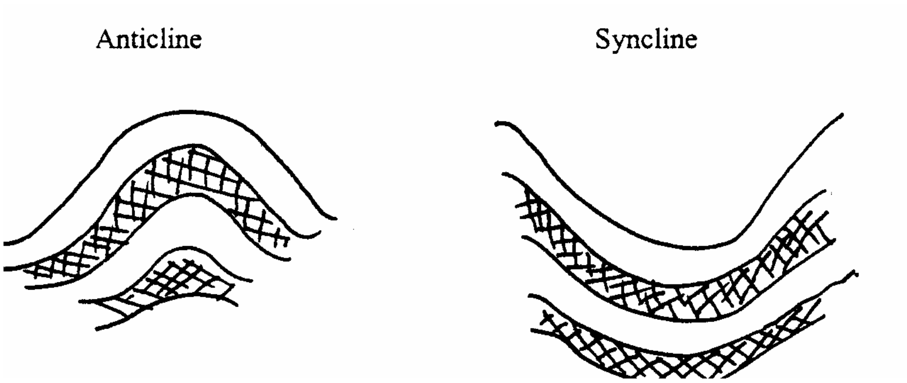
There is a substantial amount of evidence in support of plate tectonic theory. This includes the following facts:

- Shorelines of different continents fit together.
- The same type of rocks and fossils are at different places on Earth.
- The age of rocks can be determined; rocks in the ocean ridges are young and get older with distance from the ridges.
- The rock bed of the oceans has magnetic material imprinted with the magnetic polarity of Earth in ancient times.
- Precise measurements of continental positions by satellites have verified continental drift.

Folds and faults

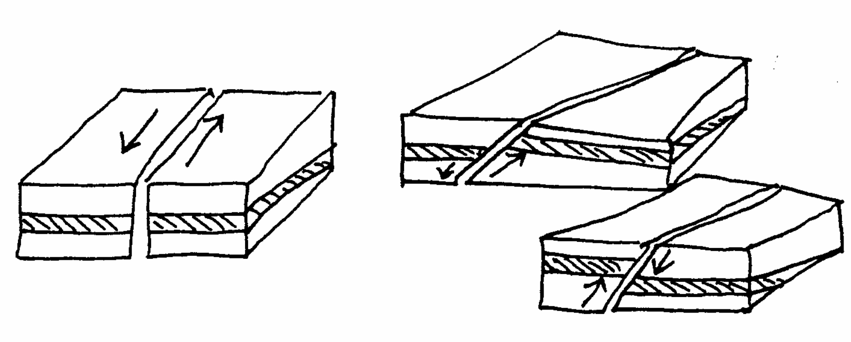
The movement of Earth's crust creates pressures in certain regions of rocks. Where pressure is slowly applied to rocks, they bend. If the temperature and pressure are high, as at great depths, the rocks bend fairly easily. The bending in the rocks creates folds. There are two main types of folds: upward folds and downward folds. The upward folds are called 'anticlines' and the downward folds are called 'synclines' (see Figure 5).

FIGURE 5: TYPES OF FOLDS



Under different conditions, instead of bending, rock can break and change position. Continued pressure causes movement along some cracks. Such cracks, along which the rocks move, are called 'faults'. Faults can vary in the way blocks of earth move relative to each other. Blocks can move over or under each other, or move sideways to each other (see Figure 6).

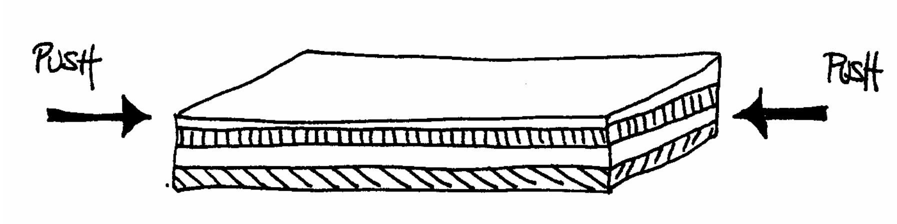
FIGURE 6: TYPES OF FAULTS



ACTIVITY: MAKING A FOLD MOUNTAIN

Mountains are formed when plates slowly push together and cause layers of rock to fold upwards. You will need three or four flat rectangles of modelling clay (alternatively, you could use layers of dishcloths). Press the rectangles of clay on top of each other. Now push the ends inwards and observe what happens (see the figure below). What mountain ranges of the world do you think formed when tectonic plates bumped into each other?

FIGURE: MOUNTAIN MODEL



Earthquakes

The earthquake in India in 2001 demonstrated the immense destructive power earthquakes can have. More than 900 000 earthquakes are recorded around the world each year. While scientists have found out a lot about earthquakes, they have not as yet been able to predict the precise location, time or intensity of an earthquake. Most earthquakes (almost 95%) take place in belts where stresses between plate boundaries occur.

An earthquake is the vibration of Earth caused by the sudden release of energy, usually located at a fault that involves the movement of blocks of rock along fractures. Following an earthquake there are usually adjustments along a fault line, which generate a series of smaller earthquakes called 'aftershocks'. Aftershocks usually continue for a few days after the initial earthquake but may persist for months.

ACTIVITY: WHERE ON EARTH DO EARTHQUAKES OCCUR?

You will need a photocopied map of the world. Based on an Internet search (try some of the sites listed in the section 'Resources' in this topic), mark the location of earthquakes from last year on your map in blue. Mark in the location of current earthquake activity using the colour red. What similarities and differences do you find? Do you find any relationship between the occurrence of earthquakes and the location where continental plates meet (refer to the section on plate tectonic theory earlier in this topic). Outline maps suitable for hand plotting earthquake locations can be obtained at <http://wwwneic.cr.usgs.gov/neis/education/maps.html>.

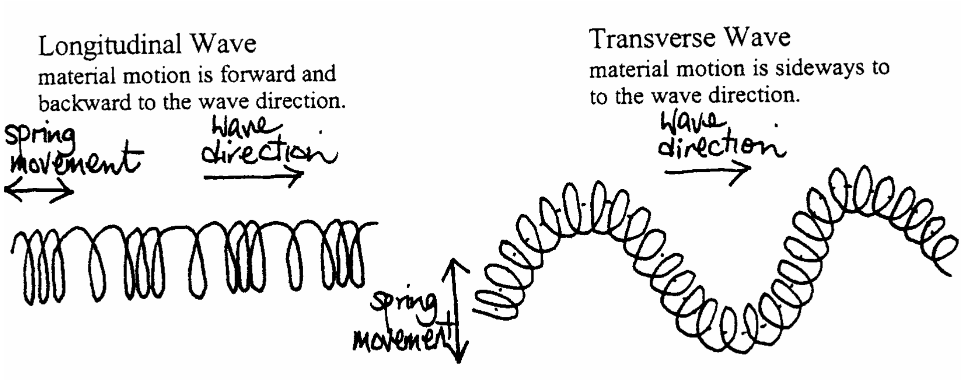
Seismic waves

Earthquakes send out vibrations, called 'seismic waves', within Earth in all directions. Some vibrations can be detected many kilometres away, even on the other side of Earth. There are three main types of travelling disturbances, or waves, that travel out from the site, or epicentre, of an earthquake: surface waves, P (primary) waves and S (secondary) waves. A wave is a disturbance, or vibration, that travels through a material (solid, liquid or gas) without the actual material moving along with the travelling disturbance. Waves in a material can be generated in two basic ways: as a longitudinal wave and a transverse wave. In a longitudinal wave the material in which the wave travels moves forwards and backwards to the direction of the wave. In a transverse wave the material moves perpendicularly to the wave direction (see the activity *Investigating waves on a slinky*).

ACTIVITY: INVESTIGATING WAVES ON A SLINKY

You will need a long helical spring, sometimes called a 'slinky'. On a linoleum or wooden floor, stretch the slinky between two people. One person holds the slinky steady and the other person makes a vibration. The vibration can be either a sideways motion or a forwards-and-backwards motion. Observe the different types of waves that travel along the spring. Where a sideways movement occurs in the spring the wave is a transverse wave. Where the movement of the spring is forwards and backwards, the wave produced is a longitudinal wave (see the figure *Types of waves*). Sound is a phenomenon that produces longitudinal waves, whereas waves on the surface of water are transverse waves.

FIGURE:
TYPES OF WAVES



P waves

These waves are longitudinal waves and are similar to sound waves. P waves can move through solids, liquids and gases. P waves are primary waves and are the fastest of the seismic wave types.

S waves

These waves are transverse waves. S waves are slower than P waves and can only move through solids. S waves are secondary waves, as they are slower than primary waves.

Surface waves

As their name suggests, these waves travel on the surface of a material rather than through it. They are transverse waves. There are several types of surface waves; the most common are called 'R (Raleigh) waves' and 'L (Love) waves'. R waves travel like surface water waves, where the material moves up and down (vertically) as the wave passes, whereas in L waves material moves sideways (horizontally) to the wave motion. Surface waves are slower than both P waves and S waves.

The speed of seismic waves varies according to the pressure and elasticity (or springiness) of the material they move through. For example, seismic waves travel slower through rocks of greater density, but faster through rocks of greater elasticity.

ACTIVITY:
MAKING
SHOCK WAVES

This activity demonstrates how shock waves travel through solid materials.

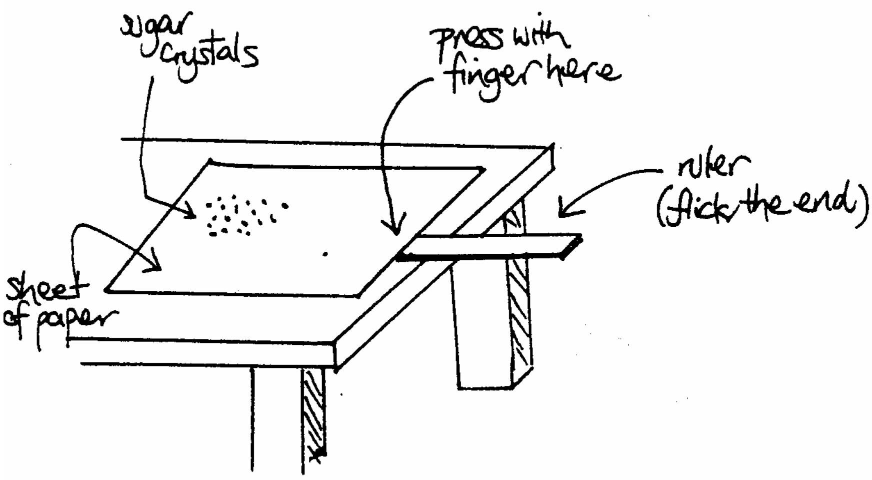
You will need:

- **a large sheet of paper**
- **sugar**
- **a ruler.**

Place the paper on a table near the edge. Put a little sugar near the centre of the paper and slip the end of the ruler under the paper (see the figure *Making shock waves*). Hold the ruler gently to the table and flick the end. Observe what happens to the sugar when you flick the ruler.

To demonstrate that even small vibrations can travel long distances in solids, find a long length of wood or metal such as the top railing of the school fence. Have one person tap the fence with a stick. Have another person move some distance along the fence and place his/her ear on the railing. How far along the fence can the vibration be heard?

FIGURE: MAKING SHOCK WAVES



Measuring and detecting earthquakes

There are two popular earthquake scales: the Richter Magnitude Scale and the Modified Mercalli Intensity Scale.

The Richter Magnitude Scale measures the total amount of energy released by an earthquake at its source, or epicentre. The Richter Magnitude Scale is an open-ended scale that begins with 1. The largest magnitude recorded is 8.6 (the earthquake in India in 2001 registered 7.9).

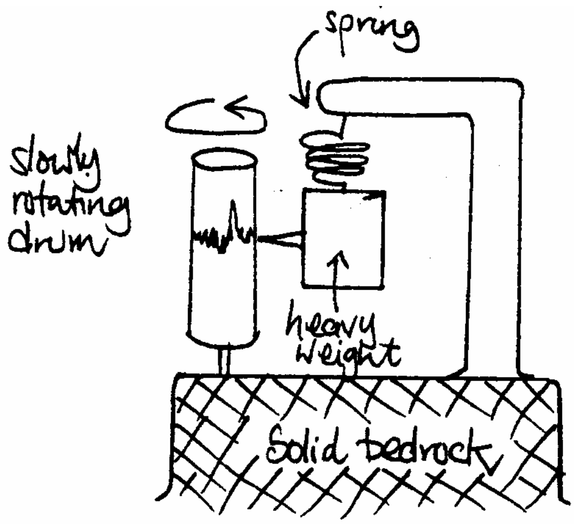
The Modified Mercalli Intensity Scale measures the kinds of damage done by an earthquake. Table 1 gives some of the Modified Mercalli Intensity Scale.

TABLE 1: PART OF THE MODIFIED MERCALLI INTENSITY SCALE

Scale	Damage
I	Not felt except by a few people under especially favourable conditions
III	Noticeable indoors, especially in upper rooms. Standing cars rock noticeably.
V	Felt by nearly everyone. Some dishes, windows broken, maybe cracked plaster. Disturbance of trees, poles and tall objects noticeable.
VII	Everybody runs outdoors. Damage negligible in good design buildings but considerable in poorly built structures; some chimneys broken. Noticed by people driving cars.
IX	Buildings shifted off foundations. Underground pipes broken.
XI	Few masonry structures standing. Bridges destroyed. Underground pipelines completely out of order.
XII	Damage total. Objects thrown into the air.

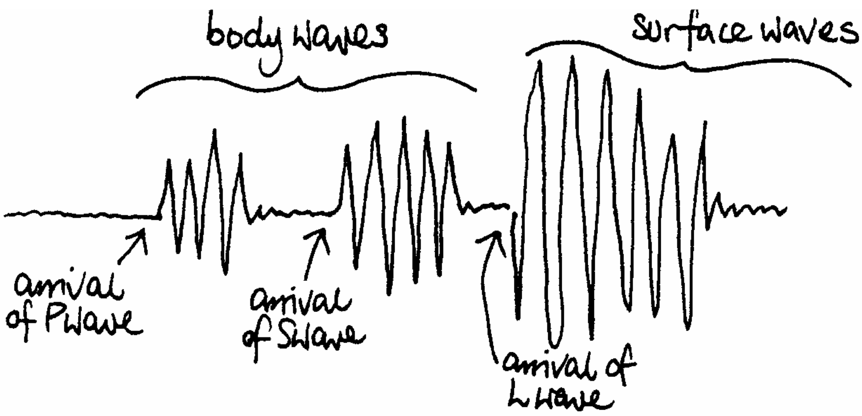
Scientists use an instrument called a 'seismograph' to detect seismic waves generated by earthquakes. A seismograph is built so that part of it is attached to solid rock and part of it is not (see Figure 7). When Earth shakes, the part of the seismograph attached to solid rock shakes too. The other part, a heavy suspended weight, moves very little. A pen records the relative movement between the two parts on a slowly rotating drum. An earthquake is recorded as a wiggly line on what is called a 'seismogram'. What has been described, and shown in Figure 7, is an early model of a seismograph. Modern versions use electronic motion detectors that are connected to solid rock. Electrical signals are sent to a pen that marks a graph on a rotating drum.

FIGURE 7: EARLY-MODEL SEISMOGRAPH



An earthquake produces different types of seismic waves that travel at different speeds. Because of this the seismograph shows different sets of vibrations from the one earthquake (see Figure 8).

FIGURE 8: SEISMOGRAM OF AN EARTHQUAKE



Seismograms can be used to locate the epicentre of earthquakes. This is done by comparing seismograms from at least three separate locations on Earth. From one particular site scientists can determine the time difference between the P and S seismic waves. Based on the speeds of these waves, scientists can determine the distance to the epicentre. Therefore, each site constructs a circle on a map for the probable location of the earthquake. The intersection of the three circles (one from each detection site) is the location of the earthquake.

This method of detecting the location of earthquakes is also used to monitor explosions from nuclear bombs. A country cannot secretly test a nuclear bomb without the rest of the world knowing about it. Information from seismograms can also be used to determine the structure of the centre of Earth. Waves travel at different speeds and reflect off boundaries between the different layers of Earth's interior. By knowing the speeds of seismic waves in different materials, scientists can build up a picture of Earth's interior.

ACTIVITY: MODEL OF A SEISMOGRAPH

A seismograph consists of a slowly rotating drum that is firmly connected to Earth's crust. A pen draws a continuous line on the drum, which has a piece of graph paper attached. When earthquakes occur, the pen vibrates, making wiggly lines on the graph paper. The larger the earthquake, the larger the amplitude of the wiggles.

To model a seismograph you will need:

- **a table, preferably with four separate legs**
- **a partner**
- **a pen or pencil**
- **sticky tape**
- **strips of graph paper.**

Tape a strip of graph paper to the table. Now slowly move your pen down the central line of the graph paper strip while keeping your other hand off the table. Have your partner bump or shake the table from the side, first gently and then harder as you are drawing the line.

The line drawn on the graph paper strip becomes your model seismogram.

Tsunamis

Tsunamis are sometimes called 'tidal waves', but they have no connection with the tides. Tsunamis are caused mainly by earthquakes, but also by underwater landslides and volcanic eruptions. They are seismic ocean waves that travel at hundreds of kilometres per hour over very long distances. These seismic waves have enormous energies. While in deep water the crest of the waves is low at sea (ships may not even notice them in the other waves) but they travel at fast speeds. As these seismic waves reach shallower water, their speed slows and their energy is converted into an increase in the height of the wave. The waves, on reaching shore, may be 38 m or more in height and can therefore be very destructive.

Volcanoes

Volcanoes are cone-shaped mountains around an opening where lava, gases and ash are erupted. They come in many shapes and sizes but most have a crater at their top. Volcanoes occur in well-defined zones or belts. Sixty per cent of all active volcanoes surround the Pacific Ocean and 20% are part of the Mediterranean belt. Most volcanoes occur at spreading oceanic ridges where plates diverge, or along subduction zones where plates converge (refer to the section 'Plate tectonic theory' earlier in this topic).

ACTIVITY: WHERE ON EARTH DO VOLCANOES OCCUR?

You will need a photocopied map of the world. Based on an Internet search of volcano websites, mark the location of as many volcanoes as you can. Make up a symbol to represent a volcano. You may wish to colour the most recently active volcanoes in a different colour. Outline maps suitable for hand plotting volcano locations can be obtained at <http://wwwneic.cr.usgs.gov/neis/education/maps.html>.

ACTIVITY: EXPLORING VOLCANOES ONLINE

Search the Internet to find answers to the following questions.

- **What are the different types of volcanoes?**
- **Volcanoes erupt solids, liquids and gases; what types of solids, liquids and gases are there?**
- **What are the constituents of lava? How hot is it?**
- **Find out about some of the more famous and more destructive volcanic eruptions? Where were they? What damage was caused? Are the volcanoes still active?**

ACTIVITY: AN ERUPTING VOLCANO

You will need:

- **sand or fine dirt**
- **a film canister**
- **1 tbsp baking powder**
- **water**
- **red food colouring**
- **3 tbsp vinegar**
- **dishwashing detergent.**

One-third fill the canister with water. Dissolve the baking powder in the water. Add a few drops of food colouring and detergent to the water. Make a volcano-shaped cone with the sand. Push the canister into the top of the cone. Add the vinegar to the canister. This will react with the baking powder to produce carbon dioxide gas. The detergent will help form foamy 'lava'. Watch the eruption.

Rocks

The dynamic nature of Earth's crust means that as new rock is formed at one location it deteriorates at other locations; this is the rock cycle. There is an enormous variety of rocks, and their constituent minerals, present in Earth's crust, but all rock varieties are classified as one of three basic types: igneous, sedimentary or metamorphic. These basic types of rock relate to the manner in which the rocks were formed. The mining of rocks and minerals from Earth's crust has provided humankind with many benefits, including building materials, fossil fuels (oil, coal and gas), and precious metals and minerals for cosmetic and industrial uses.

The rock cycle

A rock is an aggregate of minerals. Minerals are naturally occurring, inorganic, crystalline solids that have definite physical and chemical properties. There are two exceptions to this definition: naturally occurring glass, called 'obsidian', and sedimentary rock coal. More than 3500 minerals have been identified and described, but only about a dozen make up the bulk of the rocks in Earth's crust.

All rocks in Earth's crust, with the exception of meteorites, were formed from magma (molten rock material) pushed up from the mantle. While the original rock material comes from the mantle, geologists (scientists who study rocks) distinguish three distinct processes of rock formation; every rock is then generally classified according to its mode of formation. The three major groups of rocks are: igneous, sedimentary and metamorphic.

The interrelationships between Earth's internal and exterior processes of rock formation and disintegration are described by the rock cycle (see Figure 9). The rock cycle relates:

- the three rock types to each other
- surface processes such as weathering, transportation and deposition
- internal processes such as magma generation and metamorphism.

FIGURE 9: THE ROCK CYCLE

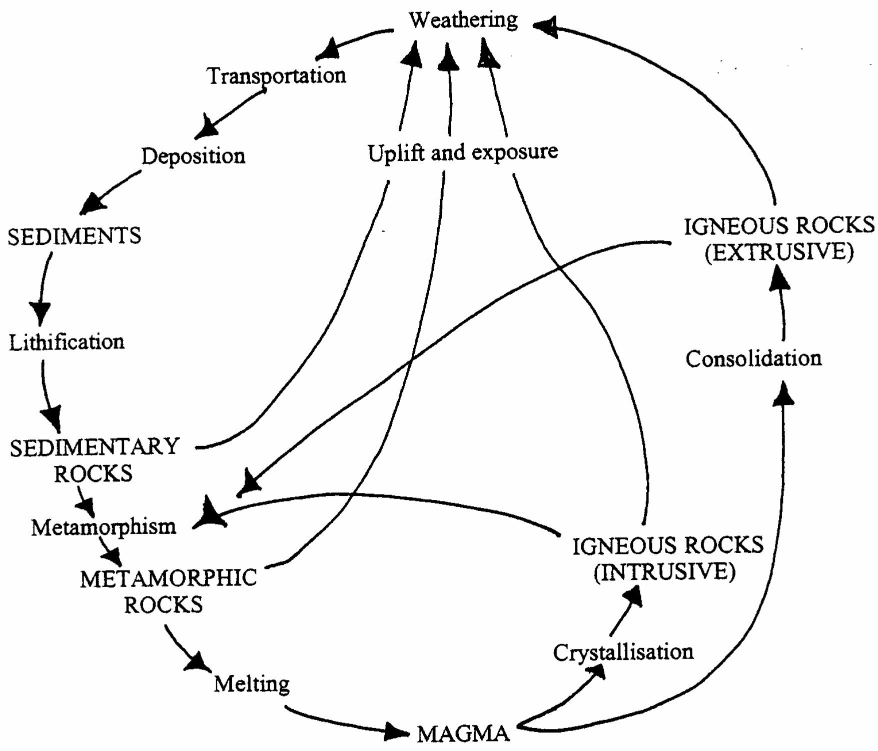


Plate movement (see the section on plate tectonic theory earlier in this topic) is the mechanism responsible for recycling rock materials and therefore drives the rock cycle. The following sections include more details about the rock cycle.

Igneous rocks

Igneous rocks are formed through the crystallisation of magma as it cools either in the mantle or on the surface after a volcanic eruption. The components of rock are minerals, and each mineral forms, or crystallises, under a certain temperature and pressure. Therefore, considering that the variation in pressures and temperatures is great when one extends from the mantle to the surface, it is not surprising that a huge variety of minerals exist. Crystallisation is the process whereby the mineral particles form tight bonds in a well-defined three-dimensional shape. As an exercise, look at the crystal shapes of sugar and salt under a magnifying glass. The size of the crystal is determined by the time that it takes to cool. If cooled slowly, the crystal shapes are large.

As magma cools, minerals crystallise, and the resulting rock is characterised by interlocking mineral crystalline grains. Magma that cools beneath Earth's surface produces intrusive igneous rocks (also called 'plutonic rocks'), while magma that cools at Earth's surface produces extrusive igneous rocks (also called 'volcanic rocks') (see Figure 9). Igneous rocks that cool slowly have a coarse-grained texture characterised by large mineral crystals, whereas rocks that cool quickly are fine-grained and have small mineral crystals. Generally, intrusive rocks are coarse-grained, whereas extrusive rocks are fine-grained.

Common volcanic rocks include tuff, rhyolite, andesite and basalt. Common plutonic rocks include granite, diorite and gabbro.

ACTIVITY: INVESTIGATING IGNEOUS ROCKS

Search the Internet to:

- **investigate the characteristics of igneous rocks**
- **find pictures of the common volcanic and plutonic rocks; can you easily distinguish the two types?**
- **find and name any igneous rocks that are located in your local area.**

Weathering, erosion and deposition

Weathering is the physical breakdown (disintegration) and/or chemical alteration (decomposition) of rocks on Earth's surface. These changes are caused by the weather—by air and water. There are two types of weathering: mechanical and chemical, usually taking place at the same time.

Mechanical weathering is the breaking up of rocks and mineral into smaller pieces. This can occur in various ways:

- trees and other plants send down roots into cracks in rocks, wedging them apart
- water and wind erode the surface of rocks
- expansion and contraction of rock through temperature changes in the environment, creating cracks in rocks
- liquid water gets into cracks and as it freezes it expands the wedging apart of rocks (water expands about 9% when it freezes)
- animals burrow and help break up the rock.

Chemical weathering includes all the chemical changes that take place when air and water attack the rocks. Chemicals in the water break down the rocks. As mechanical weathering breaks apart the rocks, there is more surface area on the rocks for chemical weathering to occur.

Weathering yields the raw materials for both soils and sedimentary rocks. The small particles of rock are called 'sediment', which is generally transported to another site, where it accumulates. The method of transportation varies. Glaciers can move particles of any size, whereas wind transports only sand-sized and smaller sediment. Waves and marine currents also transport sediments, but by far the most common method of transportation is by running water (rivers and streams). Any geographical area in which sediment is deposited is a depositional environment.

Soils are sediments that combine with humus. Humus gives many soils their dark colour and is derived by bacterial decay of organic matter.

ACTIVITY: SEDIMENTS IN LAKE AND RIVER WATER

Collect a bottle of water from a nearby lake or river. Ideally, water should be collected from moving water near the shore of the lake or from the current in the river. Don't stir up the bottom sediment when collecting the samples.

Let your sample of water stand quietly. How long does it take for the sediment to settle and the water to clear? Is there any scum or pollution collected on top of the water?

If possible, collect water from a stream after it has rained, and collect water when there has been a dry spell. Which samples had more sediment? Why?

Pour off most of the water, and let the rest evaporate. Study the sediment under a microscope? What do you see?

ACTIVITY: SOIL FACTORY

Collect some soil from different parts of the garden. Mix with plenty of water into a glass jar or beaker, shake and let settle. Note the sand/silt/clay/humus composition. Which particles settle first? Can you make some soil to match, using crushed sedimentary rock and compost?

ACTIVITY: MANIPULATING MUD—SCIENTIFICALLY

Place a teaspoon of soil in the palm of your hand. Add water drop by drop until it is thoroughly wet but there is no excess waste in your hand.

Record what happens when you try to:

- **use your finger to press the soil flat on your palm**
- **roll it into a long thin 'worm'**
- **mould it into a tiny bowl**
- **make it into a cube.**

Soil scientists operating in field locations describe soils as 'sands', 'loams' or 'clays' according to whether they fall apart (sand), hold together in blocks but do not roll into a thin 'worm' (loam), or roll out well to a thin 'worm' (clay), when moistened and then manipulated as you have done.

Sedimentary rocks

Following the weathering of rocks, the sediment formed is transported and deposited at a depositional environment. These deposits may become compacted and/or cemented and thereby converted into sedimentary rock. The process by which sediment is transformed into sediment is 'lithification'.

About 95% of Earth's crust is composed of igneous and metamorphic rocks, but sedimentary rocks are most common at or near the surface. Approximately 75% of the surfaces exposed on continents consist of sediments or sedimentary rocks.

Sedimentary rocks are generally classified as detrital or chemical. Detrital sedimentary rocks consist of solid particles of pre-existing rocks. The fragments might be tiny or they may be large. Table 2 gives the name of the original sediment, the lithification process and the rock type produced.

TABLE 2: SEDIMENT TO ROCK

Sediment	Lithification process	Rock
gravel (>2 mm)	compaction/ cementation	conglomerate (rounded particles) breccia (angled particles)
sand (2 mm to 0.06 mm)	compaction/ cementation	sandstone
silt (0.06 mm to 0.004 mm)	compaction/ cementation	siltstone
clay (<0.004 mm)	compaction	shale

Chemical sedimentary rocks originate from the weathering process where rock material is dissolved into water and transported to lakes and oceans. Here, chemical processes result in the accumulation of minerals. Organic material may also be involved in the chemical processes. The rocks produced are called 'biochemical sedimentary rocks'. For example, coal is composed of the compressed, altered remains of organisms, mainly plants. Another example is a type of limestone called 'coquina', which consists entirely of broken seashells cemented by calcium carbonate.

Areas on Earth's surface where sedimentary rock is found are characterised by distinctive layers and the presence of fossils. Rivers transport sediment from one location to another deposit in layers. Over many years different layers build up. Sometimes dead animals and plants get immersed in the sediment layers. Therefore, following lithification the sedimentary rock produced is in layers that quite often contain the remains of ancient organisms, called 'fossils'.

ACTIVITY: INVESTIGATING SEDIMENTARY ROCKS

Search the Internet to:

- **investigate the characteristics of sedimentary rocks**
- **investigate the features of at least ten sedimentary rocks (both detrital and chemical)**
- **find and name any sedimentary rocks that are located in your local area.**

Metamorphic rocks

Metamorphic rocks result from the transformation of other rocks by metamorphic processes that occur below Earth's surface. Through heat and pressure, igneous and sedimentary rocks are transformed into metamorphic rocks. In the metamorphic process the change in the rock may be minor, where the features of the parent rock are still recognisable. The change may also be a major one that results in the formation of new minerals and/or a change in texture of the rock. In this situation any features of the parent rock may be unrecognisable.

ACTIVITY: INVESTIGATING METAMORPHIC ROCKS

Search the Internet to:

- **investigate the characteristics of metamorphic rocks; what is a foliated and unfoliated texture?**
- **investigate the features of at least ten metamorphic rocks. Find out the parent rock in each case. Choose rocks that were originally igneous and sedimentary. Select rocks that underwent a slight metamorphosis and others that changed significantly.**
- **find and name any metamorphic rocks that you can find and name that are located in your local area.**

Properties of minerals

Minerals are the building blocks of rocks. They are substances that have narrowly defined chemical compositions and characteristic physical properties such as density, colour and hardness. Minerals include gemstones such as diamonds and rubies, as well as metals such as iron, gold and copper. Some of the distinguishing characteristics of minerals are:

- chemical composition
- crystal shape
- colour and lustre
- hardness
- specific gravity and density.

ACTIVITY: BREAKING UP ROCKS

Crush some sandstone, some mudstone and some limestone. Examine the materials formed. In what ways are they similar? In what ways are they different? Compare your crushed samples with soil. In what ways are they different?

Examine a small piece of coarse-grained granite. How many different minerals are present? Estimate the relative amounts of the three main components. Crush the granite with a hammer, to pieces about the size of a grain of rice, and separate into the different mineral components (quartz, felspar and a little mica). How close was your initial estimate?

ACTIVITY: ROCK FACTORY

Classify the man-made 'rocks' as sedimentary, metamorphic, conglomerate, etcetera. Survey the classroom, the building and grounds for a list of materials manufactured by humans from mineral/metal origins and now used in construction. Include the gardens, nature strip and roadway in your list.

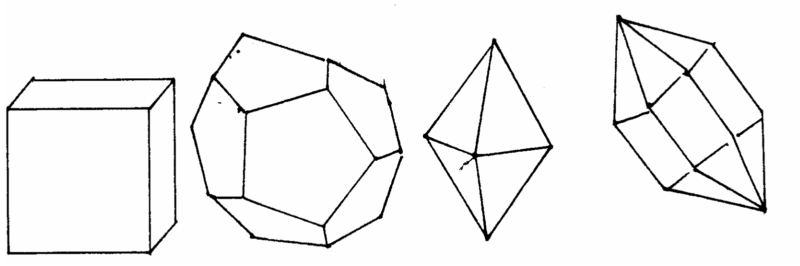
Make a sedimentary rock, using crushed sandstone and water. Investigate what works best as binding (plaster, clay, etc.)

Make some concrete blocks (conglomerate) using screenings and different proportions of sand and cement (for example, 1:2, 2:1, 3:1). Devise a test to determine the strongest concrete. Compare your samples with samples of commercial concrete.

Make bricks using clay (metamorphic). Try adding various materials that could affect the strength (for example, straw).

Minerals vary in their chemical composition. Because silicon and oxygen are the two most abundant elements in the crust, it is not surprising that many minerals contain these elements. The atoms within minerals form three-dimensional networks that form crystals. Mineral crystals occur in a variety of shapes, as shown in Figure 10.

FIGURE 10: SOME CRYSTAL SHAPES



Cube Dodecahedron Diamond A prism with pyramids

Minerals vary greatly in colour and lustre. Lustre is the appearance of the mineral in reflected light. There are two major types of lustre: metallic and non-metallic.

Hardness is the resistance of a mineral to abrasion or being scratched. An Austrian geologist, Friedrich Mohs, devised a relative hardness scale based on ten minerals. All other minerals fit within this range. Any mineral on the scale will scratch a mineral with a lower number. The Mohs Hardness Scale is shown in Table 3 below.

TABLE 3: MOHS HARDNESS SCALE

Hardness	Mineral	Hardness of common objects
10	diamond	
9	corundum	
8	topaz	
7	quartz	
6	orthoclase	steel file (6.5)
5	apatite	glass (5.5–6)
4	fluorite	
3	calcite	copper coin (3)
2	gypsum	fingernail (2.5)
1	talc	

Minerals are compared according to their densities or specific gravities. The density of a substance is the amount of mass it has per unit volume. The specific gravity of a substance is the density of the substance compared to the density of pure water, which is exactly 1 gram per cubic centimetre (g/cm^3). For example, the density of balsa wood is 0.11 g/cm^3 and the density of mercury is 13.5 g/cm^3; therefore the specific gravity of balsa is 0.11 and for mercury it is 13.5. The specific gravity of water is, of course, 1. The following activity determines the specific gravity of some rock samples.

ACTIVITY: SPECIFIC GRAVITIES OF SOME MINERALS

You will need:

- **a collection of rocks**
- **a large measuring cylinder**
- **a weighing device**
- **an ice-cream bucket**
- **a piece of plastic tubing**
- **calculator.**

Rocks are compared according to their densities or specific gravities. The density of a substance is the amount of mass it has per unit volume. The specific gravity of a substance is the density of the substance compared to the density of pure water, which is exactly 1 gram per cubic centimetre (g/cm^3). For example, the density of balsa wood is 0.11 g/cm^3 and the density of mercury is 13.5 g/cm^3; therefore the specific gravity of balsa is 0.11 and for mercury it is 13.5. The specific gravity of water is, of course, 1.

Partly fill a large-diameter graduated cylinder with enough water to completely submerge your rock. Fill it to some convenient mark, for example, 50 mL. Then immerse the rock completely and determine the new level of the water. The difference in the levels gives you the volume of the rock. For example, if the water rose to 105 mL, the volume of the rock is 105 - 50 = 55 mL. As 1 mL = 1 cm^3, the volume of the rock is 55 cm^3.

Alternatively, the volume of your rock can be determined by making an overflow can. Near the top of an ice-cream bucket place a hole and insert a small piece of plastic tubing that will run into a measuring cylinder. Fill the bucket to the point of overflow through the tube. To determine the volume of the rock, submerge it into the bucket of water and determine the volume of the overflowed water. If you don't have a measuring cylinder, weigh your overflow container before and after it fills with water. Then calculate the weight of the overflowed water in grams. As the density of water is 1 g/cm^3, the weight of water in grams is the same volume in cm^3.

Next, weigh your rock in grams. Now you can determine the density of your rock (just divide the weight in grams by the volume in cubic centimetres). What is the density of your rock? What is the specific gravity of your rock?

Age of rocks and geological time

The age of rocks is determined by measuring the amounts of radioactive particles, called 'radioactive isotopes', within the rock. A radioactive material, such as uranium, gives off radiation and in doing so begins to disintegrate. In disintegrating, the uranium material changes into another material. The half-life of a radioactive material is the time taken for half of the original material to disintegrate. By looking at the composition of the radioactive materials in a rock sample and by knowing their half-life, we can determine the age of the rock. By knowing the age of rocks, scientists can then determine the age of anything contained within the rocks, such as fossils. By dating fossils scientists have developed a geological time scale. The time scale is divided into eons that are subdivided into eras, divided further into periods and divided further still into epochs (see Table 4).

TABLE 4: GEOLOGICAL TIME SCALE

Eon	Era	Period	Epoch	Millions of years ago	Major events
Phanerozoic	Cenozoic	Quaternary	Recent or Holocene	0 0.01	 Ice age ends
			Pleistocene	1.6	Ice age begins Earliest humans
		Tertiary	Pliocene	5.3	
			Miocene	23.7	
			Oligocene	36.6	
			Eocene	57.8	Formation of Himalayas
			Palaeocene	66	Extinction of dinosaurs
	Mesozoic	Cretaceous		144	First birds
		Jurassic		208	
		Triassic		245	First mammals First dinosaurs
	Paleozoic	Permian		286	Formation of Pangaea
		Carboniferous		360	First reptiles
		Devonian		408	First amphibians
		Silurian		438	First land plants
		Ordovician		505	First fish
		Cambrian		570	Earliest shelled animals
Proterozoic				2500	Earliest fossil record
Archean				4600	Origin of Earth

ACTIVITY: GEOLOGICAL TIME LINE

You will need:

- **toilet paper**
- **Post-it notes.**

Roll out about 5 m of toilet paper. This will represent a geological time line. Use a scale of 1 billion years to represent 1 m. On one side of the toilet paper place Post-it notes to represent the different periods of time. On the other side place Post-it notes that mark the time of significant events. You can research the time for other major events.

The significance of this exercise is that it highlights the very small time period that human beings have been on Earth from a geological time perspective.

Mining

The following is an extract from the introduction to the website 'The uses of rocks and minerals' <http://www.nswmin.com.au/minerals/az-minerals.shtml>.

> Rocks and minerals that occur naturally, though sporadically, in Earth's crust perform vital roles in our everyday lives. But few of us ever make the connection between the objects, appliances and materials we use and which help to make life easier, and their source in a mine or quarry somewhere in Australia. It has been estimated that a hole of about 12 cubic metres in size needs to be dug every year to provide for the mineral and energy needs of the average Australian household.
>
> Australia is fortunate in having a relative abundance of a wide variety of minerals, sufficient to meet our own needs and also to sell to other less well-endowed countries, thereby producing wealth and employment and helping to pay for the enormous variety of imported manufactured goods.
>
> Some rocks and minerals can be used virtually in the condition they are dug from the earth, with only some grading and blending to assure consistent quality. Examples are sand, gravel and clay used for construction of buildings, road and bridges and for brick manufacture. Others require only some 'dressing up' to make them suitable for their intended uses, such as faceting of gemstones and the sawing of sandstone into blocks and sheets for building construction, or the polishing of granite for decorative cladding and benchtops. Yet others require complex refinement and a purification process, such as aluminium, which needs large amounts of electricity to separate the metal from its parent oxide, but once separated is highly resistant to corrosion and lasts a very long time. Some, such as gold, platinum, sulphur and occasionally copper and silver, occur in the earth as native elements, requiring no treatment other than separation from their host rocks.
>
> (NSW Minerals Council 2005, http://www.nswmin.com.au/minerals/az-minerals.shtml)

ACTIVITY: USES OF ROCKS AND MINERALS

Access the website 'The uses of rocks and minerals' <http://www.nswmin.com.au/minerals/az-minerals.shtml to answer the following:

- **list ten major uses of rocks and minerals; list the rocks/minerals used**
- **list five rocks/minerals that do not require extraction from other materials when they are obtained from the ground**
- **list five minerals that require a significant amount of extraction from other materials when obtained from the ground.**

Mining is the extraction of minerals from Earth's crust. Based on the activity *Uses of rocks and minerals*, you should realise that there is a great variety of uses for rocks and minerals. The extraction of minerals for use varies widely. In the activity *The mining of minerals* the choice of exploring information about mining specific mineral types is left open to you.

ACTIVITY: THE MINING OF MINERALS

Search the Internet to explore the mining of one or two minerals of your choice. In your exploration find out:

- **the technique(s) used by geologists to determine the location of your selected mineral**
- **how your selected mineral is mined; does this present any environmental problems?**
- **how your selected mineral is processed; does this present any environmental problems in terms of the waste produced?**

- **what uses your selected mineral has for humankind (assuming that this has not been done from the previous activity)**
- **how plentiful your selected mineral is?**

Further resources

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