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OnScreen Format

Earth & Environmental Science Module 1

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Earth's Resources

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Topic Outline

What is this topic about?

To keep it as simple as possible, (K.I.S.S. Principle) this topic covers:

1. STRUCTURE of the EARTH

**Formation of matter, the Solar System & Earth.
Importance of gravity & density in forming the Earth.
Earth's layered structure. Evidence. Details.**

2. ROCKS, MINERALS & SOIL

Aborigines' use of rocks & minerals. Major types of minerals & their properties. Igneous rocks. Felsic & mafic. Sedimentary & metamorphic rocks. The "Rock Cycle". Soil & how it forms. Soil components.

3. GEOLOGICAL TIME SCALE

Relative v. absolute dating. Isotopes, radioactivity, half-lives. Radiometric dating. Importance of zircons.

4. GEOLOGICAL RESOURCES

**Indigenous mining. Renewable, non-renewable & sustainability of resources.
Australia's resources & their economic significance.
Discovery of new resources. Extraction methods.**

Earth's Resources

1. Structure of the Earth

- Formation of matter, Solar System & Earth
- Gravity & Density in Earth's formation
- Earth's layered structure - details & evidence

2. Rocks, Minerals & Soil

- Indigenous peoples' use of minerals
- Overview of minerals & properties
- Igneous rocks: felsic & mafic
- Sedimentary & metamorphic
- The "Rock Cycle"
- Soil & how it forms

3. Geological Time Scale

- Relative & absolute dating
- Radioisotopes & radiometric methods

4. Geological Resources

- Indigenous mining
- Renewable, non-renewable & sustainability
- Australia's resources & economic significance
- Discovery of new resources
- Extraction methods

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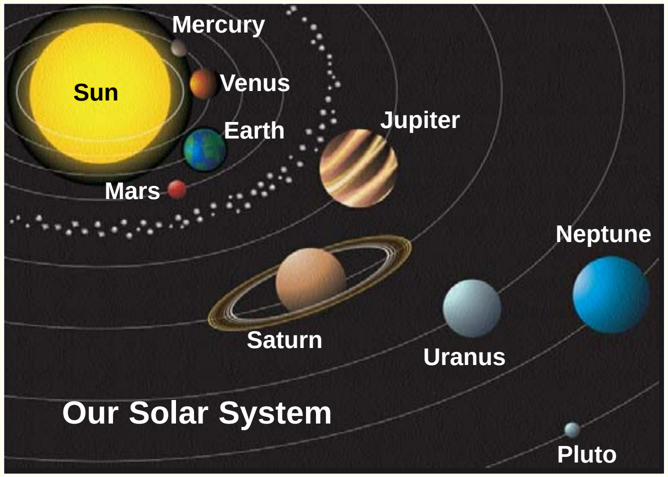
Firstly, an Introduction...

Our Place in the Universe

The **EARTH is a PLANET.** The Earth and 7 other planets (plus dwarf planets, moons, asteroids, comets, etc) are in orbit around the Sun. The SUN and all these things in orbit around it, make up our **"SOLAR SYSTEM".** Everything stays in orbit around the Sun because of gravity.

The **SUN is a STAR.** Energy is being produced inside it, due to **NUCLEAR REACTIONS.** The Sun is one of billions of stars that make up our **GALAXY.** Each star in the night sky is another "Sun" within our galaxy, the **"MILKY WAY".**

Our Sun and the other stars of the Milky Way are orbiting around the galaxy because of gravity.

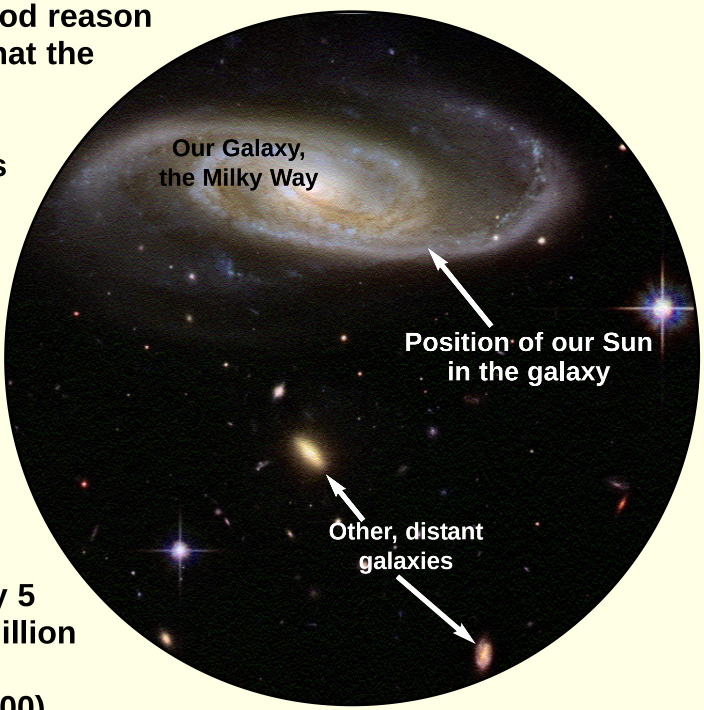


Our Solar System

Beyond our galaxy are billions of other galaxies. The distances involved are immense and unimaginable!

We have good reason to believe that the Universe is about 14 billion years old, while the Solar System and Earth have been around for a bit less than 5 billion years...

that's nearly 5 thousand million years. (5,000,000,000)



In that time the Earth has undergone many changes...

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1. Origin & Structure of the Earth

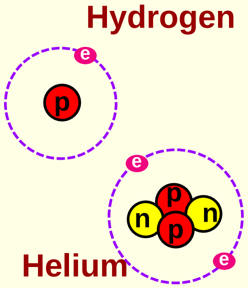
Origins of the Matter of the Universe

The "Big Bang Theory" proposes that the creation of all matter occurred about 14 billion years ago (bya) and that all the matter moved outwards rapidly, cooling and condensing to form the Universe.

The syllabus does NOT require you to know the details of the Big Bang Theory, but we think that the matter created in the beginning was virtually all simple hydrogen and helium atoms.

However, the Earth is mostly made from larger, heavier atoms such as iron and oxygen, and includes small amounts of very large atoms like lead or uranium. So where did these come from?

Photo of a cloud of dust and gas taken by the Hubble Space Telescope. Parts of the cloud are glowing because of new stars forming inside it. Photo courtesy of NASA & ESA



In the beginning, all the matter of the Universe was the simplest atoms.

Where did all the larger, heavier atoms come from?

We believe that all the atoms larger than helium were formed by nuclear reactions within the stars. Nuclear fusion is a process which joins small atoms together. This releases all the energy of a star, and builds new atoms.

At the end of their life, large stars explode in a "supernova" explosion. This scatters the zillions of tonnes of star matter, including heavier atoms, into huge gas and dust clouds in space. It is from such a cloud that our Solar System must have formed.

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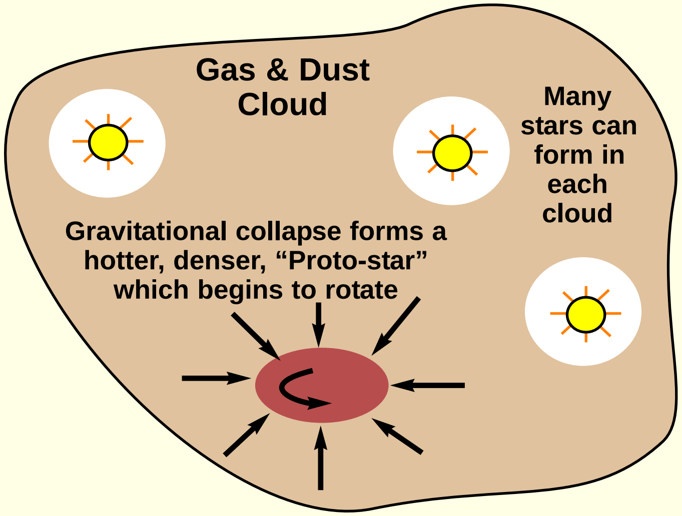
Formation of the Solar System

We believe that the solar system formed 4.6 billion years ago from the dust and gas debris from a supernova.

Slight irregularities in parts of the cloud (perhaps caused by the shock wave of another, later supernova) began to contract by gravitational attraction. As the zone of contraction became denser, gravity caused further, faster collapse. As it collapsed, the temperature rose and the mass began to spin.



Eventually, after perhaps several million years, the core of this “protostar” became dense and hot enough for nuclear fusion to begin, and the mass of collapsed gas began its life as our star, the Sun.

Other parts of the cloud nearby had by now formed a <u>disk</u> of matter, rotating around the new star. A lot of this matter condensed into small solid particles, swirling and colliding. Often, colliding particles <u>stuck together</u> to form larger lumps. This “accretion” of matter formed larger and larger bodies.

Once a certain size was achieved, the gravity of an accreted “proto-planet” would cause it to attract and “capture” all other lumps in its vicinity. Gravity would also cause the accreted matter to collapse into a spherical shape.

This is how the planets formed.

The inner, rocky planets consist mainly of rock and metals with oxygen, silicon and iron being the most common elements. The “outer” gas planets consist of hydrogen and helium with compounds of sulfur and carbon.

The various <u>asteroids</u> and <u>comets</u> of our Solar System are probably the “left-over” solid lumps. Each time a meteorite crashes into the Earth (or other planet) the accretion process gets a little closer to completion.

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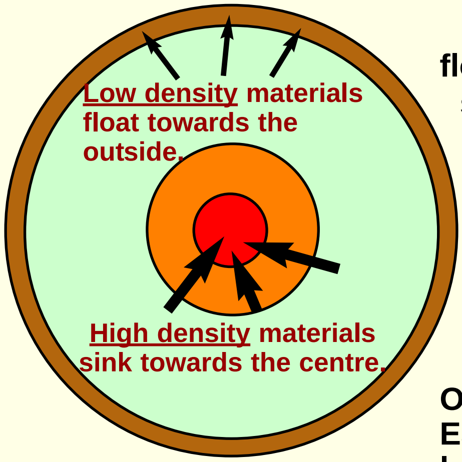
Importance of Gravity in the Formation of Earth

All matter has mass which produces a field of gravity which attracts all other matter. As described previously, the atoms of the dust & gas cloud from which the Solar System formed began to clump together under the influence of this gravity.

As the particles began sticking together ("accretion") and increasing in mass, the gravitational forces between the objects became larger. Eventually the larger lumps of accreted matter began sweeping up the remaining debris nearby. Continued accretion eventually formed the planets that make up the solar system.

Once each planet reached a certain size, (approx 200km across) gravity pulled the mass together with such force that it collapsed into the most compact shape possible... a sphere. It is gravity that has caused all planets to be spherical.

The Earth has a layered structure due to density differences



This gravitational compaction also rammed the matter together with so much force that immense heat energy was generated... and the early Earth melted!

The early Earth was a conglomeration of many substances mixed randomly. However, as gravitation compaction heated and melted this mixture, the various substances sank or floated, so that the Earth came to have a layered structure.

It is the density of things that determines flotation and sinking. A cork floats on water because its density is less than the water. A stone sinks because its density is higher than water.

Once gravitational compaction melted the primitive Earth, the various materials in the mixture formed layers according to their density.

Density

Prac Work:

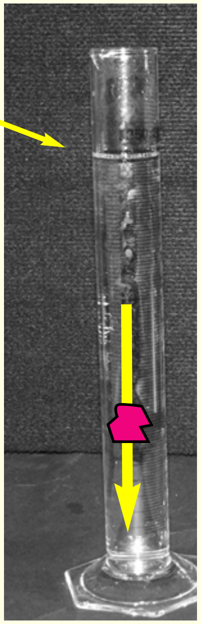
Density of Layers of the Earth

You may have carried out experimental work to learn the technique of measuring density, and apply it to measuring the density of materials which are similar to some different parts of the Earth.

In an experiment, you can weigh an object with a balance to measure its mass.

Volume is often measured by displacement of water, as suggested by the photo.

Density is then calculated as above.



Water level rises when an object is dropped in.

The change in water level is equal to the volume of the object.

Typical Results

We believe the core of the Earth contains a high percentage of iron.

The rock basalt is associated with the Earth's upper mantle & oceanic crust.**

****Actually, basalt is NOT a mantle rock, but we suggest using it here since it is the most common rock which is somewhat similar to mantle rocks.**

Rock such as granite is typical of the Earth's continental crust.

Density

You are reminded that density is the ratio between the mass of a substance and the space (volume) it occupies. All pure substances have a fixed and characteristic density.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$D = \frac{m}{V}$$

Units commonly used:
Mass is typically measured in grams (g)
Volume of solids is often measured in cubic centimetres (cm^3) and liquids in millilitres (mL).
For practical purposes these units are the same.
Density would be in grams per cu.cm (gcm^{-3}).

If the density of a sample of each of these materials was measured, you may have obtained results similar to these:

Substance Tested	Mass (g)	Volume (cm^3)	Density (gcm^{-3})
Iron	29	4.0	7.3
Basalt	17	5.1	3.3
Granite	22	8.1	2.7

If you analyse these results in terms of which part of the Earth each substance represents, you'll see that density increases towards the centre of the Earth.

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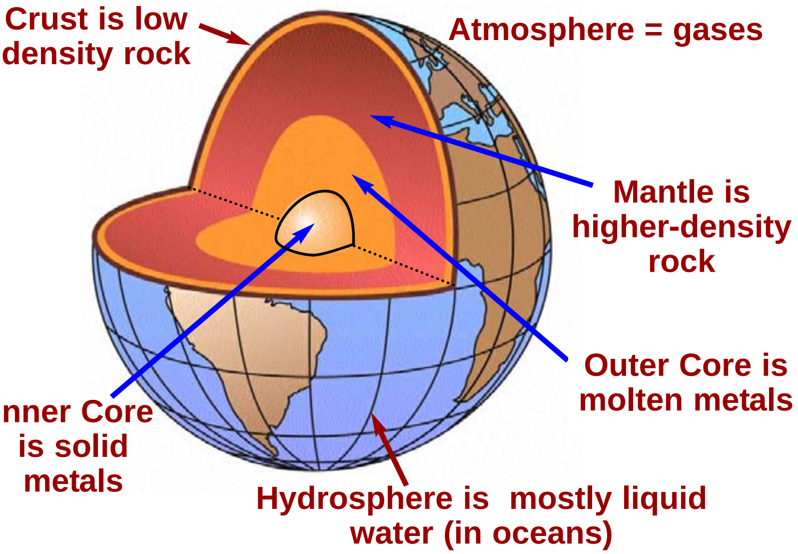
Density of Earth Materials & the Layered Structure of Earth

As the Earth was forming and still in a molten state, the higher density substances such as iron and nickel sank to the centre of the Earth to form the core. Lower density substances moved towards the outer surface. Compounds of aluminium, silicon and oxygen (and others) became the minerals which are now in the rocks of the crust. This process where the Earth formed specific layers is known as <u>differentiation</u>.

Composition of the Layers of the Earth



The core of the Earth consists largely of iron-nickel alloy and remains extremely hot even today because of the decay of radioactive materials such as uranium. The outer, liquid iron core is the source of the Earth's magnetic field.

In between the core and the crust is the thickest layer of all... the Mantle. The mantle is composed of dense minerals including olivine, pyroxene, garnet & peridotite which are higher in density than most crustal rocks. These minerals are about 90% magnesium, iron & aluminium <u>silicates</u>. “Silicate” minerals will be explained soon.

Typical rocks of the continental crust includes granite and various “sedimentary rocks” such as limestone and sandstone. These generally have a lower density than mantle rock. Most crust rocks are also <u>silicates</u>, but with higher levels of aluminium & potassium.

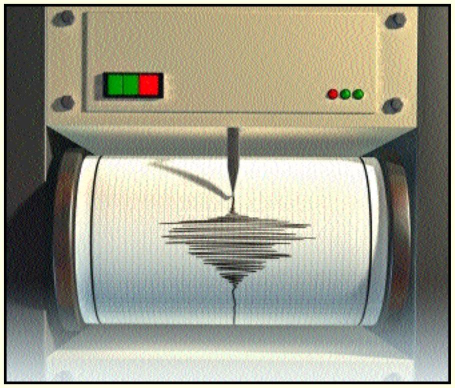
The very lowest density materials are things like water and various gases. These of course “floated” to the very outside of the early Earth forming the atmosphere and (eventually) the oceans which now cover roughly 2/3 of the crust.

Evidence for the Earth's Layered Structure

No-one has ever drilled a hole through even the thinnest part of the Earth's crust, so how do we know about these layers?

Seismology

Seismology is the study of earthquakes and their shock waves. (Greek, "seismo"= shaking)



Earthquakes are caused by sudden movements in the Earth's crust. The sudden release of enormous energies sends out shock waves which radiate out from the "focus" of the 'quake.

The shock waves are detected and recorded by a seismometer. The photo shows an old-fashioned seismometer recording the vibrations on paper. Modern seismometers use electronic detectors and record data digitally for computer analysis.

Seismic Waves

Earthquake shock waves are <u>refracted</u> by different density rocks, and some types of waves cannot pass through liquids such as the Earth's Outer Core.

Our understanding of the structure of the Earth is based on studying the seismic waves and how they behave as they pass through the different layers.

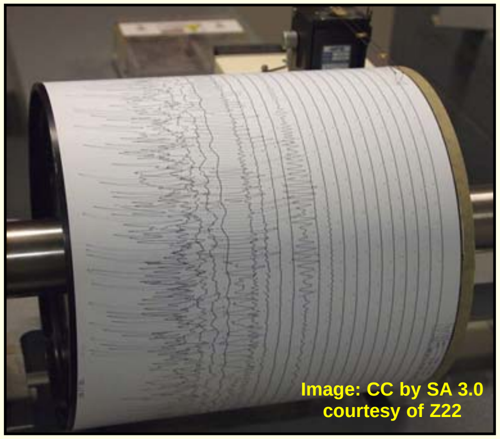


Image: CC by SA 3.0
courtesy of Z22

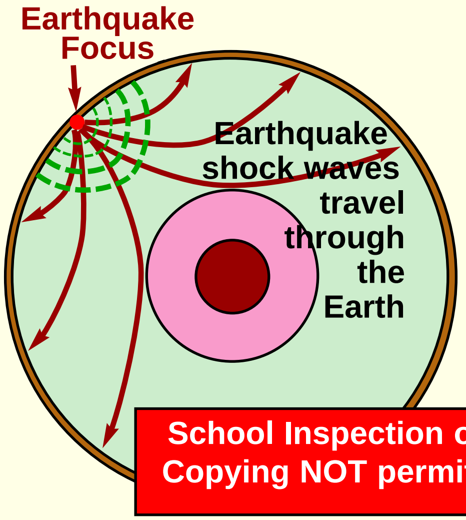
There are thousands of seismometers all over the world, including the ocean floor. Most are automatic stations sending data to central computers by radio or phone links.

Many are warning systems to alert people to possible volcanic eruptions or tsunami waves in the oceans.

The recording from a seismometer is called a "seismogram", as shown at left.

As the waves (there are several different kinds) strike a different density layer, they change direction and speed.

Some of the energy may reflect from the boundary between 2 layers and bounce back into the layer it just came from.



Some types of waves cannot travel through liquids. If there is a liquid layer in the Earth (and we believe there IS) this creates a "shadow zone" somewhere on the other side of the world.

It is very complex, but from 100 years of study, by thousands of seismologists, we have concluded that the Earth really does have a layered structure.

Evidence for the Earth's Layered Structure (cont.)

Density & Magnetism Considerations

The density of the whole Earth was calculated about 200 years ago from an accurate knowledge of its size and its mass (calculated from gravity measurements).

Immediately it was realised that the overall density was much higher than the average density of the rocks found at the surface. Therefore, it was theorised, there must be much denser materials somewhere below the surface.

The other clue was the scientific study of the Earth's magnetism. The only magnetic material known was iron, so this suggested that there must be a huge lump of magnetic iron somewhere in the Earth's core.

Image by Thomas Grau

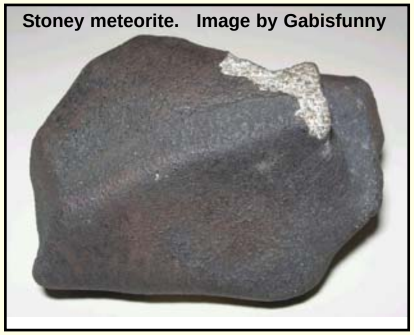
Evidence from Meteorites

A meteor is sometimes called a "shooting star". It is a piece of space debris which collides with the Earth at such a high speed that, usually, it burns away in the upper atmosphere after a brief streak of light.

Image by USGS

Occasionally, part of the meteor survives its fiery descent & reaches the surface. The larger ones create impact craters such as the famous Barringer Crater in Arizona, USA.

The surviving bits of a meteor are called "meteorites" and they can tell us quite a lot about what the Earth was originally made from.



Stoney meteorite. Image by Gabisfunny

Thousands of meteorites have been found & studied. The vast majority are "stoney" meteorites composed of silicate minerals similar in overall chemical composition to the basic minerals which make up all the rocks on Earth.

Less than 10% are "iron meteorites" composed mostly of iron oxides & elemental iron, plus other metals.

Iron meteorite
Image: CC by SA 3.0 courtesy of Meteoritekid

What does this tell us about the Earth?

Don't forget that meteorites are thought of as the "left-overs" from when the Solar System formed roughly 4.6 billion years ago. These are the bits which didn't get swept up by the accretion of the planets.

We can tell how old the meteorite material is, using dating techniques which will be described soon. Sure enough, meteorites all turn out to be about 4.6 billion years old.

We conclude that the stuff that meteorites are made from is the same stuff that the Earth was originally made from!

This tells us that the Earth should be made largely from silicate minerals, with a significant chunk of iron & iron compounds somewhere.

The seismic wave evidence tells us irrefutably that the Earth has a layered structure. The Earth's density & magnetism combines with evidence from meteorites to clearly indicate what the layers are made from. Scientific evidence doesn't get much clearer!

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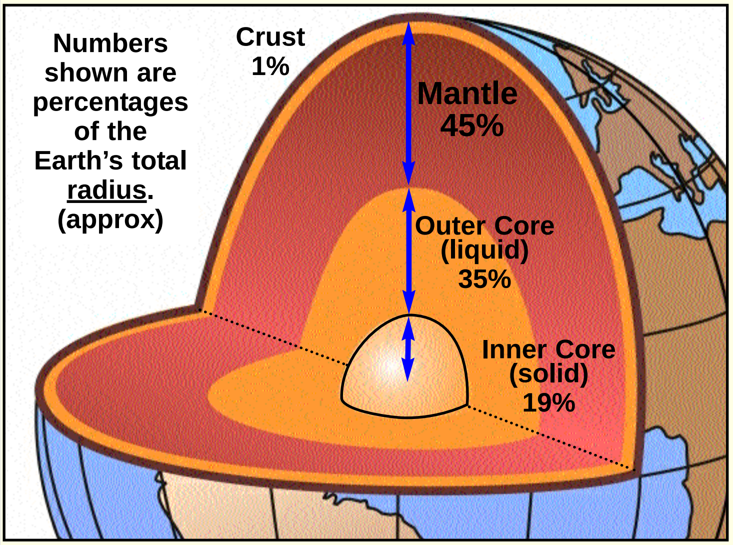
The Earth's Layers... More Details

As well as the information below, please be sure to try the KISS worksheet on Earth Structure.



Numbers shown are percentages of the Earth's total radius. (approx)

The Earth's radius is about 6,400 km. The solid part of the Earth is often called the "geosphere", but there is some disagreement about the precise definition of this word. Although the Mantle occupies about 45% of the Earth's radius, this adds up to almost 80% of the Earth's total volume.

About 2/3 of the Earth's surface is covered by the "hydrosphere"... the oceans mainly. Wrapped completely around all this is the atmosphere. Although the atmosphere extends for perhaps 500km up from the surface, by 100km up it is usually considered that you are in "space". About 75% of all the air is within about 10km of the surface.

The Junction of Crust & Mantle

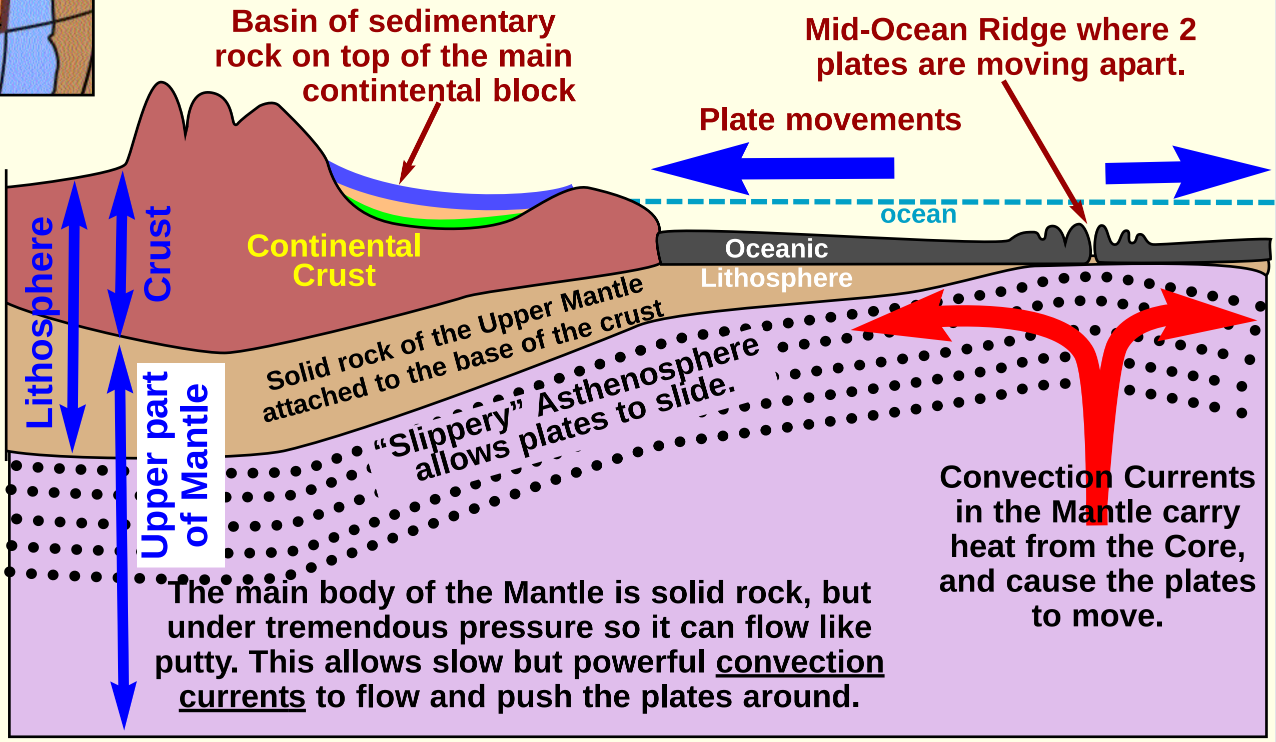
The junction between the Crust & the Mantle needs further detailed explanation:

The Crust **under the oceans is relatively thin (5km approx) and much thicker (75km approx) under the continents.**

However, up to 120km of rigid Mantle rock has attached itself to the crustal rocks in some places. These 2 layers form the "Lithosphere".

Lithosphere **makes up each of the "Tectonic Plates" which cover the outer Geosphere. Lithosphere varies from about 10km to almost 200km in thickness.**

Below the Lithosphere, the next 200km of Mantle is relatively "slippery" & fluid. This is called the *Asthenosphere.*



Convection Currents in the Mantle carry heat from the Core, and cause the plates to move.

The main body of the Mantle is solid rock, but under tremendous pressure so it can flow like putty. This allows slow but powerful convection currents to flow and push the plates around.

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Discusssion / Activity 1

The following activity might be for class discussion, or there may be paper copies for you to complete.
If studying independently, please use these questions to check your comprehension before moving on.

Structure of the Earth

Student Name ....

1. Outline how we think the Sun & planets formed.

2. Outline how the force of gravity and different densities of substances resulted in the layered structure of the Earth.

3. Discuss briefly how we know about the layered structure of the Earth, from:

a) Seismology.

b) magnetism of the Earth.

c) meteorites.

2. Rocks, Minerals & Soil

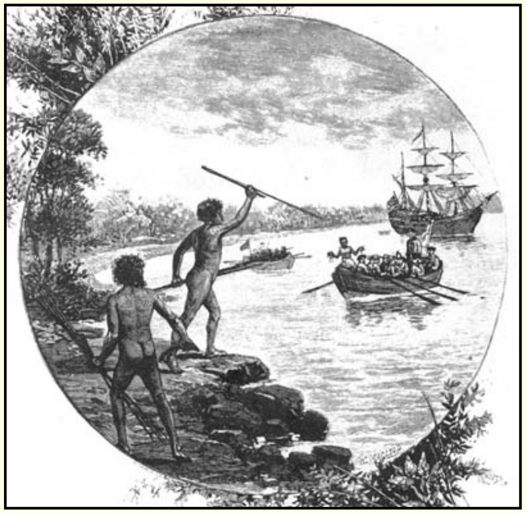
Indigenous Australian Technology

There is evidence that indigenous Australians arrived on this continent at least 40,000 years ago. Their culture was essentially “Stone-Age”, but the technologies they used were in some ways quite sophisticated. Survival for so long in a harsh environment is evidence of the suitability & sustainability of indigenous methods.

Aboriginal technologies utilised wood, bone & plant fibres, but it is the use of rocks & minerals which interest us here.

One of the most important minerals to Aboriginal culture was “ochre” which was used as a pigment for art & body decoration for various ceremonies & dances.

Ochre occurs in a variety of forms, but all are basically weathered iron-rich minerals. Chemically it is iron oxide & iron hydroxide. It occurs in many places throughout Australia and was classified by Aborigines by colour. The various colours were used for different cultural purposes.



Artistic impression of an early contact between Aborigines & Europeans

Stone technologies included the manufacture of cutting blades, spear points, abrasive tools (eg for shaping & smoothing wooden implements such as boomerangs & woomeras) and grinding “hammers” for crushing & grinding foods or ochre.

Sandstone was a favourite material for abrasive / grinding tools, while rocks such as flint or chert (which can be chipped to form very sharp edges & flakes) were prized to make cutting tools & spear points.

After contact with Europeans, the locals recognised immediately that glass bottles & ceramics were excellent alternatives for flint. Many 19th century aboriginal knives & hand axes were fashioned from cast-off beer bottles or ceramic insulators taken from the telegraph lines.

Exactly what IS a Mineral?

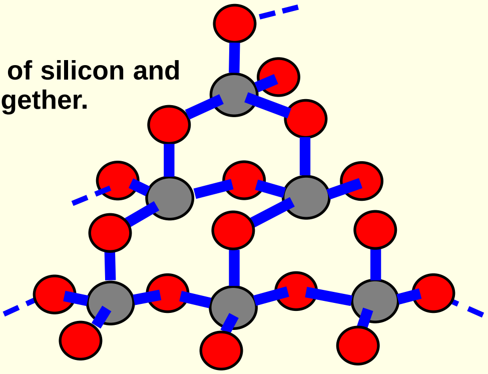
Minerals are the basic chemicals which make up the rocks of the Crust & Mantle. Each mineral has a definite chemical composition and has a set of characteristic properties.

Quartz, Silica and the Silicates

By far the most common and important minerals are those based on the compound silicon dioxide, SiO_2.

Chemically, pure SiO_2 is a 3-D network of silicon and oxygen atoms very strongly bonded together. This gives it a very high melting point, and makes it a hard and glass-like crystalline material.

(Not surprising that it is glass-like... it is one of the main ingredients in making glass!)



Often pure silica crystals occur in rocks. This is usually called “quartz”. Clean, white sand is mostly small fragments of broken quartz crystals.

Many other common rock-forming minerals are crystals of silica in which various metals are bonded within the crystal structure in place of some of the silicon or oxygen atoms.

These minerals are known collectively as silicates.

Cluster of pure Quartz crystals

Pure SiO_2 is also known as “silica”. As a mineral it is called “quartz”.

Silicates, Next Slide...

Common Silicate Minerals & Their Basic Properties

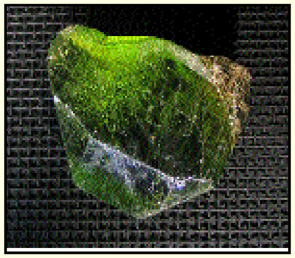
About 95% of rocks of the Crust are composed mainly of quartz & silicate minerals.

	Mineral	**Chemical Composition**	**Hardness** (Mohs)	**Colour & Lustre**
	Quartz	pure silica, SiO_2	very hard (7)	clear, glassy
Feldspar minerals	Orthoclase	K-Al-silicate	hard (6)	often white, red or brown, glassy
	Plagioclase	Ca-Al-silicate	hard (6)	yellow, white or brown, glassy
	Olivine	Mg-Fe-silicate	hard (6.5)	olive green, shiny, greasy
	Biotite Mica	K-Mg-Fe-OH-silicate	soft (2.5)	black, glassy
	Muscovite Mica	K-Al-OH-silicate	soft (2)	brown-yellow, pearly

Chemical symbols: K = Potassium Al = Aluminium Ca = Calcium
Mg = Magnesium Fe = Iron OH = Hydroxide

Orthoclase

Biotite Mica



Olivine

Plagioclase

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Non-Silicate Minerals

There are also some minerals NOT based on silica, with totally different chemical composition:

Calcite

Calcite is calcium carbonate, $CaCO_3$. It is a fairly soft, white mineral which can be easily identified by placing a drop of acid on a sample. It will react by “fizzing” with bubbles of carbon dioxide gas.

Calcite is the mineral which forms when CO_2 gas dissolves in the ocean and then reacts with dissolved calcium. The calcite forms sediments which later may become a sedimentary rock... “limestone”.

Many living things, especially corals, make shells & skeletons from $CaCO_3$. Coral reefs can also later form deposits of limestone rock.

Vast deposits of limestone are found world-wide.

Metal Ores

Some minerals are composed of a metal combined with oxygen, sulfur or other chemicals. They have a very high metal content, so they are valuable commercially. Deposits of these minerals are mined to extract useful metals from the “ore”.

Some of the most common are:
Haematite & Magnetite are iron oxides = “iron ore”
Malachite is copper carbonate & hydroxide = “copper ore”
Galena is lead sulfide = “lead ore”
Bauxite is aluminium oxide = “aluminium ore”

Much of Australia’s national wealth is due to huge deposits of these valuable minerals.

Identifying Minerals by Their Properties

Each pure mineral has its own particular properties which can be used to identify it. The identification tests have evolved to be simple, quick & require little equipment so they can be used “in the field” by geologists or amateur rock collectors.

For example, carrying a dropper bottle of household vinegar is all you need to identify calcite in a rock sample. (see above)

Some of the other properties used in identification include:

“Hardness”. This is simply assesed by “scratch tests”. Harder minerals will scratch others; softer minerals will be scratched by others. A hardness scale, called **“Mohs Scale”** has developed in which the hardest mineral (diamond) scores 10. The softest (talc) scores 1. All other minerals score somewhere in between.

“Streak”.

If a mineral is rubbed onto a ceramic tile it leaves a “streak” of colour behind which can be different to the colour of the mineral itself. The characteristic streak colour can help identify each mineral.

“Cleavage”.

The crystal structure within each mineral determines the way it will fracture, according to its lines of strength & weakness. The shapes of a smashed mineral can thereby help to identify it.

“Colour & Lustre”

The colour of each mineral can help identification, but slight impurities can often change the colour dramatically, so colour alone is unreliable. “Lustre” refers to the way the crystals reflect light. Some are “glassy”, others are “pearly”, “dull” or “greasy”.

The Rocks of the Lithosphere

Rocks can be mixtures of many different minerals combined in any proportions. This means that thousands of different kinds of rock are possible. However, all rocks can be classified into just 3 groups, according to how the rock was formed.

Classical cone-shaped volcano in New Zealand

Igneous Rocks

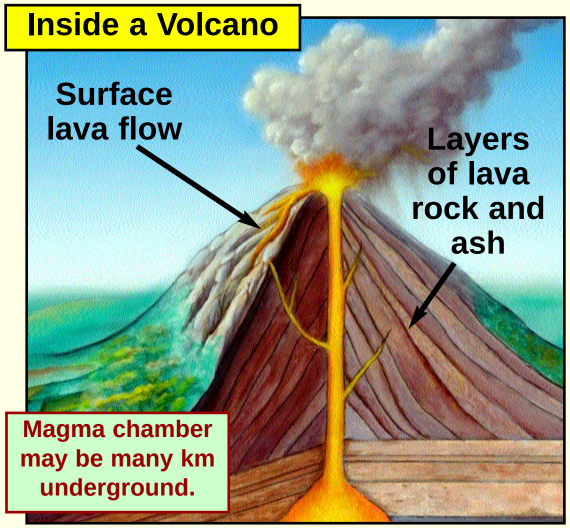
Igneous rocks are formed from molten minerals that have cooled and solidified. These rocks are associated with volcanic activity.

Magma & Lava

In many parts of the world, heat and movements in the lithosphere cause the rocks to melt deep below the surface.

This molten material is called "magma". Sometimes it can force its way to the surface and a volcanic eruption occurs. The molten rock that erupts at the surface is called "lava". In this context, "surface" includes the ocean floor where there are frequent underwater eruptions in many parts of the world.

Inside a Volcano



Magma chamber may be many km underground.

As the magma or lava cools down, the molten minerals solidify and form solid crystals. This forms igneous rocks.

Magma may cool slowly, deep underground. This may take thousands, or even millions of years to occur. This allows the mineral crystals to grow larger and be clearly visible in the rock. Lava cools quickly at the surface, and the crystals are usually too small to see by eye. Lava rocks may form within minutes of an eruption, or within a few days.

The colours vary, too. Igneous rocks with large amounts of quartz are pale in colour. If there is less quartz and more silicate minerals (of certain types), the colour will be darker.

Felsic & Mafic

Igneous rocks are often classified into 2 categories according to their mineral content:

"Felsic" refers to feldspar silicates plus silica. These rocks contain high proportions of silica (quartz) and the feldspar minerals. By definition, a felsic rock contains 63% (or more) silica and at least 75% silica + feldspar minerals. Since these minerals are colourless or light coloured, felsic rocks tend to be light in colour. They also tend to be relatively low in density. The classic example of a felsic rock is granite, very common in the continental crust.

"Mafic" refers to magnesium and ferric (iron). Mafic rocks contain lower levels of silica (around 50%) and contain denser, darker silicate minerals such as olivine & black mica which are rich in magnesium & iron. Therefore, these rocks tend to be darker in colour & have a higher density. The classic example is basalt which is very common in the crust under the oceans. Mafic rocks are thought to be closer in composition & properties to the rocks of the Mantle.

Some Common Igneous Rocks

Granite: felsic

Granite forms from slow-cooling magma. You can see the separate mineral crystals, including a lot of quartz.

Pumice: felsic

This is a rock that floats! Pumice is like the “froth” on lava, formed when volcanic gases bubble through the molten rock.

Rhyolite: felsic

Image: CC by SA 3.0 courtesy of Michael C Rygel via Wikipedia Commons

Rhyolite has the same mineral composition as granite, but much smaller crystals because it cooled quickly, at or near the surface.

Andesite: Intermediate between felsic & mafic

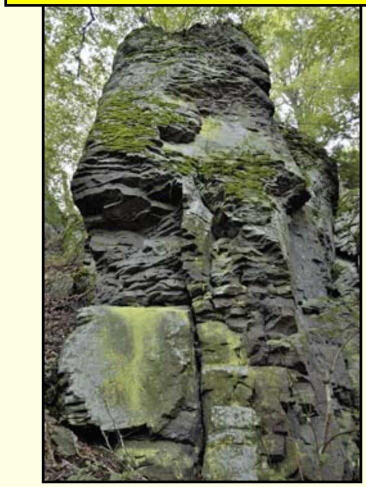
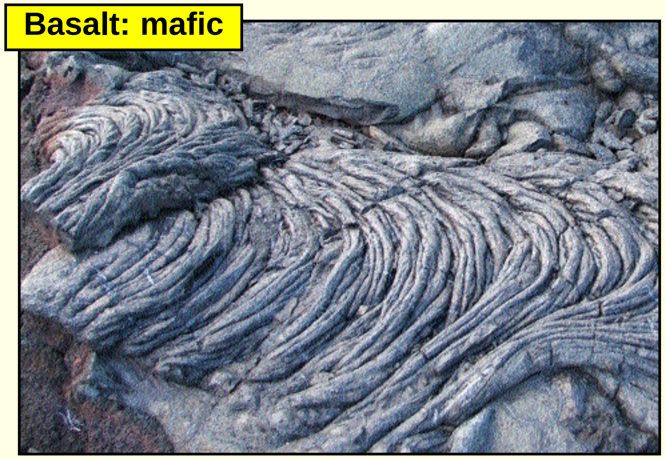


Image: CC by SA 3.0 courtesy of Doronenko

Named after the Andes Mtns of S.America, Andesite is intermediate between felsic & mafic in mineral composition. It is associated with volcanic islands & mountain ranges.

Basalt: mafic



This is basalt from a recent lava flow. You can still see the flow patterns from when it was liquid. Basalt is dark-coloured with microscopic crystals.

Gabbro: mafic

Image courtesy NASA

Gabbro has basically the same mineral content as basalt, but has larger visible crystals because it cooled slowly, deeper below the surface.

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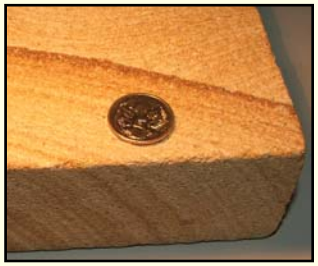
Sedimentary Rocks

The main category of sedimentary rocks are those formed from erosion products such as pebbles, sand, mud or silt which has been carried by water (or wind) then deposited in layers. Later compression, and cementing by other minerals, turns the sediments into rock.

Conglomerate
cemented pebbles.



Sandstone
compacted and cemented sand.

Shale
compacted mud, silt or clay. (also called “siltstone” or “mudstone”)

Another category of sedimentary rocks are also formed by compression of sediments, but the sediments come from chemical precipitation, or from the activity of living things.

Limestone from precipitation of $CaCO_3$ (calcite) from water, OR from buried shell & coral layers.

Chert from precipitation of SiO_2 (silica) from water. May be made up of skeletons of plankton organisms.

Sedimentary rocks are where we find fossils... the traces or remains of living things from the past. Some sedimentary rocks are almost entirely fossil material.

Sedimentary rocks are formed in layers which are usually visible when looking at a cliff or similar. In small samples, the layers might not be apparent.

Metamorphic Rocks

These are the result of existing rocks being changed by heat and/or pressure so that they have a totally new form. (Meta = change, morph = shape or form)

Some have simply been re-melted:

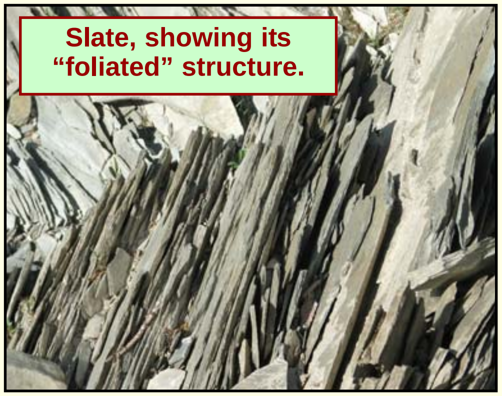
Quartzite

Re-melted <u>sandstone</u>. The sand grains are no longer visible, having melted and fused together. It becomes just a mass of glassy, impure quartz.


Quartzite Outcrop.
Image courtesy Wilson44691

Marble

Re-melted <u>limestone</u>. The rock is still mostly calcite, but harder and denser than limestone. Marble has been used as a decorative rock for flooring, sculpture, monuments, etc. since ancient times.


Slate, showing its "foliated" structure.

Some metamorphic rocks are formed by the effects of great pressure as well as heat. This results in a "foliated" structure, with thin plates like the pages of a closed book, or stripes of mineral crystals.

Slate

is pressurised <u>shale</u>. It is a hard rock which splits into plates, commonly used for flooring or roof tiles.

Gneiss

is pressurised <u>granite</u>. Often has a striped appearance due to the crystals of minerals flowing under heat and pressure.


Image: CC by SA 3.0 courtesy of Siim Sepp

Schist

is pressurised <u>basalt</u>, or <u>slate</u>, or other original rocks. In a schist, the various minerals of the original rock have been re-crystallised by immense heat and pressure. Small "sparkling" crystals of mica are often visible in thin layers. Golden flakes of "fools gold" (iron pyrites) are often present.


Image: CC by SA 3.0 courtesy of DanielCD

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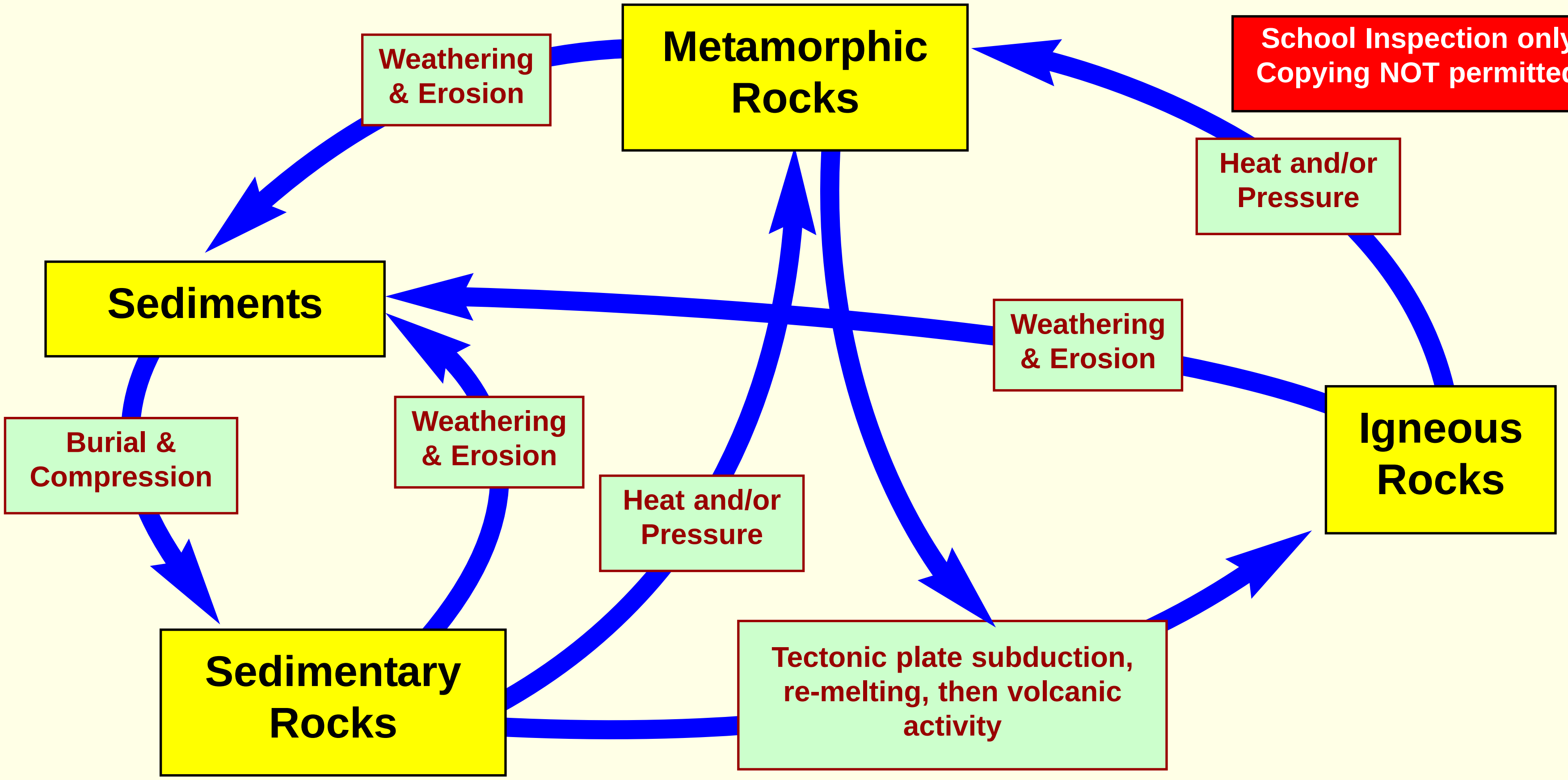
The Rock Cycle

Rocks are formed, uplifted and eroded. Sediments are carried away, deposited and compressed again into new rocks. Pressure and heat change them into new forms. Later, minerals are weathered and the rocks are eroded again. Soil forms, then washes away. It's an endless cycle of make, destroy and make again.



Metamorphic Rocks

Weathering & Erosion

Heat and/or Pressure

Sediments

Weathering & Erosion

Igneous Rocks

Burial & Compression

Weathering & Erosion

Heat and/or Pressure

Sedimentary Rocks

Tectonic plate subduction, re-melting, then volcanic activity

This relentless cycle constantly builds, destroys and re-builds the Earth's crust.
It is driven by the slow movements of the Tectonic Plates which cause the volcanic activity, the heat & pressure & the uplifting of mountains. The Earth's crust is almost completely re-cycled & re-modelled every 500 million years or so.

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Discusssion / Activity 2

The following activity might be for class discussion, or there may be paper copies for you to complete.
If studying independently, please use these questions to check your comprehension before moving on.

Minerals & Rocks

Student Name ....

1. Outline the difference between a “rock” and a “mineral”.

School Inspection only.
Copying NOT permitted.

2.
a) What is quartz, chemically?

b) What is meant by a “silicate” mineral?

c) Name a common non-silicate mineral and describe it chemically.

3.
a) In general terms, how do igneous rocks form?

b) Some igneous rocks have large, visible crystals, while others are fine-grained with microscopic crystals. Explain why.

c) Explain the distinction between “mafic” & “felsic” igneous rocks, in terms of their mineral content.

4. Outline how Sedimentary rocks are formed.

5. Outline how Metamorphic rocks are formed.

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Soil & Its Formation

What IS Soil?

Common as dirt! ...but, what is it?
Soil is a complex mixture containing 3 main parts:

Minerals

Soil contains solid particles of minerals (e.g. sand grains - quartz) and weathered minerals (e.g. clay).

There may also be various minerals dissolved in the soil water.

Humus & Life

Soil contains varying amounts of dead, decaying organic matter, and a huge population of living bacteria, fungi, insects, worms, etc.

Water & Gases

Depending on the weather and many other factors, soil contains moisture, and many gases including those of the air, plus extra CO_2 and methane.

Processes Which Produce Soil

A “good soil” may take thousands of years to form. (What is “good” is usually judged by how well plants grow in it.) The basic processes which produce any soil are:

Weathering of Rock

The mineral part of any soil is produced by the breakdown of the solid rocks which underlie and surround the area. Weathering includes 2 very different processes which often occur in parallel with each other.

Mechanical Weathering refers to the breaking of rock into smaller and smaller fragments. For example, many rocks contain small quartz crystals, and as the rock physically breaks up, quartz fragments are released as sand grains.

Chemical Weathering refers to chemical changes which many minerals undergo when they are in contact with water, oxygen and other natural chemicals. Especially important are the various weak acids which can be produced as organic materials decay.

Many silicate minerals in the rocks, such as orthoclase or mica, will chemically change to form substances we would describe as “clay”.

Overall then, the mechanical and chemical weathering of many rocks results in a mixture of fine mineral particles, usually containing sand grains (quartz) and clay (weathered silicates).

Soil & Its Formation *(cont.)*

Biological Activity

"Humus" is the natural compost of dead, rotted organic material that accumulates in the soil. Dead plant material and animal wastes rot due to the action of the decomposers... the bacteria and fungi living in the soil.

As the organic matter rots it changes to become "humus" and alters the texture and colour of the soil. Nutrients needed by plants are returned to the soil. Natural acids are released which promote further weathering of the base rock, and more soil formation.

Mushrooms are the reproductive parts of soil fungi.

Leaching

As rain water percolates through the soil it can carry substances with it, especially chemicals which are soluble and dissolve in the water. This "washing away" of soluble substances is called leaching.

In some cases leaching is a good thing: it can wash away an excess of salt, or toxic ions (e.g. arsenic) which may occur naturally in the bedrock and be released into soil by the weathering of minerals.

In other cases leaching may be detrimental to soil, such as when valuable nutrients in the soil are washed away.

The syllabus requires that you collect & analyse soil samples.

Analysing the Soil

The exact nature of the soil in any area depends on many factors...

- **nature of the bedrock and its minerals**
- **temperature and rainfall of the climate**
- **the amount of time soil formation has been active**
- **amount and type of organic matter**
- **amount of leaching**

...and many others.

One way to start understanding the soils in your area is to collect soil samples and carry out simple analyses to measure moisture content, content of organic matter, amounts of major mineral components, etc.

Prac. Work: Analysis of Soil Samples

Moisture Content

1. Accurately weigh a clean, dry evaporating basin.
2. Add a soil sample and re-weigh. By difference, calculate the mass of the soil.
3. Place in a drying oven at 80-100°C and leave overnight.
4. Allow to cool, then re-weigh. By difference from starting mass, calculate the mass of water lost by evaporation. Express as % of the soil.

School Inspection only. Copying NOT permitted.

Typical Results

Mass empty basin = 32.4 g

Mass basin + soil = 38.6 g

Mass after drying = 36.8 g

Calculation

Mass of soil sample = 38.6 - 32.4 = 6.2 g

Mass of water lost by evaporation = 38.6 - 36.8 = 1.8 g

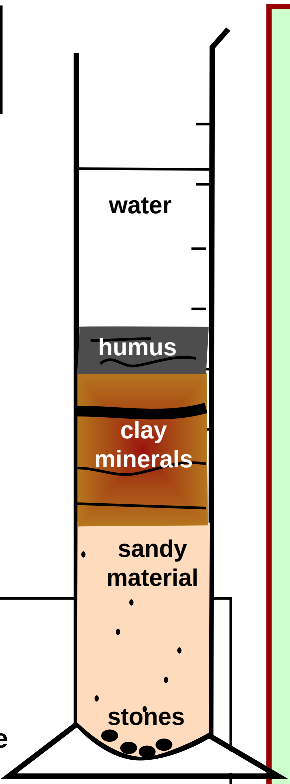
% water in soil = (1.8/6.2) x 100 = 29%

Analysing the Minerals in Soil

A simple way to analyse the proportions of major mineral categories in your soil samples is to simply mix a sample thoroughly in water (no lumps!) and pour the mixture into a large measuring cylinder. This is then allowed to settle. (May require leaving overnight)

When most of the solid material has settled, you should be able to see layers of different material, such as sand, clay & humus.

The measuring scale on the cylinder allows you to compare the relative amounts of each material in different soil samples.



Organic Content

This procedure can follow on directly from the moisture measurement and using the same (now dried) soil sample.

The sample can be placed into a very hot oven, or heated strongly over a bunsen burner in a fume cupboard.

At high temperature, the organic content of the soil burns and escapes as gases and smoke. The mineral content will not burn, and is left behind to be weighed when the equipment has cooled.

Typical Results & Calculation

Mass of basin + dried soil = 36.8 g (from expt. top left)

Mass after strong heating = 36.1 g

Mass of organic material = 36.8 - 36.1
= 0.7 g
(mass lost by strong heating)

% organic matter = (0.7/6.2) x 100 = 11%
(of original 6.2g soil sample)

(Organic matter = 16% of dried soil)

Relating Results to Bedrock

When your soil samples are collected you should take note of any nearby rock outcrops for clues about the underlying “bedrock”. You may see certain connections between your soil test results and the bedrock. For example, if the bedrock is sandstone, the soil will be very sandy. It will drain easily, so you may measure a very low moisture content. This may limit the amount of plant cover, so organic material (humus) may be low as well. In contrast, a bedrock of basalt will produce a soil with a lot of clay. This retains water, so the moisture content will be higher, given the same weather conditions. (However, be aware that some soils, such as alluvial soil in a river valley, may not relate at all to the bedrock under it. Alluvial soils are formed from minerals deposited by river floods, so the minerals are from rocks elsewhere.)

Discusssion / Activity 3

**The following activity might be for class discussion, or there may be paper copies for you to complete.
If studying independently, please use these questions to check your comprehension before moving on.**

Soils

Student Name ....

1.
a) What is "weathering" and which part of a soil does it produce?

**School Inspection only.
Copying NOT permitted.**

b) Outline the difference between "physical" and "chemical" weathering.

c) What is "humus"?

d) What is "leaching" of soil? Is it good or bad?

2. Outline the basic technique for measuring:
a) soil moisture content.

b) organic content of a soil.

3. Give an example of how the bedrock underlying the soil could have a major effect on its moisture & organic content.

3. Geological Time Scale

How do we know the age of rocks, fossils and the Earth itself?

Relative and Absolute Dating

"Relative Dating" means to determine whether one object is older, or younger, than another. Relative dating does NOT measure how old something is, but simply allows things to be placed into order of age.

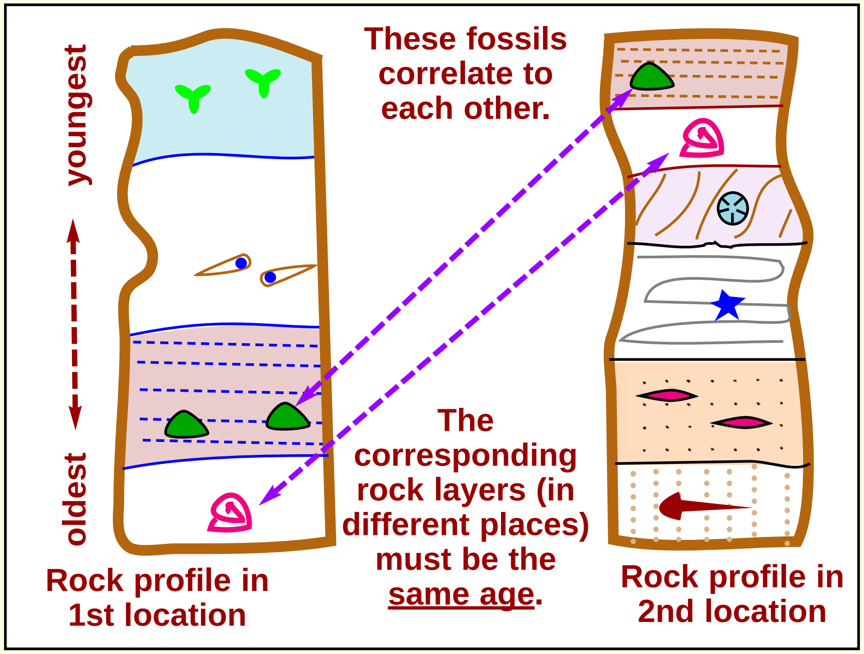
In contrast, "Absolute Dating" means the measurement of the actual age of something, in years.

Relative Dating

Relative dating arose from the study of fossils which began seriously over 200 years ago. Trained geologists & "naturalists", plus interested amateurs, began collecting fossils in huge numbers.

Almost all fossils occur in sedimentary rocks. Obviously, younger sediments always settle on top of older sediments, so the older fossils are lower down. The fossils in any profile of sedimentary rocks can be arranged in age order.

This idea can be extended further by correlating fossils from one area to another. From thousands of studies like this, scientists have built up a picture of the history of life on Earth.



These fossils correlate to each other.

The corresponding rock layers (in different places) must be the same age.

Rock profile in 1st location

Rock profile in 2nd location

Index Fossils

For the correlation between different locations, "index fossils" are vital. These are fossils of organisms which lived in many places around the world (e.g. throughout the oceans) but only flourished for a relatively short time.

They may be plants or animals, and many are microscopic plankton creatures with distinctive silica skeletons. Their remains are widespread in sediments from a particular time, and are instantly recognisable to expert palaeontologists.

The presence of an index fossil in a rock tells us immediately which part of Earth history we're looking at. Anything above that is younger, anything below is older.

Limitations

By the 20th century, this had produced a great deal of knowledge about the history of living things. However, many rocks (igneous, metamorphic) have no visible fossils, and no fossil-bearing rocks above or below them, so cannot be included in "dating".

This technique can put things in relative time order, but tells nothing about the actual age.

Absolute Dating

The Age of the Earth

We believe the Earth is 4.6 billion years old. Is that a guess?

No! It turns out that we have ways of actually measuring the age of rocks. Scientists have measured the age of many thousands of samples of Earth rock, meteorites and rocks brought back from the Apollo Missions to the Moon.

How can the age of a rock be measured?
To find out, you need to study atoms and the strange phenomenon of radioactivity.

Radioactivity

In 1896, the French scientist Henri Becquerel discovered that certain minerals, containing uranium, were emitting a mysterious, invisible radiation.

It was soon discovered that there were, in fact, 3 different radiations. They were called alpha (α), beta (β) and gamma (γ) rays. They were coming from the nucleus of atoms.

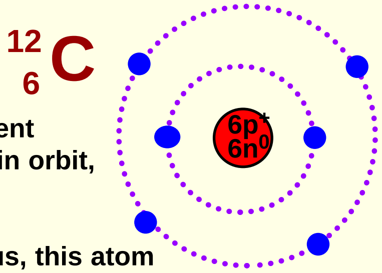
It turns out that radioactivity occurs only in atoms which have an unstable nucleus. Their nucleus is perhaps too big to hold itself together, or it has an unstable ratio of protons and neutrons.

Either way, if an atom has an unstable nucleus it will eventually “decay” and spit out energy and/or particles as it re-arranges itself into a more stable form.

Each chemical element can have a number of different isotopes... atoms of that element which have a different number of neutrons. Some isotopes are perfectly stable and do not emit any radiation. Others are unstable, and at some unpredictable time will suddenly emit a burst of radiation...

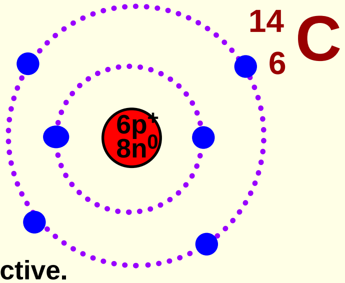
these are the “Radioisotopes”.

Radioisotopes



As an example, consider the isotopes of the element carbon. “Normal” carbon atoms have 6 electrons in orbit, with 6 protons + 6 neutrons in the nucleus.

Because there are 12 particles (total) in the nucleus, this atom is known as “carbon-12” or simply “C-12”. It is stable, and not radioactive.



There is another isotope of carbon, known as “C-14” because it has 14 particles in the nucleus.

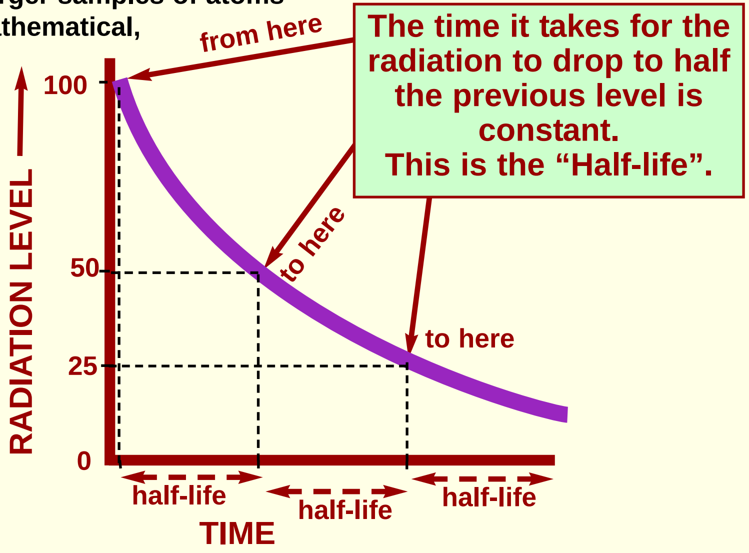
It still has 6 electrons and 6 protons (that’s what determines that it is a carbon atom), but it has an extra 2 neutrons.

The extra neutrons make C-14 unstable. It is radioactive.

“Half-Life” of a Radioisotope

Although you cannot predict when any single unstable atom might “decay” and emit radiation, larger samples of atoms always decay in a mathematical, predictable way.

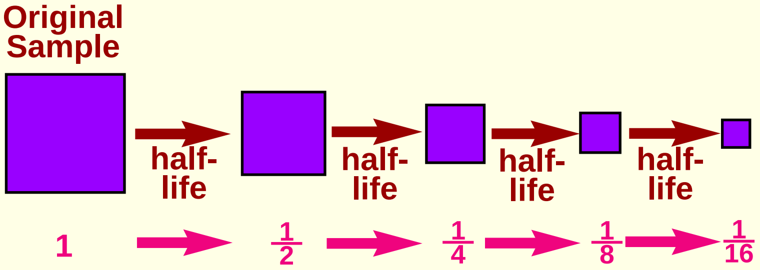
The time it takes for half of a sample of atoms to decay is always the same. We call this the “half-life”. Each radioisotope has its own fixed half-life.



The time it takes for the radiation to drop to half the previous level is constant.
This is the “Half-life”.

Half-life of Radioisotopes

To fully understand the half-life concept, and work with half-life data, you need to keep in mind this series of fractions:



As each (equal) half-life of time goes by, half of the previous sample of atoms decays. Compared to the original starting sample, the amount remaining is a fraction as shown. For example, the diagram shows that after 4 half-lives, 1/16 of the original sample remains. (Note that theoretically this series never reaches zero.)

However, please don’t think that the sample shrinks in size. The atoms are still there, and the rock (or whatever) still looks exactly the same. What declines is the amount of radiation it is emitting, because the number of radioactive atoms is getting less, as each one “decays” to a new form.

How Long are Some Half-Lives?

What is the typical half-life for some radioisotopes?
It varies enormously.

Some isotopes are so unstable that their half-life is a fraction of a second. Others have a half-life of a few days.

The isotope cobalt-60 is used in medicine and industry as a source of radiation. Its half-life is 5.3 years.

Carbon-14 has a half-life of about 5,700 years. It is used to measure the age of artifacts from human history.

The isotopes most useful for measuring the age of rocks have much longer half-lives...

Archaeologists use carbon-14 to find the age of their discoveries, such as this ancient burial site.

Example Problem

A sample containing a radioactive isotope has a radiation count of 128 units. After 12 days the radiation level has declined to 32 units.

a) What is the half-life of the isotope?
b) What radiation level would you expect after a further 18 days?

Solution

a) By halving the radiation counts:
128 ⟶ 64 ⟶ 32
you can see that 2 half-lives have gone by in 12 days. Therefore, half-life = 6 days

b) Another 18 days would be 3 more half-lives.
32 ⟶ 16 ⟶ 8 ⟶ 4
Expected radiation level = 4 units

Radioisotopes Useful to Date the Rocks

Uranium: U-235, h.l .= 704 my
U-238, h.l. = 4,500 my
U-234, h.l = 80,000 y
Potassium: K-40, h.l. = 1,300 my

Rubidium: Rb-87, h.l. = 49 my

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Radiometric Dating of the Geosphere

When a radioactive atom decays, it eventually converts itself into a different, more stable atom. Sometimes it will go through a series of decays to reach stability.

For example, when carbon-14 decays, the change is:

carbon-14 (unstable) → nitrogen-14 (stable) + radiation

Exactly how this change occurs is NOT required by the syllabus.

Isotopes of uranium decay in a series of steps to form stable atoms of lead. To measure the age of a rock containing some uranium-containing minerals, the procedure would be:

- *Measure the radiation coming from the uranium.*

This gives a measurement of how much uranium is in the rock now.

- *Measure the quantity of lead isotopes in the sample.*

(How this is done is beyond the scope of this course)
Since specific isotopes of lead are known to be formed by the decay of uranium, this allows a calculation of how much uranium was originally present when the rock was formed.

- *The half-life of the uranium isotope is already known, so the rest is calculation:*

If you know how much uranium there was to start with, and how much is present now, you can calculate how many half-lives have occurred. Since the half-life is known, the age of the rock can be determined.

Example Problem

Isotope system used to measure the age of a rock:

uranium-235 (unstable) → lead-207 (stable) + radiation

The half-life of U-235 is 704 million years.

A rock containing traces of a uranium mineral was analysed. Measurements showed 5.3 units of U-235 and 37.1 units of Pb-207 were present.

a) What was the total amount of U-235 present when the rock was formed?
b) What fraction (or %) of the original U-235 remains?
c) How many half-lives have gone by since the rock formed?
d) What is the age of the rock?

Solution

a) The Pb-207 has come from decay of U-235, so original amount was = (5.3 + 37.1) = 42.4 units

b) Fraction remaining = 5.3 / 42.4
= 0.125 = 1/8 =12.5%

c) 1 → 1/2 → 1/4 → 1/8 ∴ 3 half-lives

d) Age = 3 x 704 = 2,112 million years (2.1 billion)

The Use of Zircons to Date the Earth Itself

“Zircon” is a silicate mineral containing the rare metal zirconium. Zircon crystals seem to be almost indestructable during geological processes & can survive metamorphic change, erosion, etc. Zircon is thought to form in deep bodies of magma from near the base of the crust. Tiny zircon crystals are found mainly in felsic igneous rocks (eg granite), but then turn up in deposits of sand, and in sedimentary rocks formed after erosion of the granite. Zircons commonly contain traces of uranium, so their age can be determined by radiometric dating.


Zircons separated from a sand deposit.
The 1 cent coin gives an idea of size.

Because they survive just about everything in the rock cycle, some zircons are very ancient & were formed soon after planet Earth formed & solidified. The current record for the oldest zircons dated by their uranium isotopes is 4.4 billion years! The zircons were found in sedimentary rocks in Western Australia which are “only” about 3 billion years old. We think the zircons eroded out of an ancient granite formed soon after the formation of the Earth.

Examples of the original rocks formed in the early Earth have not yet been discovered. Perhaps they are all gone... destroyed & re-cycled by the rock cycle. However, some of the zircons have survived to tell us their age.

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Discusssion / Activity 4

**The following activity might be for class discussion, or there may be paper copies for you to complete.
If studying independently, please use these questions to check your comprehension before moving on.**

Radiometric Dating

Student Name ....

1. List the 3 types of radiation associated with “radioactivity”.

2.
a) What are isotopes?

b) What is a radioisotope?

c) What is meant by the “half-life” of a radioisotope?

3. Outline the basic technique of radiometric dating.

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4. Geological Resources

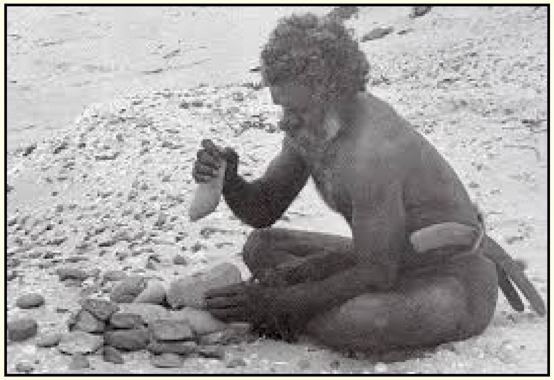
About 100 years ago, it was said that "Australia rides on the sheep's back", meaning that the wool industry was vitally important to our nation's economy. In more recent times, the Mining Industry has taken over as a major component of the Australian economy. Whether this is ultimately a good thing, or a disaster, remains to be seen.

Your task is to learn enough Earth & Environmental Science to be able to make <u>informed decisions</u> on such matters!

Aboriginal Mining Methods

Before European contact, the culture of indigenous Australians was basically "Stone-Age". Rocks & minerals were important, but the methods used to obtain the raw materials were very basic & simple.

There is archaeological evidence of the mining methods & sites. In some cases, the members of local cultural groups still retain the knowledge of where to collect rock & mineral resources. This knowledge has been passed down through the generations for thousands of years.



Where deposits of useful rocks or ochre occurred, they belonged to the custodians of that area. Other tribal groups could use them only with the permission of the custodians.

Mining was simply a matter of shallow digging, scraping or hammering of surface outcrops to collect useful sized lumps of material.

These were often roughly shaped immediately before being carried away. Final shaping / sharpening / grinding was done later. There is evidence that some useful stones were moved 500 km or more from their mining site. This suggests that a system of trade existed for those types of rock or mineral which were particularly prized.

Renewable, Non-Renewable, Sustainable

A <u>renewable resource</u> is something we need which can be replaced within a convenient time. Water is an important resource we need. It is renewable because the natural weather cycles bring rain to re-fill rivers and dams.

Wool & cotton are resources we use for clothing, carpets, furnishings, etc. These are renewable because we can grow the plants and animals they come from.

A <u>non-renewable resource</u> is something we need, or use, which CANNOT be replaced within any reasonable time.

Petroleum is used to make fuels such as petrol & diesel and to make some useful substances such as plastics. Petroleum is non-renewable, because it took <u>millions of years</u> to form. Once it is used, it cannot be replaced in any reasonable time.

Other non-renewable resources include coal and all the metal ores, such as iron ore or bauxite. In fact, all of the geological resources which are so important to our economy are non-renewable.

"<u>Sustainable</u>" refers to resources which can continue to be exploited basically forever. A renewable resource (such as water) is not necessarily sustainable if it is used at a rate faster than the rains can replenish supplies. Ocean fisheries are not sustainable if the catch rate is higher than the breeding rate of the fish.

Conversely, the use of a non-renewable resource is not necessarily unsustainable. For example, the rate at which the Aboriginies used mineral resources was sustainable (at least for some millions of years). Although the resources are non-renewable, the rate of usage was so small that it was sustainable.

Australia's Geological Resources

The Range of Resources

Australia is one of the world's largest suppliers of mineral resources.

Resource	**Australia's World Ranking** (as of 2015)
Iron ore	2nd
Bauxite (aluminium)	1st
Copper	5th
Gold	2nd
Silver	4th
Uranium	3rd
Diamonds	3rd
Coal	4th (1st in export amounts)
Petroleum	29th
Natural gas	3rd

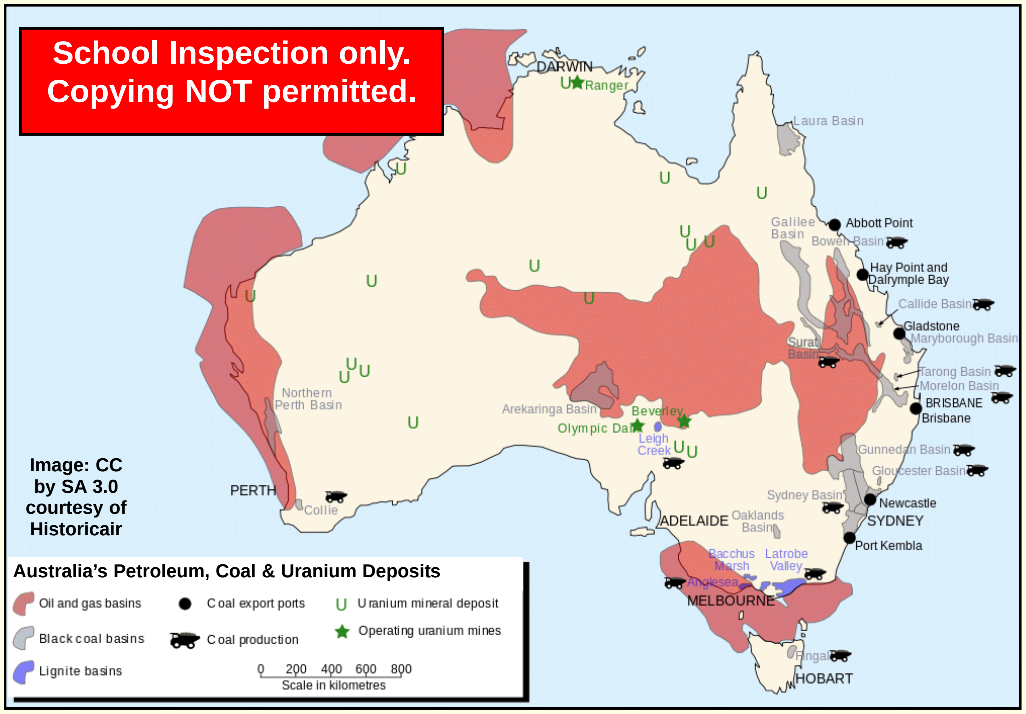
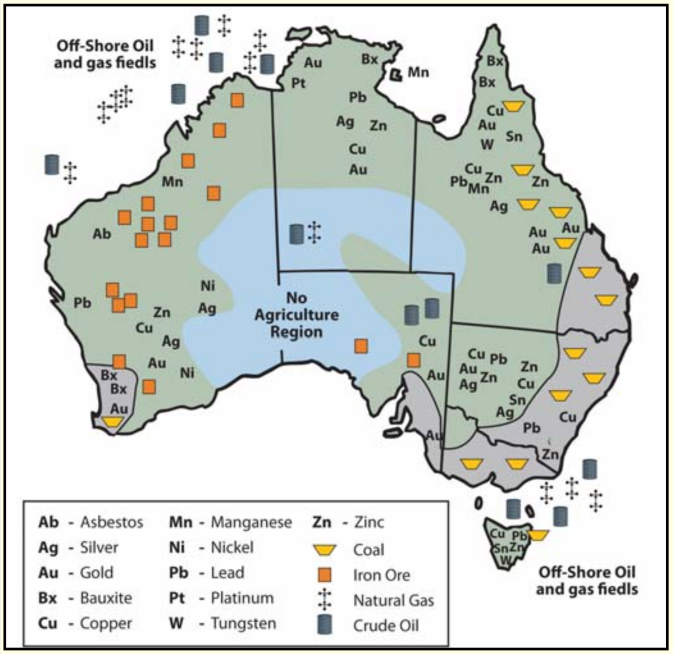


Image: CC by SA 3.0 courtesy of Historicair

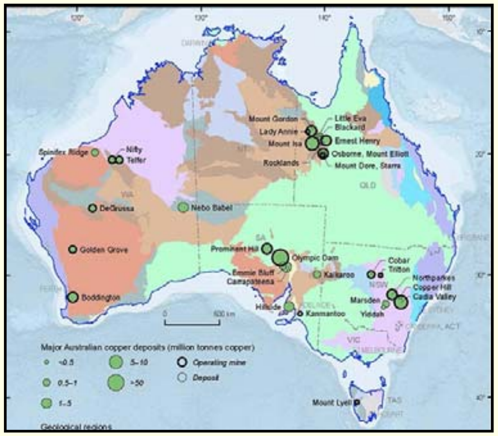
Where are Australia's Resource Deposits?



It is clear from the map at left that mineral deposits occur pretty-much all over the continent.

WA & QLD are the largest mining states.

Broken Hill (NSW) & Mt.Isa (QLD) are the best known mining towns.



The map above shows energy-related resource deposits. Australia's petroleum deposits are not huge; most of the red-shade areas above are natural gas fields.

At left is a map of copper deposits & mines. Other metals mined in large quantities in Aust. include the ores of iron, aluminium, zinc, lead, tin, gold, silver & nickel.

Important minerals include diamonds & opals.

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Australia’s Geological Resources (cont.)

Economic Importance

Australia’s economy is one of the largest (per person) in the world. An economy is commonly measured by the “Gross Domestic Product” (GDP). In simple terms, GDP refers to the total economic “turnover” per year. In 2015, Australia’s GDP was $1.6 trillion, or roughly $64,000 per person on average.

Geological resources are vital components of our economy, although this is often over-stated by politicians & the mass-media. From TV news & interviews, you would be forgiven for thinking that the mining industry and the export of coal, iron ore & natural gas are the biggest items in our total economy.

In fact, according the Aust. Bureau of Statistics, the mining industry (including support services) totals only about 8% of GDP. The largest sector of our economy is the “Services Sector” which accounts for about 70% of GDP. This includes government services, education, health services, communications, financial services (such as banking), construction, entertainment and many other industries.


Underground Coal Mining

Although geological resource mining is a relatively small part of GDP, it is far more important to the economy than the GDP story alone suggests. Exports of iron ore, coal & other mineral resources make up a large part of Australia’s international trade & economic growth.

This makes our economy somewhat vulnerable & dependent on other countries which buy our resources. If their economies slow down or decline (as has happened in recent years) it has large impacts on our mining industries. Mining companies pay large taxes & “royalties” to State & Federal Governments. Falling export prices for (say) iron ore not only cause mining companies to suffer & employ fewer workers, but governments then struggle to pay for education, pensions, hospitals, etc., because they receive less revenue from the mining companies.

There is also the matter of sustainability. Geological resources are, of course, non-renewable. At current rates of extraction, many resources are also NOT sustainable. It is estimated that our huge iron ore deposits will be mostly gone by 2050. Coal could last a lot longer, but coal’s sustainability is called into question by its environmental impacts as a proven major contributor to Global Warming.

Overall, Australia walks an economic & environmental tight-rope. The nature of modern politics tends towards short-term gains & popular, vote-getting policies rather than long-term planning for sustainability for future generations of citizens. By choosing to study this subject you have put yourself in a position to learn about many things that are important to both our economic and environmental futures. Learn well!

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Discovering New Resources

In the "old days", mineral resources were often discovered by accident, or by prospectors wandering in the wilderness, chipping rock outcrops with a hammer, or panning for gold in creeks & hoping to "strike it rich". This image may be largely an urban myth, but it is certainly a long way from the modern methods of discovering new mineral resources.

Aerial Photography

Perhaps the first modern technology to enhance the exploration for geological resources was taking photos from the air. This allowed surveying & mapping to be done rapidly & faster than laborious on-ground methods. Geological features could be identified for later examination & sample-taking.

Image by Eduard Spelterini

This photo was taken from a balloon over 100 years ago.

Can you guess where?

A photo taken for geological survey helps identify hills, rock-outcrops, drainage patterns, possible surface rock types, location of fault-lines, etc. These features give clues to possible underlying rocks & minerals, at least as far as helping to decide where to send a team in on the ground to collect specimens or drill for core samples.

Satellite Imaging

Image courtesy NASA

A logical extension from aerial photography was to collect images from space. The photo shows the satellite "Landsat-7" being prepared for launch about 20 years ago. The "Landsat" series of satellites have been perhaps the most important & useful for mapping & exploration since the beginning of the "Space Age".

Landsat data is useful for not only mineral exploration, but for environmental studies of forest, water resources, arctic ice conditions, urban planning, and much more.

As well as simply mapping the world in great detail, satellites are equipped with cameras which "see" in narrow wavelengths, including infra-red. This allows different types of soils, rocks, vegetation, temperatures, etc., to be identified.

The lower photo shows an infra-red image of an urban area. The colours are false, but show different temperature areas. This could help urban planning, or even criminal investigation. In geology this could detect deep volcanic activity.

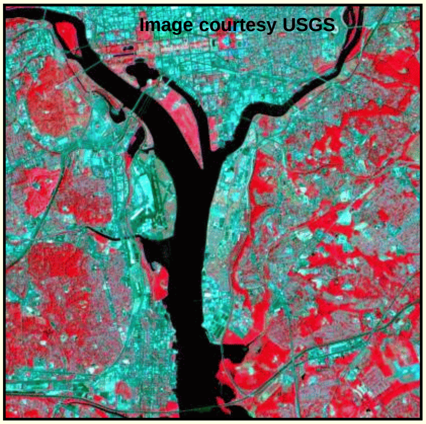

Image courtesy USGS

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Discovering New Resources (cont.)

Geophysical Data

Modern technologies for locating new resources include:

Magnetic Techniques

The use of a magnetic compass for navigation has been done for centuries. In the 19th century, it was discovered that the Earth's magnetism is not uniform, but varies in strength & direction from place to place.

Originally developed for war (eg submarine warfare) we now have a variety of very sensitive magnetometers which can detect tiny variations in magnetic field strength. Instruments can be used on the ground in a backpack, or flown in aircraft, towed behind a ship or deployed in space by satellite.


Image: CC by SA 3.0
courtesy of YSSY
at Wikipedia

The plane shown has long nose-boom with a magnetometer at the tip, for geological survey from the air.

Bodies of rock containing certain minerals, even if deep under the surface, can affect the magnetometer. Lines of magnetic anomaly can identify seams of minerals, or fault lines, or intrusions of volcanic rock.

Magnetometry is useful not only for mineral exploration, but has become an important tool in achaeology to discover ancient building sites even when absolutely nothing is left of the structures.

Gravitational Measurements

Not only does the Earth's magnetic field vary, but so does the force of gravity. It can be influenced by bodies of rock with different densities. Tiny variations in the strength of gravity can be measured by an instrument called a "gravimeter" and help locate bodies of useful minerals.

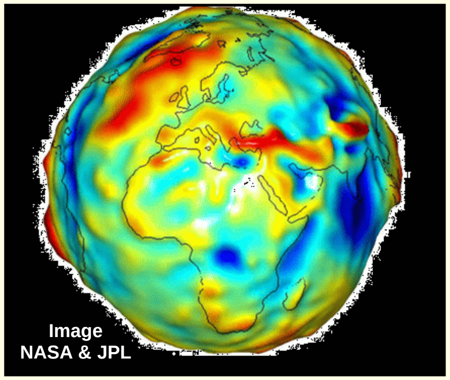
Image
NASA & JPL

This gravimeter image, obtained by satellite, shows whole-Earth gravity variations in different colours.

Seismic Methods

There are also a host of different measurement techniques which measure the reflections, or refractions, or scattering of shock waves passing through the rock of a local area. Rather than wait for a convenient earthquake, these techniques rely on detonating small explosive charges & studying the shock waves.

These methods are particularly useful for imaging the underlying rock layers & fault lines. This often gives important clues for locating bodies of petroleum or natural gas because oil & gas tends to collect under rock layers of a particular shape or arrangement

All of these discovery methods can help geologists to find possible deposits of geological resources, but cannot definitely identify them. The next step is usually to send in a team to carry out test drilling & collecting samples for chemical analysis, microscopic examination to identify minerals, etc.

Extracting the Resources

Just because a new deposit of a geological resource has been discovered, this does not automatically mean that it will be mined. The decision to mine, or not, depends on many factors, such as the quality of the ore, the demand & price for that commodity, the location of the resource with regard to access & transport systems, labour and the location of necessary processing plants. However, if the decision is taken to begin mining, there are various methods available:

Drilling

Extraction of petroleum or natural gas is usually done by drilling a pipe down into the resource. Originally, drill-rigs were all on land, but new technologies of (firstly) discovering the oil and (secondly) to drill under the sea-bed, have resulted in many offshore platforms.


Offshore oil drilling platform

A relatively recent technique, called "fracking", is used mainly for extracting coal-seam gas (CSG). A pipe is drilled into the porous rock containing the gas, then high-pressure water & chemicals are pumped down until the rock fractures & cracks. This allows the gas to flow to the extraction pipeline more readily & efficiently.

Surface (Pit or Open-Cut) Mining

For solid minerals which are relatively close to the surface and spread out over large areas, the usual mining method is "open-cut mining". Surface layers of soil & rock are removed, then the resource is simply extracted by cutting, scraping, bucket excavators, etc., often after loosening with explosives if necessary.


Open-cut coal mining

This method is commonly used for mining coal & tar-sands.

In Australia, it is also used for the extraction of low-yield gold ores, and for iron ore in the wide-open spaces of WA.

Underground Mining

If the mineral resource is deep underground, mining is usually achieved by shafts & tunnels. The deepest Australian mine is almost 2km deep at Mt.Isa, QLD. At Broken Hill, the main mine tunnel spirals down to the ore body, so that motorised equipment can drive up & down without requiring a vertical shaft & lift.

In some cases, tunnels can follow the ore seams horizontally into the side of a mountain. However, in many cases a vertical shaft is needed, with elevators to move workers, equipment & ore between surface & mining tunnels.


Typical underground mine tunnel

Image: CC by SA 4.0 by Kaupo Kikkas

The mining tunnels can radiate from the shaft at various levels & in all directions, often for several kilometers.

Coal mining often involves "long-wall" & "gallery" mining rather than tunneling. This means that wide-area "rooms" are excavated for the coal, rather than simple tunnels. Regular columns of rock must be left in place to prevent roof collapse. Alternatively, supporting pillars & beams of steel & concrete are used for support. (But this is expensive)