SPOTLIGHT

NSW

MODULES 1 and 4

Earth and Environmental Science

• David Heffernan • Rob Mahon •

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Chapter vocabulary links

At the start of each chapter a QR link to a vocabulary list for that chapter has been included. These take the user to a Quizlet study set, which allows students to interact with the new vocabulary for this chapter in a variety of ways. At the top of the study set are a number of tabs to select from. These are explained below.

Note: Students can study either the full set of terms or they can select specific words to revise by selecting the star symbol next to each term.

Flashcards: The ideal starting point when being introduced to new terminology. The definition is shown and the student tries to guess the correct word (which is revealed by clicking/tapping on the card). Note that you can customise the settings to suit yourself.

Learn: Once you have been introduced to the terminology, practise typing in the terms when prompted. This helps with improving your spelling of these terms.

Match and gravity: These are single player games that challenge your recall of the terminology in different ways.

Live: This is an online team game using the vocabulary. Watch the introductory video, then play this during class.

Test: This is by far the most valuable interactive feature of Quizlet. This will autogenerate a test in a variety of question styles. You can include all terms or only the terms you select. It will then correct your answers and provide feedback. *Note:* The most valuable learning will come from from studying the terms you answered incorrectly, then immediately generate another test. You can keep doing this until you regularly score 100% in these tests.

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Contents

Words to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Chapter 1

STRUCTURE OF THE EARTH, THE EARLY GEOSPHERE, ATMOSPHERE AND HYDROSPHERE

Figure 1.1 The universe Formed as a result of the big bang.(NASA)

1.1 Formation of the Earth

Investigate and model the processes that formed the geosphere (ACSES018), atmosphere (ACSES022) and hydrosphere (ACSES023)

In the aeons after the **Big Bang**, as the universe as the universe was flying apart, stars formed and clumped together into galaxies due to their combined gravitational force. In the outer arms of the Milky Way galaxy were massive clouds of gas and dust (which we can still see today; Figure 1.1). Much of this matter is hydrogen that formed during the early universe, while some of it is heavier elements formed in the cores of earlier giant stars which have long since exploded and been scattered. These include carbon, oxygen, silicon and iron. It was in a dust cloud such as this that our solar system began to form.

The protoplanetary disc

For some reason, perhaps due to a shock wave resulting from a nearby supernova, an area of dust and gas measuring light years across began to contract. Within this **protoplanetary disc**, fine particles began to clump together and the whole cloud began to rotate at a faster rate (Figure 1.2). Eventually, most of the material was located in a central sphere with a wide disc of material extending around its equator.

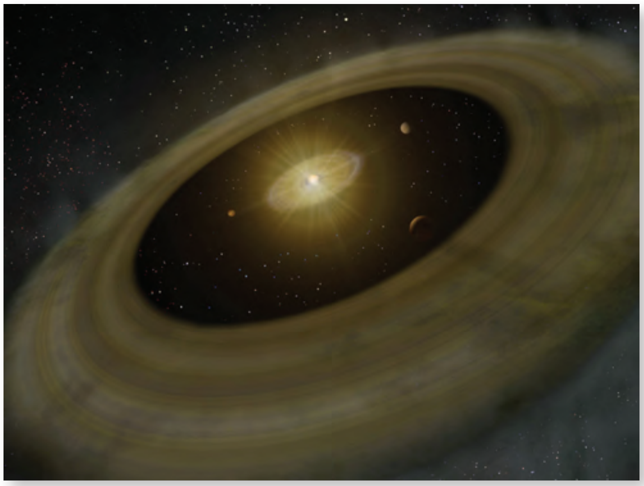


Figure 1.2 Protoplanetary disc (a) An artist's impression of a protoplanetary disc. The centre region eventually ignites as a true star while the surrounding disk of debris forms the protoplanets. (NAO) (b) A protoplanetary disc as seen through the Hubble space telescope. The light coloured background is the Orion Nebula.(NASA)

ACTIVITY 1.1 EXPERIMENT: ICE SKATING AND THE FORMATION OF THE SOLAR SYSTEM

What does ice skating have in common with the formation of the solar system? Both are good examples of what is known as the conservation of angular momentum. In both cases, as widespread arms are pulled toward the centre of a rotating body, the speed of rotation changes.

To simulate the change in rotational speed of the solar system as it contracted.

Aim:

As the arms of a rotating object pull in, the object will….*(select one)*

- Rotate slower.
- Rotate faster.
- Rotate at the same rate

Adding mass to the arms as they are pulled in will… *(select one)*

- Magnify the effect.
- Reduce the effect.
- Have no influence on the effect

Apparatus

1 × swivel chair

2 × 2kg masses or similar (e.g. bricks).

Risk assessment: Low. Remove obstacles within 2 m of chair. To avoid motion sickness, change students or alternate the direction you spin each time.

Method:

1. Have one student sit on the swivel chair with arms and legs pointing out parallel to the floor.
2. Spin them firmly. After a few spins the student should then pull their arms and legs inwards back towards their body. Describe what happens. If unsure, try it yourself or ask the student in the chair to describe what they felt.
3. Repeat the experiment at a slower speed. Does the same thing happen?
4. Repeat the experiment, but this time begin with arms and legs pulled in at the start and extend them outwards after a few spins. Record what happens.
5. Repeat the experiment (both pulling in and extending out) while holding masses in your hands. Record whether or not this affects the result.
6. Which causes the greatest change to the rate of spin; pulling in your arms or pulling in your legs? Infer a reason for this difference and test your hypothesis. Write this up as a separate practical report.
7. Search the internet for video of the world record figure skating spin. Who holds the record, how fast did they spin and what they did with their arms and free leg to achieve it?
8. Whilst on YouTube, search for the best short video you can find which illustrates the formation of the solar system. Save this to your files.

Due to the huge internal pressures caused by its collapse, the central protoplanetary sphere became very hot and glowed dimly, forming a **protostar**. Debris within the disc around the protostar gathered into numerous large clumps or **protoplanets** by the process of **accretion** — the gathering together of small bodies into larger ones by gravity (Figure 1.3). Accretion is the underlying process responsible for the initial formation of the solar system and the associated changes that occurred. These protoplanets numbered in the hundreds if not thousands. They would ‘vacuum’ up and concentrate most of the dust in the disc surrounding the protostar that was to become our Sun.

Gravitational squeezing caused temperatures and pressures within the protostar to increase to enormous levels. When pressure and temperature reached the critical temperature of tens of millions of degrees, hydrogen atoms – the most abundant component of the protostar – began to fuse together to make helium atoms. This **nuclear fusion reaction** releases huge amounts of energy in the process. It follows Einstein’s famous equation $\mathbf{E = mc^2}$. This equation states that energy (E) = mass (m) multiplied by the speed of light squared (c^2). The speed of light squared is a huge number, so in effect this equation means that even small amounts of matter can be converted into very large amounts of energy. As it undergoes constant nuclear fusion reactions our Sun loses 4 tonnes in mass every second!

When fusion reactions started, the protostar ignited like a massive and sustained nuclear bomb, becoming a **true star**. Further collapse was prevented by these nuclear fusion reactions in the core of the Sun pushing outwards against gravity. The ignition of our Sun blew away much of the surrounding material, including most of the gases around the inner planets. This is why the inner planets of our solar systems are small and rocky while the outer planets are gas giants (they were far enough away from the Sun to avoid being blasted so strongly). The ignition of fusion reactions within the Sun marks the moment of ‘birth’ for our entire solar system, and it occurred around 4.6 billion years ago.

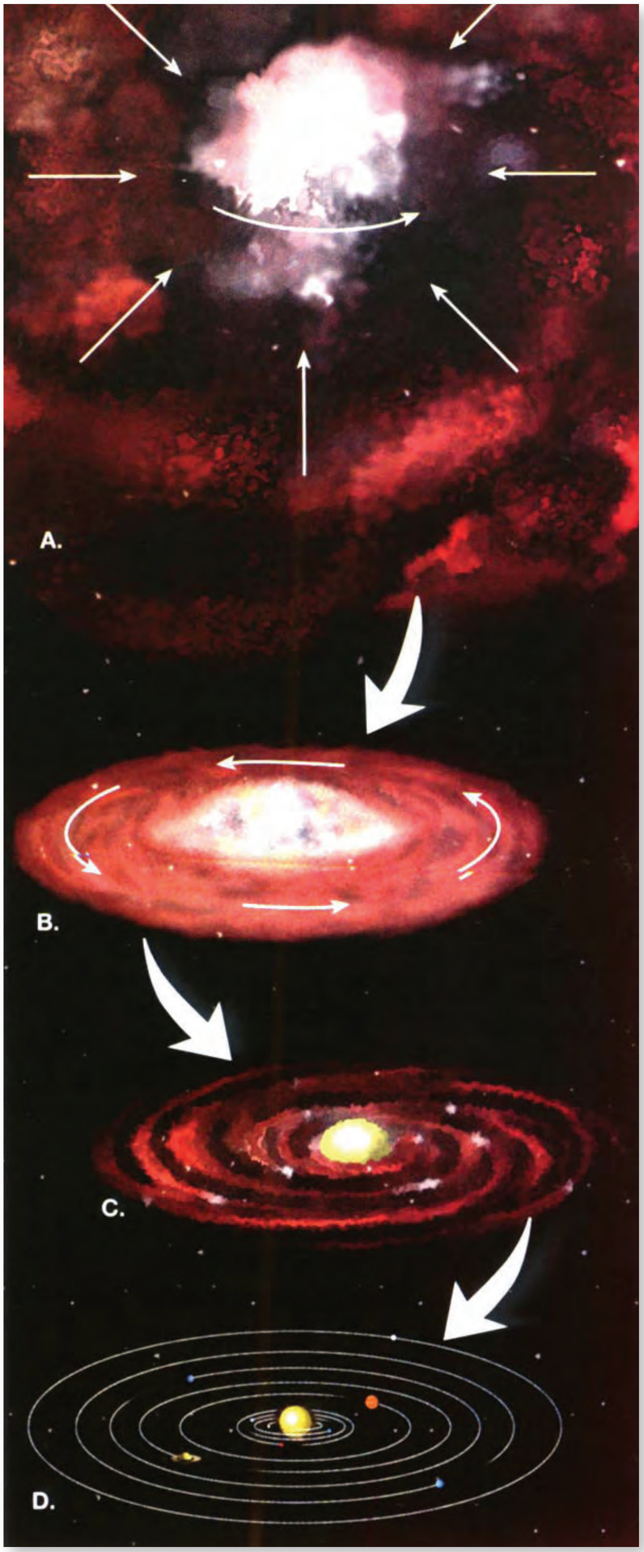


Figure 1.3 Formation of the solar system The Earth and other planets are the result of the accretion of dust and gases orbiting the sun.

The formation of the Earth

Even though the planets were forming by accretion of dust particles at the same time as the Sun was forming, it would be a mistake to think that the planets were 'born' as we know them today at the same time as the Sun exploded to life. The infant solar system would have contained hundreds of small protoplanets with overlapping orbits. At this time the solar system would have resembled a giant smash-up derby.

These protoplanets would have been constantly bombarded with meteorites as they swept into each other or cleared their orbits free of debris. This bombardment increased each planet's size and mass. In the case of the rocky planets such as our own Earth, it also heated its rocks to melting point. The gases released from these molten rocks would form Earth's first atmosphere. Below the surface, heavier metallic elements sank deep into the liquid Earth, while the lighter elements floated at the surface like volcanic froth.

Eventually, the planets as we know them today where the 'winners' of the protoplanetary smash-up derby. As the planets settled into stable orbits and swept the space around them free of debris, they experienced decreasing meteorite impacts and began to cool.

ACTIVITY 1.2
HAPPY BIRTHDAY EARTH!

18th birthdays are a special occasion in our society. They mark the transition from the age of childhood to the age of adulthood. They are often accompanied with embarrassing childhood photos or videos and speeches remembering the key moments of the person's life to date.

You are to organize a presentation of the key events (described previously in this chapter) which led to the formation of a solid Earth with land and ocean. It should include pictures with descriptions, stories or anecdotes (either written or spoken). Don't just restate the science content as told in this text. Deliver your story as though the Earth is your best friend and that you are doing a slideshow at Earth's 18th birthday party.

The formation of the Moon

Our moon is believed to have been born out of one colossal impact between the Earth and another protoplanet the size of Mars (Figure 1.4). Huge amounts of debris exploded into space; much of it falling back to Earth and some of it coalescing to form the moon. This theory accounts for the fact that moon rocks seem to have formed 100 million years after the Earth did. It also explains the fact that although moon rocks have a similar chemical composition to Earth rocks, they are deficient in iron. If the Mars-sized meteorite hit the Earth with an off centre blow, Earth's core (where most of the heavy molten iron had accumulated) would have remained intact.

Figure 1.4 Formation of the Moon Artist's impression of the collision that led to the formation of our moon.(NASA).

ACTIVITY 1.3
THE MAKING OF THE MOON

Search online for an animation, applet or video on the formation of the moon. Save screenshots to show a sequence of steps starting with 'Earth and protoplanet on collision course' and ending with 'Moon fully formed and in orbit around Earth'.

How the atmosphere formed

The majority of life forms on Earth today have evolved to be well adapted to the current atmosphere, specifically to the high levels of oxygen. However if oxygen-loving organisms, such as humans, were exposed to the Earth's *original* atmosphere, they would die quickly (Figure 1.5). This would be the result of not only a lack of oxygen but also high concentrations of poisonous gases, like ammonia and carbon monoxide.

Earth's original atmosphere

The original source of the gases that made up Earth's original atmosphere was the planet itself. The process is called **outgassing**. The molten rocks of the young, hot Earth released a mixture of gases, just as volcanoes still do today. Some of these gases remain in the atmosphere to this day; others were quickly removed by a variety of processes. While their relative proportions are uncertain, the main gases of the original atmosphere seem to have been nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O).

Figure 1.5 Life on Earth Current life-forms like whale could not survive in the Earth's original atmosphere.

Earth's current atmosphere

Careful measurement and chemical analysis have allowed scientists to determine the proportions of gases that make up the atmosphere. Those for dry air are found in Table 1.1. Water vapour, which is not listed with the others because of its variability, ranges between 0.1 and 3 per cent.

Figure 1.6 Limestone This limestone was formed in ancient sees.

Where did the original atmospheric gases go?

- **Nitrogen** Most of the original atmospheric nitrogen remains in the air to this day because it is unreactive, although some of it cycles through the biosphere as part of the nitrogen cycle.
- **Carbon monoxide** and **carbon dioxide** The early atmosphere contained 100 to 1000 times as much carbon dioxide as it does now. These gases were mostly combined with calcium and magnesium dissolved in seawater, creating insoluble carbonate sediments that formed carbonate rocks, such as limestone (Figure 1.6). High levels of carbon dioxide early on might have acted as a greenhouse blanket for the Earth while the young Sun was much weaker than it currently is.
- **Hydrogen** Being so light, hydrogen vented from molten rocks was lost into space.
- **Water vapour** As the Earth cooled after its formation, most of this water vapour condensed and fell as rain, filling the ocean basins.
- **Methane** A reaction between methane and oxygen produces carbon dioxide and water. Trace amounts of oxygen would have been produced as intense ultraviolet rays split atmospheric molecules apart.

Table 1.1 Atmospheric chemistry.

Gas	Formula	Proportion
Nitrogen	N_2	78.1%
Oxygen	O_2	20.9%
Argon	Ar	0.93%
Carbon dioxide	CO_2	0.034% (increasing)
Others	Ne, He, CH_4	0.036%

Where did the current atmospheric gases come from?

- **Nitrogen** remains from the original atmosphere.
- **Oxygen** was produced as 'waste' during photosynthesis by green plants. At high altitudes, ultraviolet rays split oxygen molecules, forming ozone (O_3). This ozone layer blocks most of the sun's damaging ultraviolet rays, making life on land possible.
- **Argon** is an inert gas formed by the radioactive decay of some elements within the mantle. It is then released as a volcanic gas.
- **Carbon dioxide** is added to the air by volcanic eruptions, the weathering of carbonate rocks and the respiration of living things. It is also removed by a variety of processes and cycled throughout the lithosphere, hydrosphere and biosphere as well as the atmosphere.
- **Water vapour** Water is continually being cycled throughout the lithosphere, hydrosphere and biosphere, as well as the atmosphere. Most of the water on Earth today was vented from molten rocks, with meteorites providing additional quantities.

ACTIVITY 1.4
CHANGING ATMOSPHERE

1. Compare the composition of the Earth's original and current atmospheres.
   Note: *Compare* means to discuss similarities and differences.

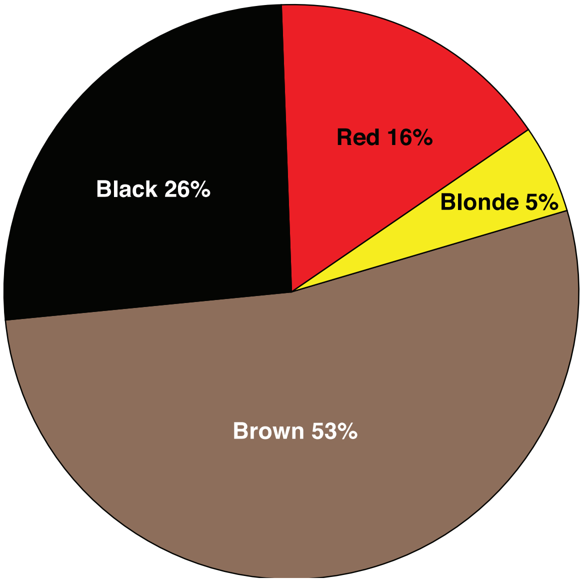


Figure 1.7 Pie charts The percentage of students with various hair colours is represented as segments of a circle.

2. Construct a pie chart to show the proportions of gases in today's atmosphere. Figure 1.7 is provided as an example. Pie charts represent portions of a whole as segments of a circle, like slices of a pie. To convert a percentage (out of 100 per cent) into an angle of a circle (out of 360 degrees), simply multiply the percentage by 3.6. For example, how much of the pie chart should 50 per cent take up? The answer is $50 \times 3.6 = 180$ degrees, or half the pie chart.

Origin of Earth's water

Scientists still do not know for sure the origins of water on the Earth (Figure 1.8). There are a number of possibilities. One involves icy bodies from space. Studies of asteroids show that some contain water. Perhaps in the early stages of the formation of the Earth, water arrived as these bodies bombarded the surface.

Another possibility is volcanic outgassing. We know that present-day volcanoes produce large amounts of water. After the Earth cooled enough for the abundant water vapour in the atmosphere (released from the molten rock) to condense and form thick clouds. Rain fell heavily (probably for many decades) and continued until oceans covered the low-lying areas and most of the planet's surface.

Figure 1.8 Planet water How did we get the oceans around us.

SCIENCE SKILLS

1. ***Identify*** means *to recognise and name*. You may need to recognise an image or a verbal statement. For example, **identify** the source of water produced by the Earth.

   Answer:

   Water was produced during volcanic eruptions of the early Earth.

2. ***Describe*** means to *provide characteristics and features*. Be as thorough as the word limit will allow, making sure you concentrate on the most important points. You do not have to explain or interpret. For example, **describe** the origin of argon that we find in the Earth's atmosphere.

   Answer:

   Argon is an inert gas formed by the radioactive decay of some elements within the Earth's mantle. It is then released during volcanic eruptions.

3. ***Explain*** means to *relate cause and effect; to make the relationships between things evident; to provide why and/or how*. You need to clarify and interpret the material you present. Where appropriate, give reasons for differences of opinions or results, and try to analyse causes. For example, **explain** the role of gravity in the formation of the Earth.

   Answer:

   Gravity has two roles in the formation of the Earth. Firstly, gravity is important in the accretion of matter during the formation of the solar system. A disc of matter gathers around the protosun. Matter in this disc forms into clumps that grow to become a protoplanet. Meteorite bombardment helps increase the new planet's size as well as heating the rocks to melting point. This releases gases from rocks that would form the first atmosphere.

   Secondly, gravity then causes heavier metallic elements sink deep into the liquid Earth, while lighter elements floated at the surface. This early differentiation of material within the Earth is preserved in its layered internal structure.

4. ***Outline*** means sketch in general terms, indicate the main features of something. You emphasise the structure or arrangement, omitting minor details. Outlines are often in point form. For example, *outline* the origin in the oceans.

   Answer:

   - The source of the oceans is not completely understood.
   - Some may have come from meteorites that bombarded the early Earth.
   - Some may have come from outgassing as water vapour is produced during volcanic eruptions.

TO THINK ABOUT

Set 1

1. **Explain** the role of supernovae in the formation of a protoplanetary disc.
2. **Describe** the formation of a protostar.
3. **Outline** the role of accretion in the formation of protoplanets.
4. **Describe** the source of energy in a star.
5. **Describe** the transition of a protostar to a true star.

Set 2

6. **Outline** the stages in the formation of the Earth.
7. **Describe** the formation of the Moon.
8. **Describe** what happens during a smash-up-derby. **Explain** how this provides an analogy for the formation of the planets.
9. **Explain** the origins of the atmosphere.
10. **Identify** a gas present in the Earth's original atmosphere but no-longer present. **Explain** where this gas has gone.

1.2 Investigating the structure of the Earth

Investigate evidences for the structure of the Earth using technologies, including:

- Seismic wave velocities
- Meteorite evidence to demonstrate differences in density and composition (ACSES009, ACSES018)

Conduct a practical investigation to compare the differences in the density of representative rock samples found in the crust, mantle and core (ACSES003)

'My soul can find no staircase to Heaven unless it be through Earth's loveliness.'

Michelangelo: Renaissance Artist

'It suddenly struck me that that tiny pea, pretty and blue, was the Earth. I put up my thumb and shut one eye, and my thumb blotted out the planet Earth. I didn't feel like a giant. I felt very, very small.'

Neil Armstrong: Astronaut

Figure 1.9 Earth from space What is inside our Earth? (NASA)

Working out what is in the heavens around us is relatively easy. Space is empty, and we can therefore see through it and even travel through it with relative ease. The Earth is not empty or hollow; it is full of rock and minerals and mysteries. It is a strange fact that we know more details about the galaxy spreading for light years around us than we do about what lies a few dozen kilometres below our feet. Space offers us boundless opportunities to observe and measure data to inform our theories about what processes are shaping the universe.

In contrast, humans have never succeeded in digging through the thin surface crust of the Earth. We have relied on weak spots and gaps in this crust that allow us to catch an occasional glimpse of what lies beneath. An alien world of magma and movement that appears to be totally removed from our experience of conditions on the surface.

It's what's inside that matters

Most primary school students can recall the fact that the Earth has a layered internal structure. The obvious question is … how do we know this if we have never been there?

ACTIVITY 1.5
THE EARTH REVEALED

This group activity is designed to give you a clearer perspective of the internal layered structure of Earth. It also gives you practice in scale drawing. Your group is to calculate the measurements needed to draw an accurate scale drawing of the Earth's internal structure. Your wedge-shaped diagram will represent a segment of the Earth from the centre of the core to the crust.

Apparatus

- Sheet of butcher's paper at least 1.2m long
- String 1.2 m long
- Pencil
- Coloured textas/ chalk/ crayons
- Sticky tape
- 1 m ruler

Risk assessment: Low.

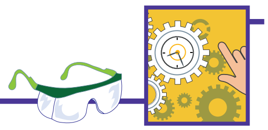
Method

1. Make a dot at the bottom centre of a cut/torn edge of the butcher's paper. This will represent the centre of the Earth and it is the reference point that your measurements are to be made from.
2. Use the metre ruler to draw angled lines exactly 1m long forming a large 'V' (the dot is at the base).
3. Use the data in Table 1.2 to mark the distances from the centre of the Earth that each layer starts/finishes. For example, make a mark 195 mm up each line to mark the boundary between the inner and outer core. Mark these exact distances on each line of your 'V'.
4. To join the measurements on each side with a smooth curve, tape one end of your string to your pencil (near the tip) and fix the other to the bottom of your V. Adjust the string to the correct length, pull tight and swing the pencil across the diagram.
5. The height of the International Space Station (ISS) orbit has been included to give a perspective of scale in this diagram.
6. Use colours to identify your different layers. Select colours that indicate cool for the crust, hot for the mantle and increasingly hot for deeper layers.
7. Add labels and the temperatures of each layer (research). Once you finish Activity 1.12 include the densities you calculated for each layer to this poster

Table 1.2 Earth structure.

Layer	Thickness (km)	String Length for a 1 metre radius scale drawing (mm)
Inner Core	1250	195
Outer Core	2200	539
Mantle	2900	992
Lithosphere	50 (av.)	1000
Space Station Orbit	400	1048

ACTIVITY 1.6 EXPERIMENT: MIXING FLUIDS OF DIFFERENT DENSITIES



Density is a measure of how much mass something has compared with how much space (volume) it takes up. Like solids, liquids have a variety of densities. Their density is calculated using the formula:

$$\text{Density (g/cm}^3) = \frac{\text{Mass (g)}}{\text{Volume (cm}^3)}$$

When determining the mass of any liquid, the mass of the container holding the liquid must be subtracted from your calculations.

To calculate the density of different liquids and to observe their behaviour when mixed.

Aim: Write your prediction about what you think will happen when low-density liquids are mixed with higher density liquid.

Risk assessment: Medium. Glycerine and copper sulfate can be mild irritants. Avoid skin contact and wear safety goggles.

Apparatus

- Beaker containing copper sulfate solution
- Beaker containing glycerine
- Beaker containing vegetable oil
- 1 × 20mL measuring cylinder
- 3 × 10mL measuring cylinders
- Beam or electronic balance
- 3 × disposable pipettes

Method

1. Accurately measure the mass of a 10 mL measuring cylinder. Label this as measuring cylinder 1 and record its mass in your copy of Table 1.3.
2. Using the pipette, add exactly 5 mL of glycerine into measuring cylinder 1. *Note:* 1 mL = 1 cm^3.
3. Use the balance again to calculate the new mass of measuring cylinder 1. Record this in your results table.
4. Using fresh pipettes, repeat steps 1 to 3 using copper sulfate solution (measuring cylinder 2) and vegetable oil (measuring cylinder 3).
   Note: do not assume that all similar measuring cylinders have the same mass.
5. When the mass and volume of all three liquids have been measured, calculate:
   (a) The mass of the liquids by subtracting the initial measuring cylinder mass from that of the cylinder with liquid.
   (b) The density of each liquid by using the formula given above.
6. Pour the vegetable oil into the 20 mL measuring cylinder. Tilt the 20 mL measuring cylinder at an angle and slowly pour the glycerine into it. When this has settled, slowly pour the copper sulfate into the 20 mL cylinder in the same way.
7. Let the liquids settle and draw what you observe. Label each liquid and its calculated density.

Results

Table 1.3 Fluid density results table.

Liquid	Mass (g)			Volume (cm^3)	Density (g/cm^3)
	Measuring cylinder	Measuring cylinder plus liquid	Liquid		
Glycerine					
Copper sulfate					
Vegetable oil					

Conclusion: *Complete this conclusion by selecting one of the underlined words:* When liquids of different densities are mixed, the denser liquids settle above/below/between the less dense liquids.

Discussion: What implications do these results have to the formation of Earth's interior structure?

Gravity and differentiation

Put simply, **gravity** is the force of attraction between two masses. This force is greater when the masses are larger and closer together. For example, a person experiences less gravity on the moon than on Earth because the moon has less mass. Gravity plays a fundamental underlying role in many of Earth's processes, including the water cycle, plate tectonics and differentiation.

Differentiation is the process whereby a mixture of fluids with different densities organises itself into layers (Figure 1.10). The densest layer will be on the bottom and the least dense will be on the top. This process is driven by gravity and it is the reason for the different layers that are believed to be inside Earth.

Figure 1.10 Differentiation Produce layering effects in cocktails.

Figure 1.3 illustrates the Earth and other planets forming as the result of accretion of material orbiting the Sun. As Earth grew in size and mass, its gravity also grew and attracted a hail of meteorites. This period of meteorite bombardment melted the rocks of the young Earth and allowed the molten ingredients to differentiate according to density. The densest materials, such as iron and nickel, sank to the centre under the pull of gravity while the less dense materials, such as oxides and sulfides, were pushed to the surface.

As the Earth swept its orbit free of large debris, the meteorite strikes reduced in size and frequency. This allowed the surface of our planet to cool enough for a thin crust of rock to form over the hot interior. The interior remains hot to this day because the radioactive decay of some elements acts as an additional heat to boost to the inner furnace that would otherwise have slowly cooled over time.

Internal layered structure

The early differentiation of material within the Earth is preserved in its layered internal structure. Scientists have never drilled through the crust, yet they can infer what lies deep beneath it. These inferences are based on calculations of Earth's mass, on observations of the behaviour of **seismic (Earthquake) waves** as they travel through the Earth (Figure 1.11) and on the analysis of meteorites that have preserved the original ingredients of the solar system.

Earth's mass can be calculated by carefully measuring its gravitational pull and factoring in Earth's diameter. If Earth's interior consisted of rocks with similar densities to those in its crust, its gravity should be considerably less than it is. The only way to account for this sizeable difference is if the rocks within Earth's interior are much denser than those on the surface.

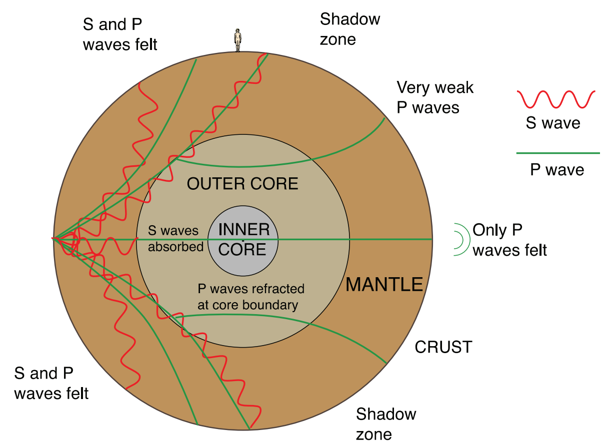


Figure 1.11 Seismic waves The structure of Earth's interior can be inferred from the behaviour of seismic waves as they pass through the planet.

Seismic waves produced by Earthquakes provide geologists with the best tool for indirectly observing the Earth's interior. Whenever an Earthquake occurs, it releases different types of waves which travel at different speeds and in different ways. The slowest of these waves (**L waves** or Love waves) move along the Earth's surface only. The other two types (**Primary or P waves** and **Secondary or S waves**) can move through the deeper layers of the Earth. P-waves are compression waves that can travel through both solids and liquids. S-waves are transverse waves and can travel through solids but not through liquids. By measuring speed changes as well as direction changes caused by reflection and refraction of the waves, geologists can determine the internal structure of the Earth.

We know that the upper mantle is partly molten at about 100 kilometres deep because both P and S waves slow down at this depth (Figure 1.12). We know that density and pressure increase with depth in the mantle because the velocity of both P and S waves increases with depth (waves travel faster through denser material). We know that the boundary between the mantle and the outer core is about 2900 kilometres in depth and that the outer core is a dense liquid. This can be determined because S waves are stopped at this depth (they cannot travel through liquids) and P waves are slowed and bent. A surge in the velocity of P waves at a depth of 5100 kilometres indicates a solid and even denser inner core. These results are supported by faint echoes of P waves being reflected back to the surface from the changes at these depths.

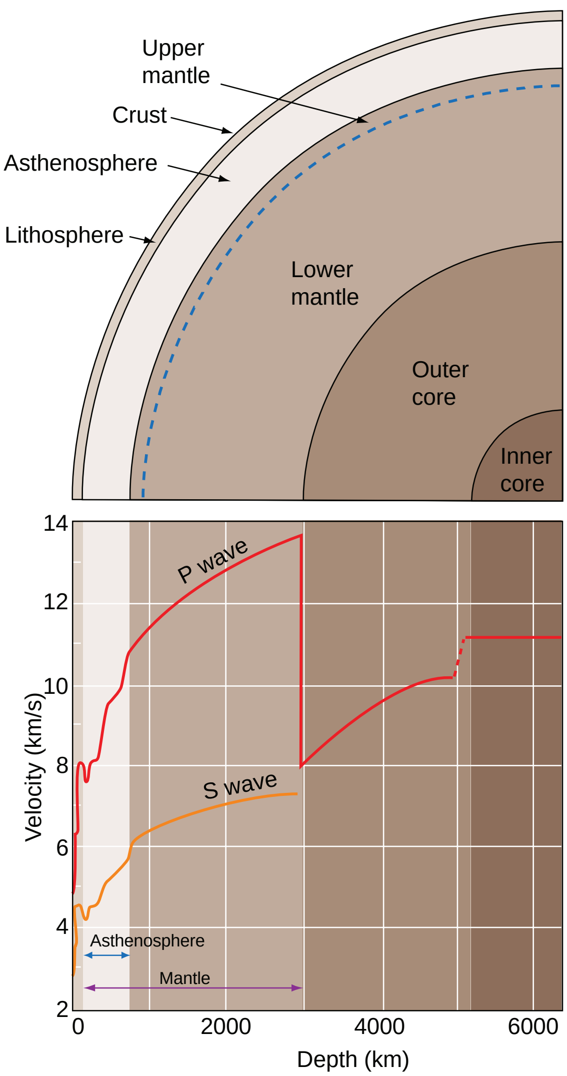


Figure 1.12 Earth's internal layered structure
(a) The layered structure of Earth – the crust is very thin at this scale. (b) Changes in the speed of seismic waves helped geologists to determine the internal structure of the Earth.

Meteorites

The oldest crustal rocks yet found are from Western Australia and date back to about 4.2 billion years. The regular processes which breakdown and recycle rocks have destroyed the first rocks that formed on our planet. However, these ancient Australian samples are not the oldest rocks found by geologists (Figure 1.13).

Meteorites were made from the same ingredients at the same time as the Earth and the rest of the solar system — around 4.9 billion years ago. Therefore, analysis of the physical and chemical composition of meteorites allows scientists to read our planets original recipe Table 1.4. Most meteorites are much like ordinary Earth-stones, but are a little denser. A small percentage of meteorites are contain abundant heavy metals, such as iron, nickel and iridium. When you compare the overall density of the Earth (5.5 g/cm^3) with the lower density of stony meteorites (chondrites; 3.3 g/cm^3), we must explain why the overall density is so high. There is no problem if the centre of the Earth is made of iron/nickel similar to the iron meteorites (4 to 8 g/cm^3). This data confirms what has been found during seismic studies. The inference can be made that these dense materials were part of the early Earth, but melting and differentiation has caused them to sink out of sight to the deep interior.

Figure 1.13 Antarctica offers a treasure trove for meteorite hunters Ice flowing over buried mountain ranges pushes the dark meteorites to the surface where they can be easily spotted. These meteorites are samples of the original ingredients from which the Earth was built. (Royal Belgian Institute)

ACTIVITY 1.7 EXPERIMENT: ROCK DENSITY

Rocks are made up of minerals that have specific chemical and physical properties. Minerals are classified according to their chemical make-up and physical characteristics. Density is one of these physical characteristics.

To determine and compare the densities of materials that represent different layers of the Earth.

Risk assessment Low. Slide or lower the materials into the measuring cylinders to avoid breakages

Apparatus

- Beam or electronic balance
- Measuring cylinder
- Cotton thread or similar
- Paper towels
- Small specimens of these rocks (able to fit in a measuring cylinder):
  - Granite and/or rhyolite (representing the continental crust)
  - Basalt and/or gabbro (representing the oceanic crust)
  - Haematite or an iron bolt (representing the core)
  - Peridotite or olivine (representing the mantle)

Table 1.4 Meteorites.

Type	Percentage of all found (%)	Average density (g/cm^3)	Appearance and composition
Stony	63	3.3	Generally have a dark gray or black surface due to melting and a lighter gray interior. Mainly silicate minerals they contain small round structures.
Carbonaceous	3	2.4	Contain traces of biological material.
Enstatite	1	3.6	Contain small amounts of the mineral enstatite (magnesium silicate).
Achondrites	3	3.1	Similar to stony meteorites but they do not contain the small round internal structures.
Stony-iron	1	4.5	Mixture of iron and nickel with silicate material.
Iron	4	7.5	Composed of iron-nickel alloys.
Unclassified	25		

Method

1. Select the rock that is to represent continental crust (granite or rhyolite). Measure and record its mass in your copy of Table 1.5.
2. Half fill the measuring cylinder with water and make an accurate reading of water volume in cubic centimetres (cm^3). Record this. (*Note:* that 1 mL = 1 cm^3.)
3. Carefully slide the rock into the angled measuring cylinder or lower the rock into the water using thread until it is fully submerged. Record the new volume reading.
4. The volume of the rock can be calculated by subtracting the original volume from the second volume reading. Calculate and record the volume of the rock.
5. Repeat these steps with rocks representing:
   (a) oceanic crust, such as basalt or gabbro
   (b) the mantle, such as peridotite or olivine
   (c) the core, such as haematite or the iron bolt (*Note:* haematite is not formed in Earth's core but is rich in iron, which is a major component of the core.)
6. Calculate the density of each rock by using the formula used in the last activity.
7. Copy a diagram of the Earth's structure into your notebook (Activity 1.8 or Figure 1.12(a)). Label the densities you have determined and where they are located.

Results

Table 1.5 Rock density.

Rock used	Region of Earth represented	Mass (g)	Volume (cm^3)	Density (g/cm^3)
	Continental crust			
	Oceanic crust			
	Mantle			
	Core			

Conclusion Write a sentence that summarises the observed trend of density in comparison to depth.

Our Earth was once a molten ball of materials gathered together by the accretion of dust in the disc around a young star. The last two activities illustrate how the denser materials, such as iron and nickel, would naturally have sunk to the core while the less dense materials, like granite and basalt, would naturally have risen to the surface. This explains the indirect observation that Earth has a layered internal structure, with denser materials closest to the core and the lighter materials nearer the surface.

ACTIVITY 1.8
CHEMICAL COMPOSITION OF THE EARTH

Cumulative bar charts are a type of graph that shows the proportions of things making up a whole, similar to pie charts. For example, a cumulative bar chart showing the proportion of flavours in Neapolitan ice-cream might look like Figure 1.14. Bar charts must be accurately measured and may be vertical (like Figure 1.14) or horizontal.

1. Use the data in Table 1.6 to construct two cumulative bar charts: one for the relative abundance of elements in the entire Earth; the other for the relative abundance of elements in the Earth's crust.
2. Use a spread sheet program of your choice to graph this data (Table 1.6). Copy the graph type that you think best illustrates these results into your notes.
3. Iron is the most abundant element in the Earth, yet it is only present in relatively small amounts in the crust.
   (a) Where is the rest of the Earth's iron?
   (b) Account for this uneven distribution.
4. With specific reference to two other elements, account for their high or low abundance in the crust.

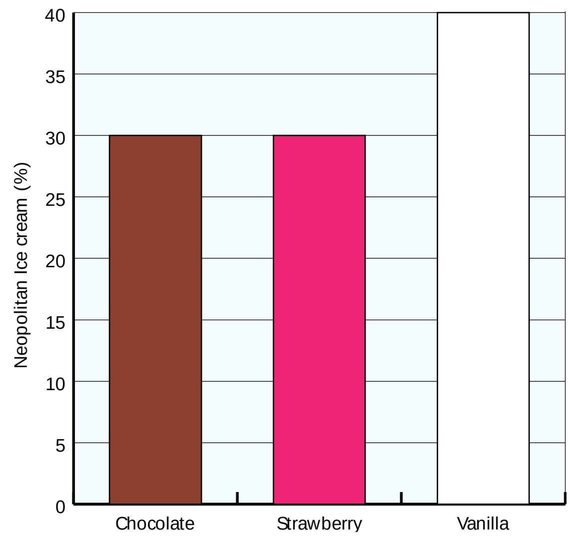


Figure 1.4 Cumulative bar chart The proportion of flavours in Neapolitan Ice-cream.

Table 1.6 Relative abundance of elements.

Element	Abundance in Whole of Earth (%)	Abundance in Crust (%)
Iron	35	6
Oxygen	30	46
Silicon	15	28
Magnesium	13	4
Nickel	2.4	0.009
Sulfur	1.9	0.04
Calcium	1.1	2.4
Aluminium	1.1	8
Potassium	0.16	2.3
Sodium	-	2.1
Other	0.5	1.2

SCIENCE SKILLS

1. **Define** means to *state meaning and identify essential qualities*. You may need to state the limitations of the definition, and may need to state multiple meanings. For example, define the term Meteorite.

   Answer:

   A piece of rock or metal that has fallen to the Earth's surface from outer space as a meteor.
2. The Flat Earth Society 'is dedicated to unravelling the true mysteries of the universe and demonstrating that the Earth is flat and that Round Earth doctrine is little more than an elaborate hoax.' (http://www.theflatEarthsociety.org/tiki/tiki-index.php; accessed March 2015).
   (a) **Outline** at least one piece of evidence that the Flat Earth Society uses to show that the Earth is flat and not roughly a sphere.
   (b) **Describe** how the Flat Earth Society accounts for the visit of astronauts to the Moon.
   (c) How good are the claims made by the Flat Earth Society? **Explain** your answer.
3. Using Table 1.6, construct a bar graph to show the relative abundance of the top eight elements in the Earth's crust.

TO THINK ABOUT

Set 1

1. **Explain** why it is easier to study outer space than it is to study inner space – inside the Earth.
2. **Outline** the role of gravity in the formation of the Earth.
3. **Describe** the difference between L-waves and S/P- seismic waves.
4. **Explain** why Earth's rocks become more dense with depth.

   Explain how scientists are able to describe Earth's interior when it has never been directly observed.

Set 2

6. **Describe** how meteorites can help understand the formation of the Earth.
7. What is differentiation? **Describe** an experiment that can simulate the differentiation of the early Earth.
8. Some elements in the Earth's crust have higher concentrations than when they are in the core, while others occur at lower concentrations in the crust than in the core. **Explain** this uneven distribution.
9. **Define** the term density. **Describe** how the density of rock samples can be accurately determined.
10. **Draw** a labelled diagram of the Earth in cross-section.

1.3 Structure of the Earth

Describe the compositional layers and thickness of Earth's layers, including:

- The lithosphere (ACSES015)
- Asthenosphere
- Crust mantle and core and their compositional layers (ACSES006)

An attempt to study the nature of the Earth's crust was undertaken by Russian scientists on the Kola Peninsula (Figure 1.15). Beginning in 1970 they were able to drill a borehole to a depth of 12,262 metres by 1989. The deepest drill hole in Australia only gets to around 3000 metres. The Kola borehole reach around one third of the way to the bottom of the continental crust estimated at 35 km thick in that location. As you can see, we need other techniques such as seismic wave analysis to determine the inner structure of the Earth.

Figure 1.15 Kola borehole (a) Looking down the deepest hole on Earth. (b) Kola drill site.

As we saw in Unit 1.2, the Earth is made up of a number of layers, a bit like an onion. There are a number of ways in which we can group these layers (Table 1.7).

Table 1.7 Structure of the Earth.

Depth (km)	Layer	
0 to 35	Lithosphere (varies from 200 km)	Crust (varies from 5 to 70 km)
35 to 60		Uppermost part of the mantle
210 to 270	Mantle	Upper mantle
660 to 3000		Lower mantle
3000 to 5000	Outer core	
5000 to 6500	Inner core	

Crust, mantle and cores

The outermost layer of the Earth is also known as the **crust** (Figure 1.16). Under the ocean basins the crust is 5 to 10 km thick, and is composed of dense igneous rocks such as basalt. It has a density of around 2.9 g/cm^3 which is lower than the density of the mantle at 3.3 g/cm^3. **Oceanic crust** is much simpler in structure than continental crust. Information about the oceanic crust comes from samples collected from the floor of the ocean, as well as a few locations where oceanic crust has been exposed on land.

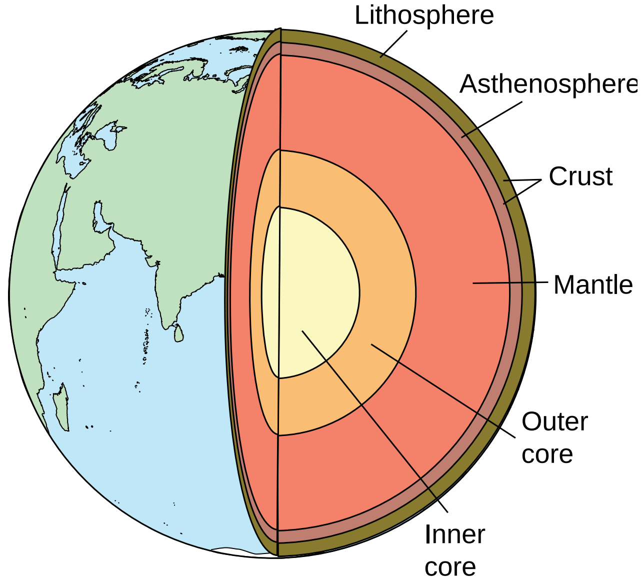


Figure 1.16 Our layered Earth The many onion-like layers of planet Earth.

Continental crust is thicker with a range from 25 to 70 km and its density is lower at around 2.7 g/cm^3. Continental crust has a more complex structure than oceanic crust. While most is made up of rocks such as granite, there are extensive amounts of sedimentary and metamorphic rock. Most parts of the continental crust are accessible from land, as well as deep mines and boreholes such as Kola in Russia.

The **mantle** (Figure 1.16) is a layer of rock found beneath the crust but above the outer core. It has an average thickness of around 2800 km and is more dense than rocks in the crust. There are a few places on the surface of the Earth where mantle rock has been pushed to the surface of the Earth by tectonic activity. One of the more common rocks at this level is peridotite containing minerals such as pyroxene, garnets and olivine.

The mantle is divided into layers. The **upper mantle** starts at the base of the crust is relatively rigid and has a temperature of around 1000°C. The boundary between the crust and mantle is called the **Mohorovičić** discontinuity or 'Moho' for short. Below this is another layer called the **lower mantle** that is more plastic allowing very slow movement of material in the form of convection currents and with a temperature of around 3700°C. Some of these movements can reach the surface as **mantle plumes**. Very little is known about the lower mantle.

The liquid **outer core** (Figure 1.16) lies beneath the mantle and above the solid inner core. The outer core is around 2300 km thick and is composed mainly of nickel and iron. This composition is similar to the inner core, but is not under enough pressure to become solid. It is believed that the Earth's magnetic field is generated in the moving liquid of the outer core.

The solid **inner core** (Figure 1.16) is believed to be a ball of a nickel and iron alloy with a radius of about 1200 km. There is also some sulfur present. The temperature is thought to be in the range of 4400 to 6000°C.

The heat source for planet Earth is twofold. Much is heat leftover from the formation process when the early planet suffered intense bombardment. Heat is also generated by radioactive decay.

Lithosphere and asthenosphere

The **lithosphere** of any planet including the Earth is the solid outer crust (Figure 1.16). For the Earth this includes the crust and the solid upper mantle. It varies in thickness from 80 to 200 km with a temperature of around 1300°C at its base. Beneath the lithosphere is the **asthenosphere**, part of the mantle that is made of a more plastic material that is able to move slowly. It is around 500 km thick and has a temperature ranging from 1300°C at the top to around 3000°C at its base. It carries heat from the core towards the crust in huge convection currents, and is the source of magma for volcanoes. The intense heat from the core makes the asthenosphere slightly fluid that allows the rigid lithosphere to move.

ACTIVITY 1.9 THERMAL GRADIENT

1. Figure 1.17 shows the geothermal gradient for the borehole on the Kola peninsula.

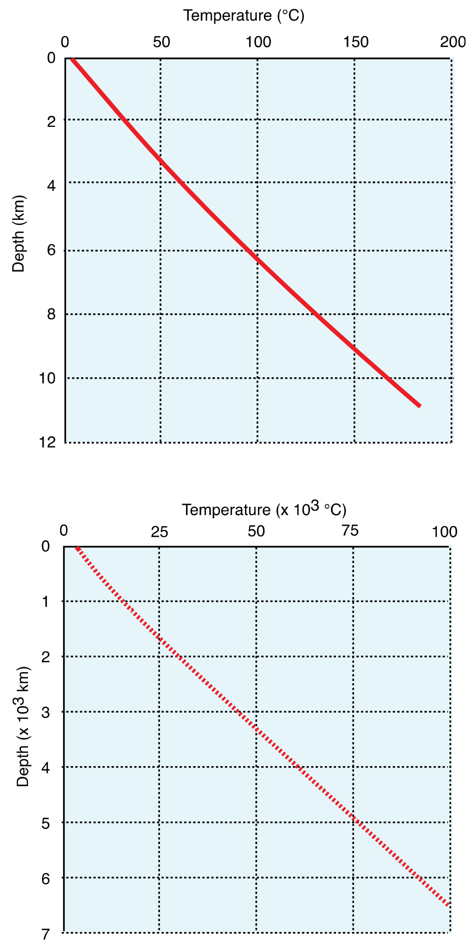


Figure 1.17 Geothermal gradient (a) Change in temperature with depth on the Kola Peninsula. (b) Extrapolating the data.(Fig 4.5)

(a) Using the data from Figure 1.17 (a) calculate the geothermal gradient measured in degrees-celsius per kilometre depth.

(b) Using the extrapolated data in Figure 1.17(b), what is the temperature in the centre of the Earth.

(c) Is the answer in (b) above reasonable? Justify your answer.

2. Construct a table of data to summarise the properties of the crust, mantle, inner and outer core.

Table 1.8 Earth's vital statistics.

Mean radius (km)	6371.0
Equatorial radius (km)	6378.1
Polar radius (km)	6356.8
Equatorial circumference (km)	40075.017
Volume (km^3)	1.08321×10^{12}
Mass (kg)	5.97237×10^{24}
Mean density (g/cm^3)	5.514
Equatorial rotation velocity (km/h)	1674.4

SCIENCE SKILLS

1. ***Compare*** means to *show how things are similar and/or different*. For example, **compare** the inner and outer core.

Answer:

The inner and outer core have similar nickel/iron composition, but differ in that the outer core is liquid and the inner core is solid and more dense.

2. ***Contrast*** means to *show how things are different or opposite*. For example, **contrast** the crust with the mantle.

Answer:

The solid crust is less dense than the slightly fluid mantle, and has a different composition.

3. ***Distinguish*** means to *recognise or note/indicate as being distinct or different from; to note differences between*. For example, **distinguish** between Love seismic waves and primary seismic waves.

Answer:

Love seismic waves are transverse waves that travel over the surface of the Earth. Primary seismic waves are compression waves and can travel through both solids and liquids.

4. ***Sequence*** means *to place in order of size or some other quality*. For example, **sequence** the density of Earth layers from largest to smallest.

Answer:

Inner core; outer core; mantle; crust.

TO THINK ABOUT

Set 1

1. **Compare** the lithosphere with the asthenosphere.
2. **Contrast** oceanic and continental crust.
3. **Identify** the layer inside the Earth that has the greatest volume.
4. **Describe** how the mantle influences life on Earth.
5. **Distinguish** between the inner and outer core.

Set 2

6. **Describe** why the 'Moho' is important.
7. **Explain** why the Russians wanted to drill the borehole on the Kola peninsula.
8. **Sequence** of the layers inside the Earth from thickest to thinnest.
9. In Table 1.8, **explain** why the equatorial and polar radii are different.
10. **Identify** where you would find the following rocks and minerals beneath the Earth's surface.
    (a) Olivine.
    (b) Iron-nickel alloy.
    (c) Granite.

1.4 Age of the Earth

Analyse evidence for the Earth's age, including:

- The formation and age of zircon crystals
- Radiometric technique
- Meteorite evidence (ASCES009)

'It has not been easy for man to face time. Some, in recoiling from the fearsome prospect of time's abyss, have toppled backward into the abyss of ignorance.'

Claude C. Albritton, *The Abyss of Time* (1980)

It would be pointless to study history without also considering the order and time in which historical events occurred. Likewise, when studying the history of our planet, we must first understand the concept of **geologic time** — the vast period of time over which Earth's rocks have formed.

For centuries the question of 'How old is the Earth' proved to be a challenging problem for scientists. Finding an answer to this puzzle would profoundly change the way in which humans would view their home planet and their place on it.

How old is the Earth?

In the year 1510 Florentine artist, inventor and genius Leonardo da Vinci (1452–1519) concluded that the sediments deposited by the River Po in Italy must have taken 200 000 years or more to accumulate and that the Earth itself must be much older than this. However his conclusion was not made widely known. Typically for da Vinci, he was far ahead of his time in using evidence and observations (i.e. science) to inform his theories.

Figure 1.8 Creation James Usher calculated that the Earth was created in 4004 BC.(Wiki)

Figure 1.9 How did these form? (a) Beds of rock. (b) Fossils in sedimentary rock. (c) Columnar jointing in basalt.

Figure 1.19 Evidence (a) Unconformity showing that, after rocks had been tilted, they were eroded over time before further sediment was deposited to become horizontal rock. (b) Granite penetrating other rock showing that it must have been molten at the time.

James Usher calculated that the Earth was created in 4004 BC (Figure 1.18). He arrived at this date by starting with the birth of Jesus Christ (the start of year zero on our calendars), adding together all of the generations described in the Bible back to Adam (listed there as the first human) and then multiplying this by his estimated average generation gap.

Many scientists thought that Ussher's estimate of 6000 years was far too short a time span to explain such features as cliffs showing accumulated sediments hundreds of metres thick (Figure 1.19(a)). However, due to the lack of any other credible theories, Ussher's estimate became widespread in European religious and scientific circles. Given the Bible's description of a catastrophic flood, the idea that the world had been shaped in the past by sudden, short-lived catastrophic events took hold. This idea is called **catastrophism**, and was used to explain a number of things seen in the rocks:

- Layers of sedimentary rocks were due to a worldwide flood where huge tides deposited massive loads of sediment that over a short period of time formed rocks (Figure 1.19(a)).
- Fossils found in such rocks were buried during The Flood (Figure 1.19(b)).
- Rocks such as basalt and granite had been crystallised from the waters of The Flood (Figure 1.19(c)).

In 1778 French mathematician and naturalist Georges de Buffon (1707–1788) estimated Earth's age based on experimental observation. Correctly inferring that the interior of the Earth must be like iron, he heated iron cannon balls of various sizes and studied the rate at which they cooled. He applied the observed cooling rates to the Earth's diameter and concluded a much older age of 75 000 years.

Uniformitarianism

James Hutton (1726-1797) had been a gentleman farmer where he noticed how the soil on his farm was continually eroded away. He realised that the same thing happened to rocks, but much more slowly. Rocks slowly disintegrated before the particles formed were eroded away. How were the rocks and soil replaced?

Hutton went searching for evidence to try and solve his problem. Hutton examined **unconformities**, where layers of rock are at an angle to each other (Figure 1.20(a)). It showed that after the original rock layers had been formed they were tilted and then partly eroded as solid rock. Then further sediment was deposited and gradually converted into rock. This would have taken a long period of time by normal geological processes and would not have occurred in a single catastrophe.

He also found examples of granite penetrating other rocks including both metamorphic and sedimentary rocks (Figure 1.20(b)). The idea that granite was formed by precipitation from water could not explain the patterns found. The only way this could have happened was if the granite was molten when the penetration took place.

Natural processes could explain the evidence he found – there was no need for a catastrophe. This lead to the principle of **uniformitarianism**: that the rate of processes such as erosion and the deposition of sediments has been fairly constant throughout Earth's history. This means we can use present day geological process to explain the geology from the past. It is often popularised as 'the present is the key to the past.'

Charles Lyell (1797-1875) was a British lawyer with an intense interest in Geology. Such was his interest that he spent his honeymoon in Switzerland and Italy on a geological tour! Lyell worked as a lawyer for a time and as a professor of Geology. He is most famous for his textbook *Principles of Geology* (Figure 1.21). He helped establish Geology as a scientific discipline and to popularised James Hutton's principle of uniformitarianism.

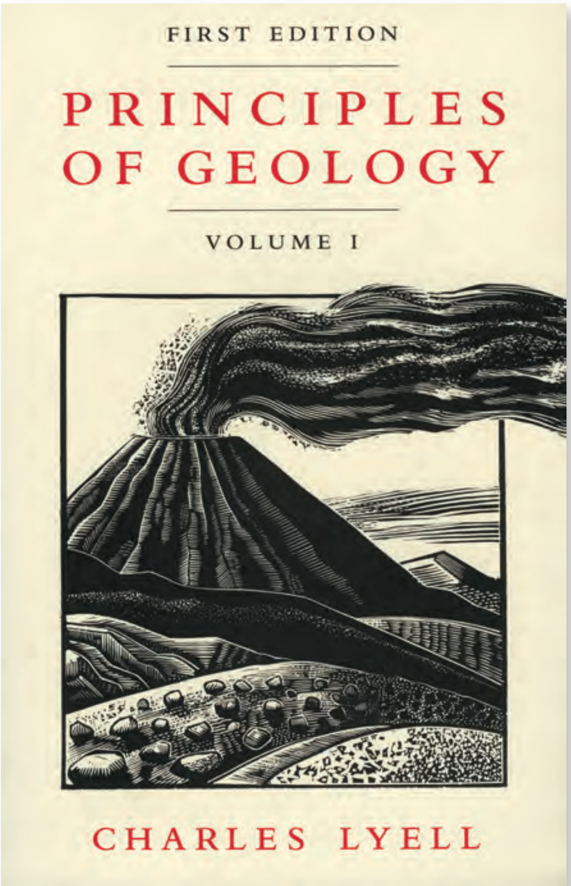


Figure 1.20 Principles of Geology First published in 1830 this was the first modern geology textbook.

In 1898 Irish chemist John Joly (1857–1933) devised another method for calculating the Earth's age. He determined the total amount of salt in the oceans and divided this by the estimated annual rate at which salt is added by erosion from land. He concluded that 100 million years were required to produce the current salinity. Had he used modern measurements of the different chemicals in the oceans, he would have arrived at these figures: 260 million years if using sea salt, 45 million years if using magnesium or only 8000 years if using silica. There is obviously a problem with this method. The problem lies in the incorrect assumption that nothing leaves the ocean.

In 1855 eminent British physicist William Kelvin (1824-1933) – also known as Lord Kelvin – waded into this debate. Using de Buffon's principle of rate of heat loss, he announced that the Earth was 20–30 million years old. Most geologists did not challenge this estimate, even though it was not enough time to explain the variety of landscapes and life forms we observe around us. This was partly because of the high esteem in which physics generally (and Lord Kelvin particularly) was held, and partly because they could not show that Kelvin was wrong.

One of the few scientists willing to challenge Kelvin was American geologist Thomas Chamberlin (1843–1928). In 1899 he boldly declared that if physics determined Earth's age to be only 30 million years, physics must be wrong! He argued that another source of energy other than heat left over from its formation must exist to have driven Earth's geological processes for much longer than this. Luckily for Chamberlin, breakthroughs to support his theory were just around the corner.

Radiometric dating

In 1896 French scientist Henri Becquerel (1852–1908) placed some uranium salts in a drawer along with sealed photographic plates. Normally photographic plates are only exposed (altered) by visible light. However these plates produced images of uranium salt crystals even though they were in the dark (Figure 1.22). The outline of a metal Maltese cross that sat between some of the salts and the photographic plate is clearly visible. Becquerel had accidently discovered **nuclear radiation** – a 'new' form of energy.

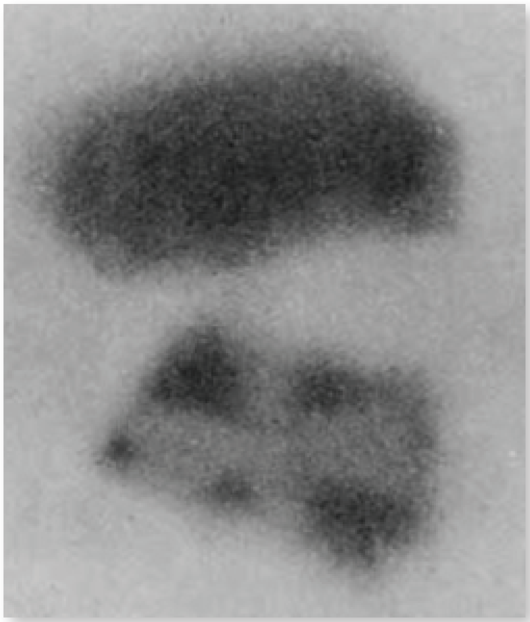


Figure 1.21 Effects of radiation Radioactive particles from uranium salts produced this image.

In 1902 Nobel Prize-winning New Zealand-born physicist Ernest Rutherford (1871–1937) outlined his hypothesis of how **radioactive decay** occurs. Certain atoms such as Uranium have nuclei that are unstable, and give off high energy particles. As a result of giving of particles, the nuclei become stable and cease to be radioactive. In 1904 Rutherford suggested that radioactive decay of elements within the Earth acts as an additional source of internal heat, thus supporting Chamberlin over Kelvin.

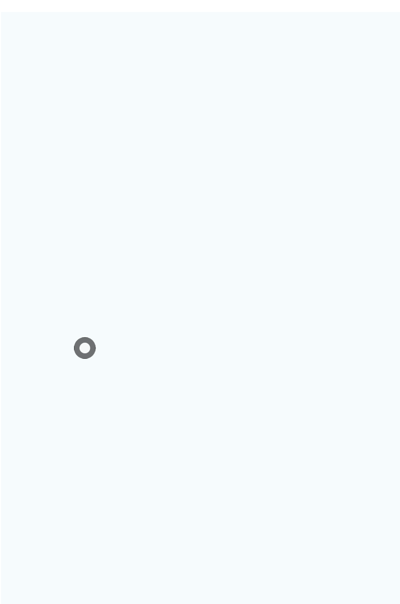


Figure 1.22 Radioactive decay Radioactive particles are emitted by the nucleus.

When radioactive substances decay, they do so in a random manner that can only be studied statistically. The **half-life** measures the time needed for half the original number of atoms present to decay away (Figure 1.23). If we had 20 grams of a radioactive isotope with half-life 2 minutes, then after two minutes only 10 grams is left. After 4 minutes only 5 grams is left (half the 10 grams). After 6 minutes, only half the 5 grams is left, or 2.5 grams. And so on. Half -life is independent of environmental effects such as pressure and temperature, and whether it is joined to other chemicals. Some examples important in radiometric dating are listed in Table 1.9.

Table 1.9 Half-lives.

Element	Symbol of isotope	Half-life
Uranium-238	$^{238}_{92}U$	4.5×10^9 years
Carbon-14	$^{14}_{6}C$	5730 years
Potassium-40	$^{40}_{19}K$	1.3×10^9 years
Rubidium-87	$^{87}_{37}Rb$	48.8×10^9 years

In 1905 American chemist Bertram Boltwood (1870–1927) and British mathematician and physicist J W S Rayleigh (1842–1919) developed a relatively simple radioactive-dating technique to determine the age of certain minerals commonly present in suitable rocks.

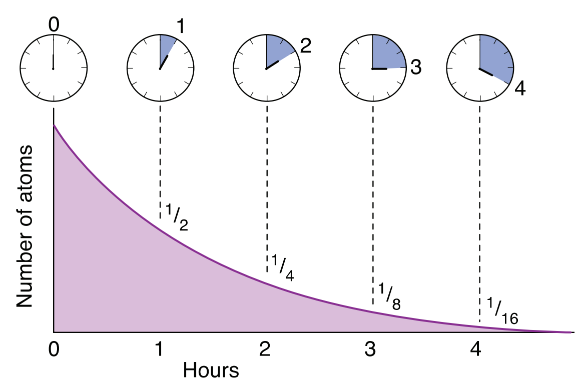


Figure 1.23 Radioactive decay Decay is at a constant rate.

All rocks and minerals contain tiny amounts of these radioactive elements. These elements decay at a uniform rate called the half-life, as described above (Figure 1.23). Radiometric clocks begin when each rock forms. 'Forms' means the moment an igneous rock solidifies from magma, a sedimentary rock layer containing suitable minerals is deposited, or a rock heated by metamorphism cools off.

A commonly used radiometric dating technique relies on the breakdown of potassium-40 to argon-40. For example, in igneous rocks, the potassium-argon 'clock' is set the moment the rock first crystallizes from magma. Precise measurements of the amount of potassium-40 relative to argon-40 in an igneous rock can tell us the amount of time that has passed since the rock crystallized.

The initial results of radiometric dating showed that the Earth was as much as 2000 million (2 billion) years old. With increased accuracy and wider sampling, the Earth's age was raised to 3500 million years by 1960.

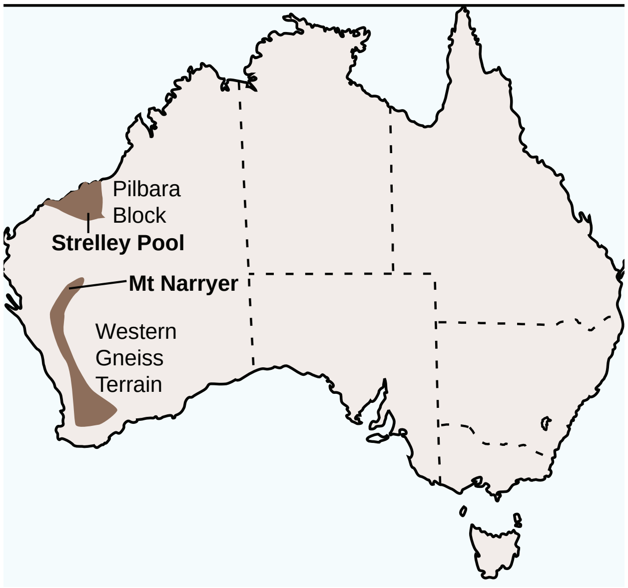


Figure 1.24 Mount Narryer One of the oldest sections of Earth's crust.

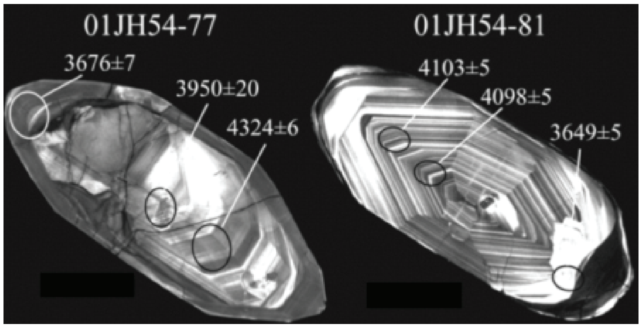


Figure 1.25 Zircon crystals These microphotographs show 2 tiny zircon crystals from Mt Narryer in Western Australia. The circles show areas where the crystals were analysed using radiometric dating techniques comparing uranium-lead isotopes. The numbers show the estimated age of each section in millions of years. While not all tests give the exact same age, averaging multiple samples allowed geologists to determine that these are the oldest pieces of the Earth yet found.

Presently, the oldest piece of the Earth's crust ever sampled is from Mount Narryer in Western Australia (Figure 1.25). The highly resistant mineral zircon has been found in rocks here and these have been dated to between 4100 and 4200 million years (Figure 1.26).

Because the Earth's crust is continuously recycled and destroyed, we are unlikely to find many rocks that have remained unaltered since their original formation. Luckily, however, meteorites that fall to Earth give us access to rocks that formed at the same time as Earth and the rest of the solar system. Radioactive dating of these rocks puts our current estimate for the age of the Earth at 4.54 (± 0.05) billion years.

ACTIVITY 1.10
TIME (TO) SCALE

To gain a perspective of geologic time.

Apparatus

Each student needs a pencil, ruler, geologic event dates (Table 1.10).

Risk assessment: Low.

Table 1.10 Geologic events.

Number	Geologic event	Time (Millions of years ago)
1.	End of Pre-Cambrian Period and start of Cambrian Period	570
2.	End of Cambrian Period and start of Ordovician Period	505
3.	End of Ordovician Period and start of Silurian Period	430
4.	End of Silurian Period and start of Devonian Period	395
5.	End of Devonian Period and start of Carboniferous Period	345
6.	End of Carboniferous Period and start of Permian Period	280
7.	End of Permian Period and start of Triassic Period	225
8.	End of Triassic Period and start of Jurassic Period	190
9.	End of Jurassic Period and start of Cretaceous Period	135
10.	End of Cretaceous Period and start of Tertiary Period	65
11.	End of Tertiary Period and start of Quaternary Period	2
12.	Formation of the Earth	4600
13.	Oldest Earth rock (from Western Australia)	4200
14.	Oldest known fossils (from Western Australia	3500
15.	First plants (algae)	3200
16.	First multicellular life	600
17.	First Dinosaurs	220
18.	Death of the Dinosaurs	65
19.	Mass extinction	630
20.	Mass extinction	505
21.	Mass extinction	430
22.	Mass extinction	360
23.	Mass extinction	248
24.	Mass extinction	213
25.	Mass extinction	144
26.	Mass extinction	65
27.	Possible mass extinction	present
28.	First abundant fossils	570
29.	First vertebrates	505
30.	First land plants	430
31.	First amphibians	395
32.	First reptiles	305
33.	First mammals	190
34.	First birds	150
35.	First primates	65
36.	Ice Age	2 to 0.01
37.	Ice Age	340 to 250
38.	Ice Age	470 to 420
39.	Ice Age	660 to 620
40.	Ice Age	780 to 750
41.	Ice Age	860 to 840
42.	Ice Age	1500 to 1200

Method

1. Stick the two sheets of A4 paper together end to end to give a long sheet at least 46 cm long.
2. Rule a line 46 cm long down the left hand side of this page, marking a small dash every centimetre. Label the top of the line as *Present*; the other end as *Start*.
3. Every centimetre on this time scale = 100 million years. Counting back from *Present*, label every 500 million years back to *Start*.
4. Don't throw your timeline away. You will need it later.

SCIENCE SKILLS: GRAPHS

1. A graph for the radioactive decay of Technetium-99 is found in Figure 1.27.
   (a) Determine the count rate at 3 hours.
   (b) **Calculate** the half-life of this isotope.
   (c) Do you think this isotope would be useful for radioactive dating? **Explain** why.

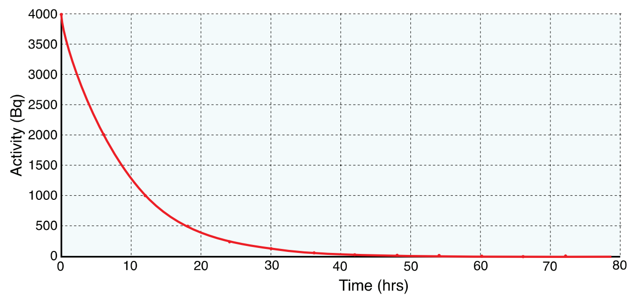


Figure 1.26 Radioactive decay Decay of the element Technetium-99.

2. Table 1.11 shows readings taken during the radioactive decay of Magnesium-28.
   (a) **Graph** this data on a spreadsheet or using paper. Make sure the axes are clearly labelled.
   (b) **Calculate** the half-life of this isotope.
   (c) Do you think this isotope would be useful for radioactive dating? **Explain** why.

Table 1.11 Radioactive decay.

Time (hours)	Mass of Magnesium-28 (mg)
0	10.0
10	7.1
20	5.0
30	3.6
40	2.5
50	1.8
60	1.25
70	0.9
80	0.62
90	0.4
100	0.31

TO THINK ABOUT

Set 1

1. **Define** the word *uniformitarianism*.
2. **Identify** who proposed the principle of uniformitarianism.
3. **Describe** why catastrophism was the prevailing theory to explain the Earth's geology before the days of modern Science.
4. **Identify** the modern technique used to give an absolute date for suitable rocks.
5. **Describe** the role of meteorites in determining the age of the Earth

Set 2

6. **Explain** why the evidence of Lord Kelvin was thought to be final.
7. **Describe** the role of new evidence in showing that Lord Kelvin had been wrong.
8. Do you think we should call Lord Kelvin a stupid or a fool for being wrong? **Explain** your answer.
9. Leonardo da Vinci studied the River Po in Italy. The average thickness of sediments is 1 km. **Calculate** the average thickness of sediment deposited each year if it took 200 000 years to form that thickness of sediment.

Figure 1.27 Basalt layer How can this lower layer of basalt rock be explained?

10. Figure 1.28 shows a layer of basalt.
    (a) Use catastrophism to **explain** this layer of rock.
    (b) Use uniformitarianism to **explain** this layer of rock.

1.5 Summary

- The big-bang resulted into material flying apart.
- Gravity caused dust to coalesce to form larger particles. These in turn formed even bigger particles which were pulled into a ball-shaped structure that eventually resulting in nuclear fusion and the formation of a protostar.
- Around the protostar was a protoplanetary disc inside which protoplanets formed by accretion.
- Differentiation is the process whereby a mixture of fluids with different densities organises itself into layers.
- Bombardment of the early Earth by meteorites results in a molten interior that allows layers to form by differentiation.
- The moon may have been formed when the early Earth was hit by another protoplanet the size of Mars.
- The atmosphere formed during outgassing during volcanic activity.
- The presence of water may have come from meteor bombardment and/or from outgassing of water during volcanic activity.
- Seismic (Earthquake) waves can travel along the surface or through the Earth. The slowest of these waves (L waves or Love waves) move along the Earth's surface only. The other two types (Primary or P waves and Secondary or S waves) move out through the deeper layers.
- By analysing how P and S waves behave as they move through the Earth, we can deduce properties of the material they are travelling through.
- The overall density of the Earth is too high to have the same composition as the crust, so there must be denser material inside the Earth.
- Meteorites are often composed of iron and nickel which have a density high enough to explain the overall density of the Earth.
- In the centre of the Earth, the inner core is solid iron and some nickel. Then comes the outer core which is mostly molten iron with some nickel. Next is the mantle made of rock that is nearly solid, but which allows slow movements of the crust above. At the surface is the relatively thin crust divided up into crustal plates.
- The lithosphere consists of the crust and solid parts of the mantle. The asthenosphere is composed of the more fluid parts of the mantle.
- The boundary between the crust and mantle is called the **Mohorovičić** discontinuity or 'Moho' for short.
- The Earth is subject to change – some is very gradual such as erosion, and some very fast such as a volcanic eruption.
- Geologic time is the vast period of time over which Earth's rocks and fossils have formed.

- Before the modern era, the Earth was believed to be around 6000 years old.
- Geological rocks and strata were explained by catastrophism – sudden, short and catastrophic events.
- Evidence mounted that this was too short a time.
- In the 1700s, James Hutton explained geology in term of uniformitarianism – ancient geological events were very slow and could be explained by the same geological processes taking place today.
- In the 1800s, Hutton's ideas were publicised by Charles Lyell and used by Charles Darwin to help develop his theory of evolution.
- In the late 1800s the physicist William Kelvin used the rate of heat loss from the Earth to estimate the Earth as 20 to 30 million years old.
- The discovery of radioactivity in 1896 showed there was another source of heat in the Earth so that Kelvin's age was too small.
- Radioactivity also allowed suitable rocks to be dated more accurately. The Earth is currently believed to be between 4100 and 4200 million years old.

1.6 Exam-style questions

Part A Multiple choice questions

Select the alternative, A, B, C or D, that best answers the questions.

1. During the formation of the Earth, outgassing was important for the formation of:

(A) Atmosphere and photosynthesis
(B) Hydrosphere and photosynthesis
(C) Photosynthesis and respiration
(D) Atmosphere and hydrosphere

2. The age of the Earth can be determined using:

(A) Radioactivity
(B) Seismic data
(C) Salt concentration of the oceans
(D) Thickness of river sediments

3. Accretion is best described as:

(A) The evolution of the solar system
(B) A process of the accumulation of small pieces into large pieces
(C) A process by which a star begins its nuclear reactions
(D) A band of colour produced by passing white light through a prism

4. Which of the following was the main source of the Earth's atmosphere?

(A) volcanic eruptions
(B) meteors
(C) the Sun
(D) comets

5. The order of the Earth's layers starting from the surface is:

(A) inner core; mantle; crust; inner core
(B) mantle; crust; outer core; inner core
(C) crust; mantle; outer core; inner core
(D) outer core; inner core; mantle; crust

Part B Short answer and longer response questions

6. **Explain** the role of nuclear fusion in the development of our solar system.

7. **Compare** the inner core with the outer core of the Earth.

8. **Outline** the role of meteorites in explaining the history of the Earth.

9. **Explain** the importance of uniformitarianism is determining the history of the Earth.

10. **Describe** the nature of the asthenosphere.