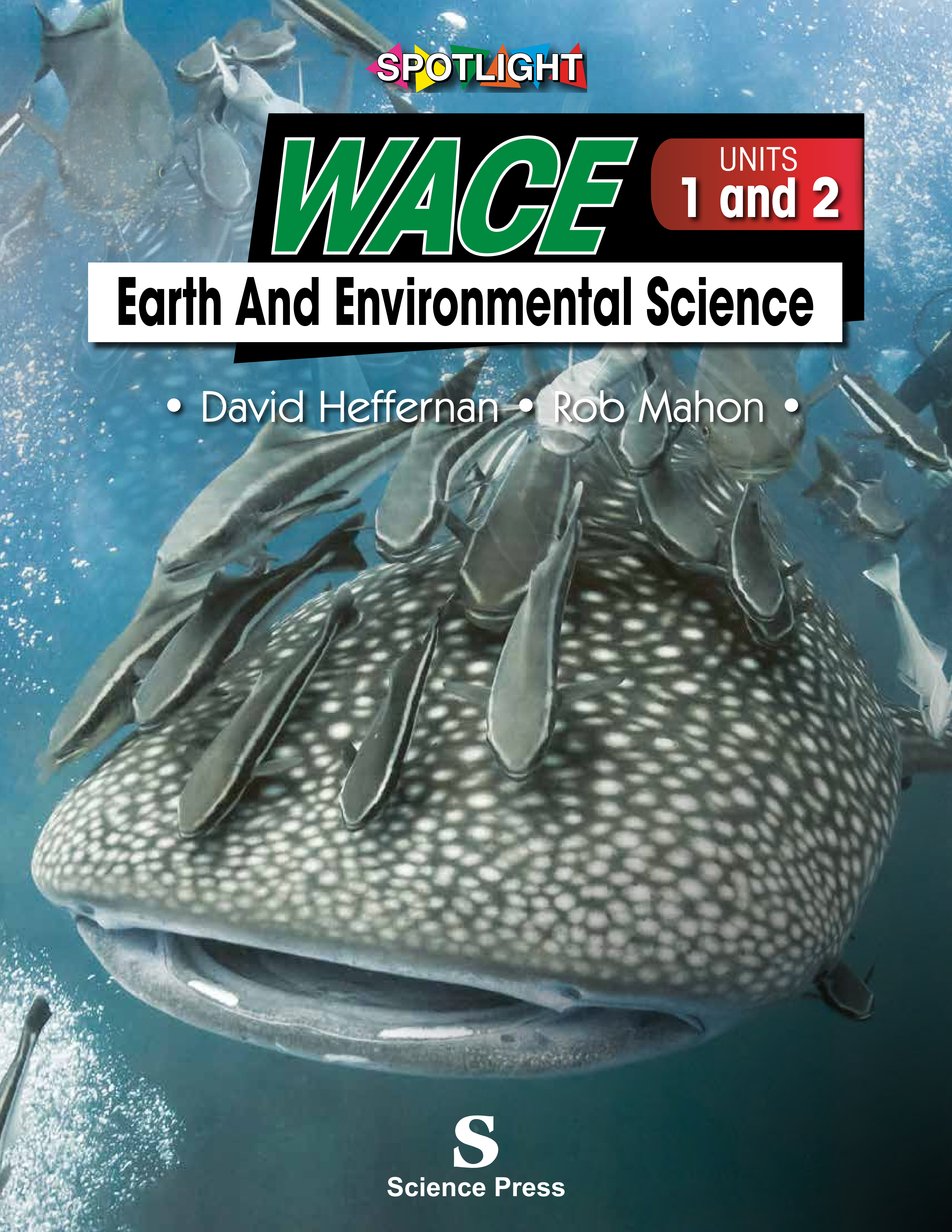
SPOTLIGHT

WACE

UNITS 1 and 2

Earth And Environmental Science

• David Heffernan • Rob Mahon •



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Science Press

Science Press
Private Bag 7023 Marrickville NSW 1475 Australia
Tel: (02) 9516 1122 Fax: (02) 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

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
DEVELOPMENT OF THE GEOSPHERE

‘When we try to pick out anything by itself, we find it hitched to everything else in the Universe.’

John Muir: pioneering naturalist and preservationist.

The study of the Earth is the study of changes and of connections. At times throughout its long history the Earth has experienced many periods of stability in its geology, climate and life forms. Inevitably however, these times are always overturned by changes in one form or another; from the very gradual (such as continental drift) to the very sudden (such as the eruption of a volcano or the impact of a meteorite).

Figure 1.1 Change and interactions Takes place throughout the Universe.

1.1 Change and interactions

We are all familiar with the concept of change. During your lifetime your body and mind change dramatically. The ‘you’ of today is very different from who you were ten years ago, or who you will be in another 10 years. Human society itself changes. Today’s society seems to be changing at an ever increasing rate.

In your short life you may have noticed large changes in the way you have been taught at schools or how you communicate with others. The Earth itself has undergone drastic changes too, though usually over much longer time frames than humans live for (and so it can be hard for us to notice them happening). At one time in the past the entire Earth was covered with thick ice from pole to pole, and at other times it has been a planet free of any ice, with warm temperatures and even lush forests at the South Pole.

With the convergence of social media and digital communications in the 21st century, most students have an understanding of the intricate network of connections between people. What science continues to reveal to us is that nature itself also contains a vast number of interconnections, ranging from the powerful to the miniscule to the downright strange.

The purpose of this chapter is to focus on the major changes that Earth has undergone during its long ‘life’, to reveal the origins of some of its vital features, and to explore some of the ways in which its different systems interact with each other.

The most astounding fact
https://youtu.be/9D05ej8u-gU

Introduction to earth science
https://youtu.be/T20RT0GgOB4?list=PLISBHwlJXpn0ZHc3t7dpz_pFf2Cnd39y_

Earth Science
https://youtu.be/_twWDPBNiD4

ACTIVITY 1.1
BRAINSTORMING INTERACTIONS

Aim: To share ideas about what we mean by the term 'environment' and to identify connections within it.

Apparatus: Butchers paper, coloured markers

Risk assessment: Low.

Method

1. Divide into groups of 4 and appoint a scribe to record notes for the group.
2. Go around the group one at a time and get each person to suggest a word that they associate with the term 'environment'. The scribe is to record these on a piece of A4 paper. Each person needs to contribute at least 5 or 6 words.
3. Use a colour key to classify your group's ideas as relating to rocks, water, air, humans or other life.
4. Write the following headings around the edge of the butchers paper (Figure 1.2) .
   - Humans
   - Atmosphere: zone of gas
   - Lithosphere: zone of rock
   - Hydrosphere: zone of water
   - Biosphere: zone of life
5. Draw two parallel lines between 'Humans' and 'Hydrosphere'. Make one of these an arrow towards 'Humans' and the other an arrow away from 'Humans'. Repeat this process between 'Humans' and each other heading, then draw similar arrows to and from every other heading (Figure 1.2).

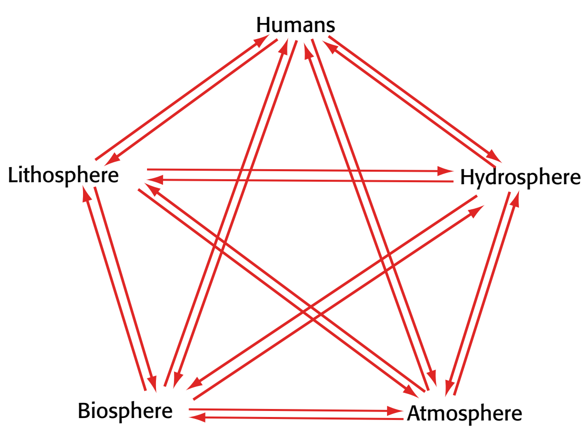


Figure 1.2 Interactions How does each component affect the others?

6. On each arrow add one or more words from your list that identifies how one of these things affects the other. For example, on the arrow from Lithosphere to Humans, you could add words such as 'soil', 'earthquakes', 'farmland', 'volcanoes', 'avalanche', etc. If any arrow does not have a label, discuss and decide on something appropriate.
7. Compare with other groups what labels you attached to specific arrows. Do others have ideas that your group did not think of or that you disagree with? Discuss similarities and differences. Are some things hard to put in one category? If so; why?
8. For homework start a vocabulary list with the definitions for each of the following terms: environment, atmosphere, lithosphere, hydrosphere and biosphere.

SCIENCE SKILLS

Each of the verbs in bold type used in these questions has a very specific meaning in terms of what it is asking you to do. You are required to understand the specific meanings of the verbs that may be used in examination questions. Whenever you answer a question, always start by focusing on the meaning of the verb – it is telling you *how* to answer the question.

1. The verb **identify** means *to recognise and name*. You may need to recognise an image or a verbal statement. For example, identify the main band of stars in Figure 1.1.

   Answer:

   The main band of stars is known as the Milky Way.
2. **Compare** means to *show how things are similar and/or different*. For example, compare the way people communicated electronically in 1990 with how they communicate today.

   Answer:

   In 1990 both landline phone and mobile phones were in use. However, by 2015 both types of phone were much smaller and many people only have a mobile phone and not a landline phone.

TO THINK ABOUT

1. **Identify** a major technological change that has occurred in your lifetime.
2. **Identify** a slow geologic change taking place in your local environment.
3. **Compare** a fast and a slow geologic change taking place in Australia or nearby.
4. **Compare** a slow and a fast ecological change that has taken place in your local environment.
5. **Identify** an interaction taking place in your local environment.

1.2 Geologic time

‘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 1.3 Creation James Ussher calculated that the Earth was created in 4004 BCE.

James Ussher calculated that the Earth was created in 4004 BCE (Figure 1.3). 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 1.4 (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, including the following.

- 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 1.4 (a)).
- Fossils found in such rocks were buried during The Flood (Figure 1.4 (b)).
- Rocks such as basalt and granite had been crystallised from the waters of The Flood (Figure 1.4 (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 cannonballs 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.

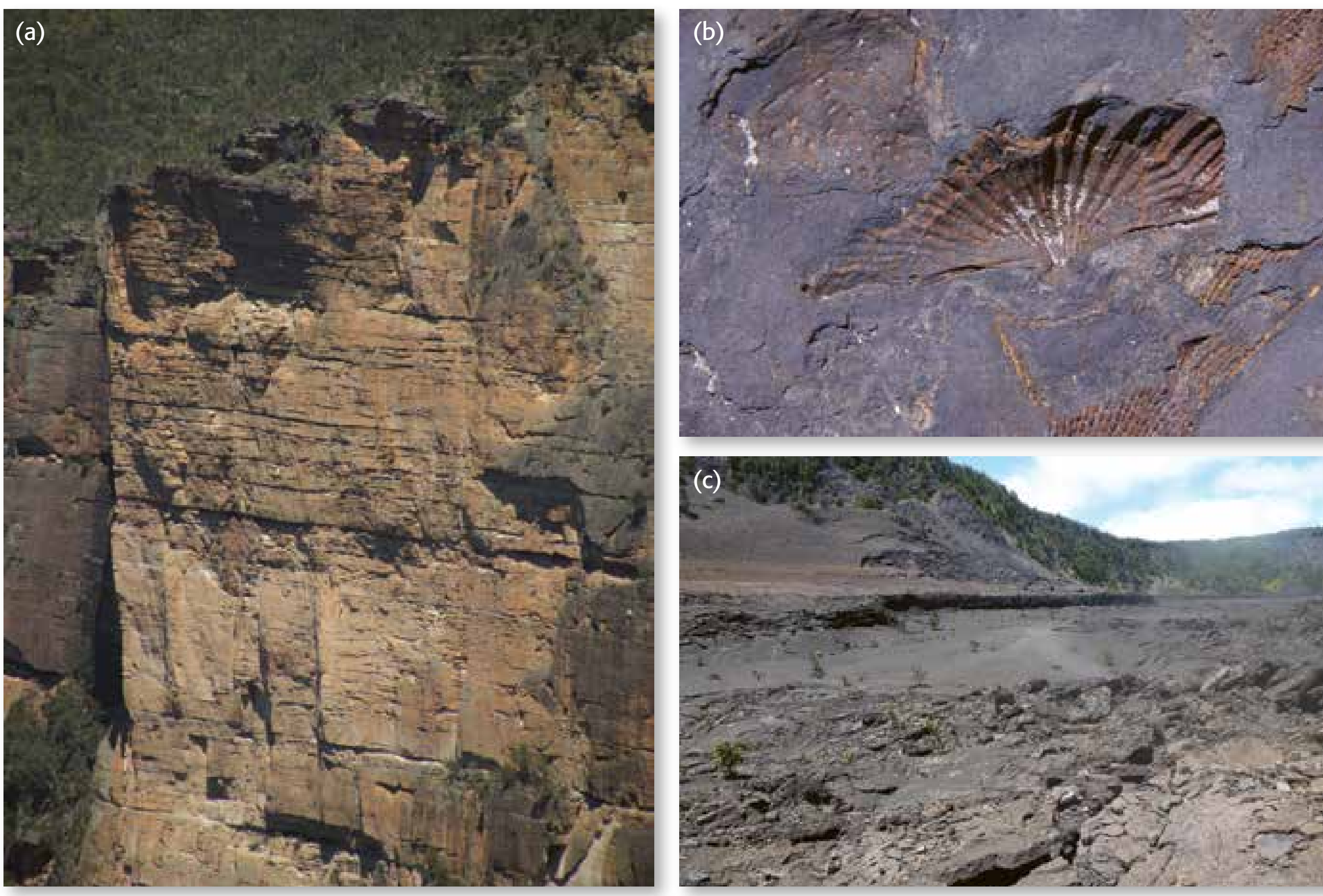


Figure 1.4 How did these form? (a) Beds of rock. (b) Fossils in sedimentary rock. (c) Layers of basalt.

Figure 1.5 Evidence (a) Unconformity showing rocks at different angles. The bottom rocks were deposited first before being tilted to a near vertical position. After being eroded, another layer of rocks was deposited horizontally and the whole formation tilted again. (b) Granite penetrating other rock showing that it must have been molten at the time.

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 1.5 (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 geologic 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 1.5 (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 evolution, erosion and the deposition of sediments has been fairly constant throughout Earth's history. This means we can use present day geologic processes 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 geologic 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 1.6). He helped establish geology as a scientific discipline and also popularised James Hutton's principle of uniformitarianism.

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 Joly used modern measurements of different added 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.

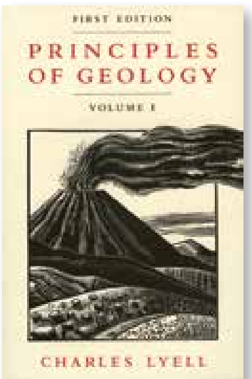


Figure 1.6 Principles of Geology First published in 1830 this was the first modern geology textbook.

In 1855 eminent British physicist William Thomson (1824-1907) – 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 to 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 geologic 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 1.7). 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 1.7 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 off 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.

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 1.8). If we had 20 grams of a radioactive isotope with a half-life of 2 minutes, then after 2 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 1.1.

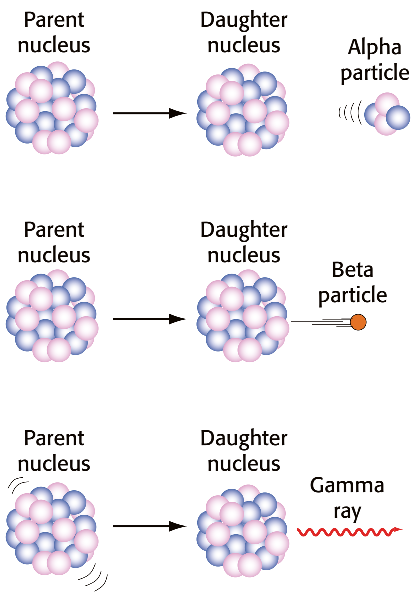


Figure 1.8 Radioactive decay Radioactive particles are emitted by the nucleus.

Table 1.1 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 JWS Rayleigh (1842-1919) developed a relatively simple radioactive dating technique to determine the age of certain minerals commonly present in suitable rocks.

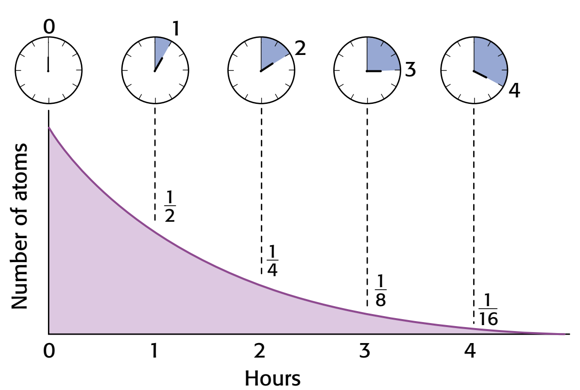


Figure 1.9 Radioactive decay Decay is at a constant rate.

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 1.9). 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.

How Scientists Found the Oldest Rock on Earth
https://www.youtube.com/user/DNewsChannel

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 crystallises 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 crystallised.

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.

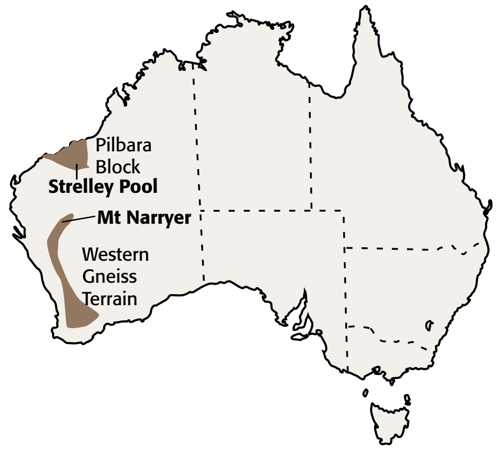


Figure 1.10 Mount Narryer One of the oldest sections of Earth's crust.

Presently, the oldest piece of the Earth's crust ever sampled is from Mount Narryer in Western Australia (Figure 1.10). The highly resistant mineral zircon has been found in rocks here and these have been dated to between 4100 and 4200 million years (Figure 1.11).

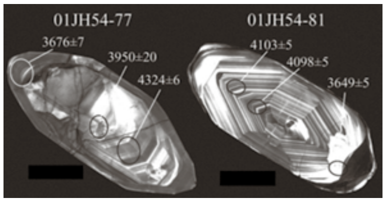


Figure 1.11 Zircon crystals These microphotographs show two tiny zircon crystals from Mount Narryer in Western Australia. The circles show areas where the crystals were analysed using radiometric dating techniques comparing uranium-lead isotopes. The numbers show the estimated age of each section in 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.

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.

Table 1.2 Geologic events.

No.	Geologic event	Time (millions of years ago)
1.	End of Precambrian 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

ACTIVITY 1.2
TIME (TO) SCALE

Aim: To gain a perspective of geologic time.

Apparatus: Each student needs a pencil, ruler, geologic event dates (Table 1.2).

Risk assessment: Low.

Method

1. Stick 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 for Activity 1.3.

SCIENCE SKILLS

Graphs

1. A graph for the radioactive decay of technetium-99 is shown in Figure 1.12.

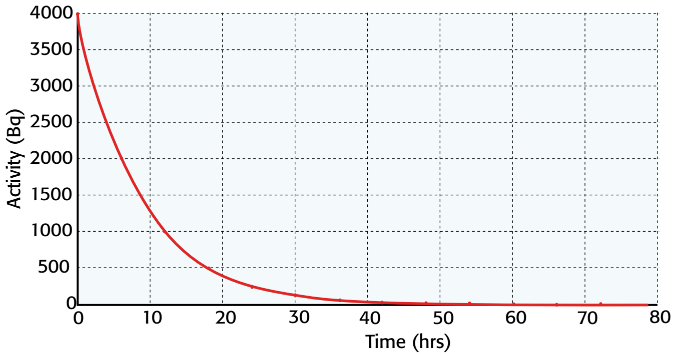


Figure 1.12 Radioactive decay Decay of the element technetium-99.

(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.

2. Table 1.3 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 1.3 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

SCIENCE SKILLS

Here are three more verbs we will be using.

1. **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 how radioactivity can be used to date rocks.

Answer:

Imagine that element A undergoes radioactive decay to form element B. In igneous rocks, the radioactive ‘clock’ for element A is set the moment the rock first crystallises from magma. Precise measurements of the amount of element A relative to element B in the igneous rock can tell us the amount of time that has passed since the rock crystallised and hence its age.

2. **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 uniformitarianism.

Answer:

Uniformitarianism is the principle that we can use present day geologic processes to explain the geology from the past.

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 how catastrophism failed to account for a geologic features found on Earth.

Answer:

Granite has been found penetrating other rocks including both metamorphic and sedimentary rocks and could not have crystallised from water. The only way this could have happened was if the granite was molten when the penetration took place.

TO THINK ABOUT

Set 1

1. **Define** the word unconformity.
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 stupid or a fool for being wrong? **Explain** your answer.

Figure 1.13 Basalt layer How can this black strata be explained?

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.
10. Figure 1.13 shows a layer of basalt.
    (a) Use catastrophism to **explain** this layer of rock.
    (b) Use uniformitarianism to **explain** this layer of rock.

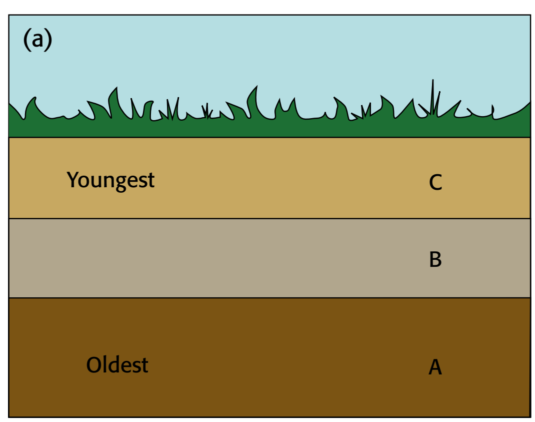
1.3 Stratigraphy

Can you believe in **catastrophism** and still make major advances in science? Nicolas Steno (1638-1686) was just such a person (Figure 1.14). While motivated by the Bible (he joined the priesthood after becoming a medical doctor), he was able to make major advances in our knowledge of human anatomy as well as in geology.

Figure 1.14 Nicolas Steno Made contributions to many aspects of science.

Stratigraphy

Steno became interested in rock strata (layers) and the inclusions found within them. He tried to work out the geologic history of Tuscany in Italy, where he was living at the time. As he did so, he was able to devise some simple rules that are still used today. These rules form the basis of what we now call **stratigraphy** – the science of identifying the *relative* ages of the layers of sedimentary rocks.



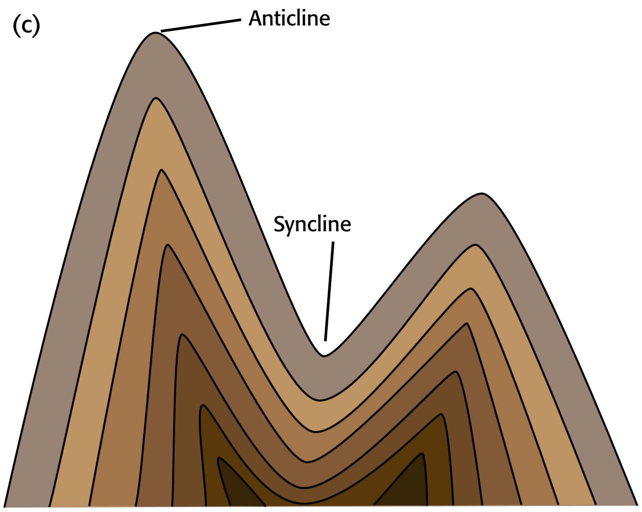


Figure 1.15 Superposition (a) Sedimentary strata are younger than the ones below them, like layers of icing on a cake. (b) These beds (which were horizontal when they formed) have been deformed into folds. (c) Folds that point upwards are known as anticlines, and those that point downwards are called synclines.

1. The law of superposition

Normally sedimentary rocks are deposited from water. They settle to form horizontal layers. As long as they are not deformed in some way, a bed of rock is older than the one above but younger than the one below. Figure 1.15 (a) shows beds of rock where layer B is younger than A, but older than layer C. This is called **superposition**. These same principles work with beds of volcanic rock formed from lava flows or from volcanic ash. Figure 1.15 (b) shows rocks that have been deformed by folding and great care is needed to interpret them.

2. The law of cross-cutting relations

When rocks fracture and move relative to each other we say that a **fault** has been formed (Figure 1.16 (a)). The fault must then be older than the rocks that it cuts across. This is called **cross-cutting**.

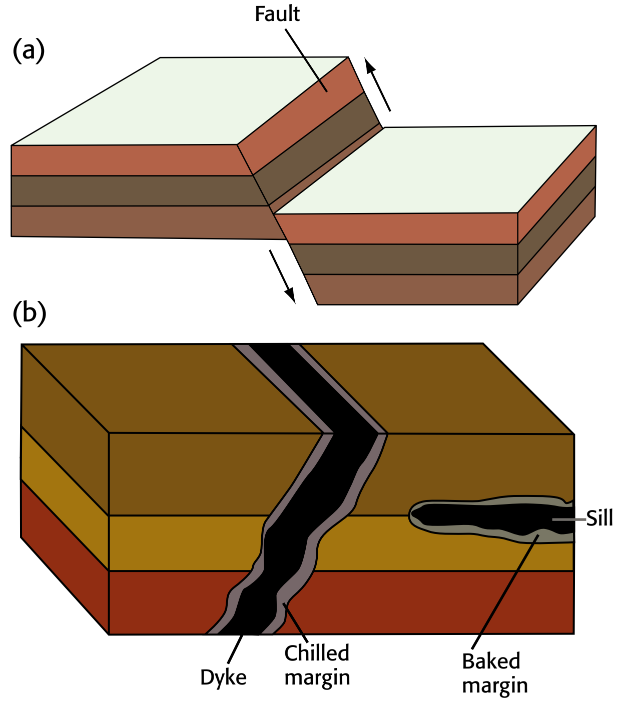


Figure 1.16 Cross-cutting (a) Because the sedimentary layers had to pre-exist the fault that broke through them, this fault is younger than the rocks it cuts across. Also the matching but displaced layers on either side of the fault are the same age. (b) Both the volcanic dyke and sill are older than the rocks they cut across.

Molten rock is called **magma**. When magma forces its way into other rocks we say that it is an **intrusion**. It may solidify to form a **dyke** that cuts across other rocks (Figure 1.16 (b)). This dyke must be younger than the rocks it cuts across. The magma may also form a **sill** if it forces its way between other rocks. The sill is younger than the rocks that it intrudes.

3. The law of inclusions

The law of inclusions was also described by James Hutton. Fragments of a rock unit (*xenolith* meaning foreign rock) which are found inside another (host) rock unit must be older than the host rock (Figure 1.17). This may occur in sedimentary environments, where pieces of pre-existing rock can be ripped up and included in younger sediments. Alternatively, when igneous rocks are intruded, fragments of the existing rock may be incorporated into the intrusion.

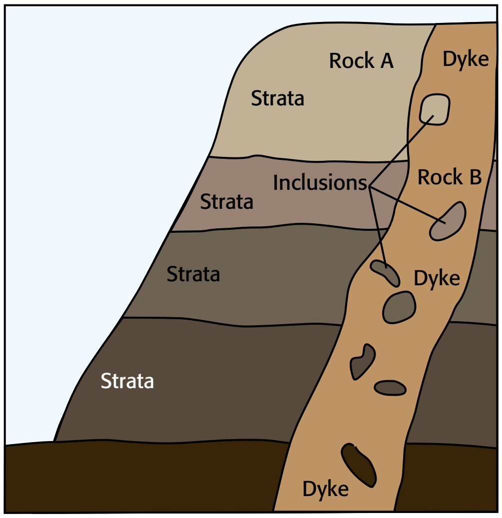


Figure 1.17 Inclusions If a rock body (Rock B) contained fragments of another rock body (Rock A), it must be younger than the fragments of rock it contained. The intruding rock (Rock A) must have been there first to provide the fragments.

Correlation

William Smith (1769-1839) started his career as an assistant to a surveyor (Figure 1.18). While working at a coal mine he noticed that rocks of the same appearance were always in the same relative positions. His observations continued when he was involved in the construction of canals. He compared the appearance of rocks he found and discovered they had similar collections of fossils.

Figure 1.18 William Smith Used correlation to draw some of the first geologic maps.

The use of fossils allowed similar rocks to be mapped over quite large distances. The appearance of the rocks may change but the fossils they contain remained the same. As he travelled the country, he examined the sequence of rocks and their fossils in cliff faces, along road cuttings, canals and railway embankments and in quarries. He was able to construct a sequence of rocks that he represented in cross-sections (Figure 1.19). Not all regions had strata with the same fossils. Some fossil types were missing but using those that remained a complete picture could be put together.

This process of comparing rocks by appearance, the minerals they contain and the fossils present is called **correlation**. Geologists have been able to construct a sequence of such rocks and their fossils from all over the world. Since we know that the rocks above a known layer will be younger, it gives a **relative date** for each (i.e. layer B is older than layer A but younger than layer C) (Figure 1.19).

For a long time, geologists were frustrated by their inability to attach any **absolute dates** (i.e. years) to rocks or fossils. However, the discovery of radioactivity provided a solution. Igneous rocks contain some radioactive minerals which, with the right technology and expertise, can be read like a clock. The presence of igneous rocks anywhere in a geologic cross-section allows for absolute ages to be estimated in years (Figure 1.20).

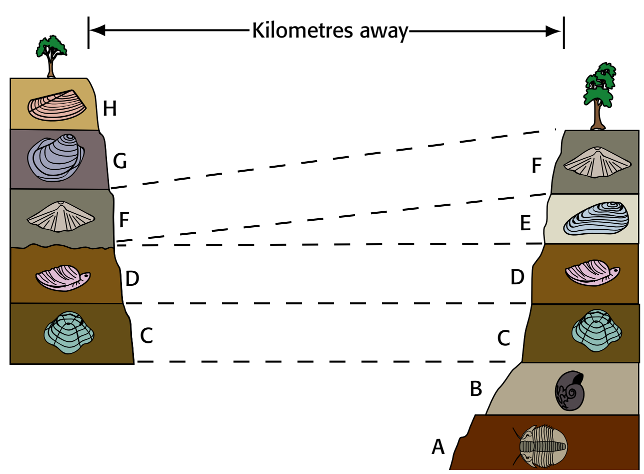


Figure 1.19 Cross-section The same sequence of rocks and their fossils appeared all over the country.

Answers

Chapter 1 Development of the Geosphere

1.1 Change and interactions

1. Many answers: Smartphones; Facebook; watch phones.
2. Many answers: Weathering of rocks and buildings; soil erosion; movement of Australia towards New Guinea.
3. Many answers: Slow movement of New Zealand towards Australia; volcanic eruptions and earthquakes in New Zealand.
4. Many answers: Slow ecological change includes the invasion of cane toads; fast ecological change includes clearing of forests for housing.
5. Many answers: Interaction between trail bikes and the forest they ride through; interaction between a flowing stream and nearby forest or grassland.

1.2 Geologic time

1. A gap in layers of rock due to a period of non-deposition, weathering, or erosion. In particular, when rocks are at an angle to each other after tilting and erosion before new layers are deposited.
2. James Hutton.
3. Catastrophism seemed to explain the geologic strata around the world. It had the backing of the Church and there was no other viable theory at the time.
4. Radiometric dating.
5. 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.
6. Lord Kelvin was a physicist who was able to use mathematics to arrive at his date. He measured the rate of cooling of spherical metal balls, and then extrapolated to the known size of the Earth. He assumed that the only heat available came from the molten magma in the interior of the Earth.
7. Lord Kelvin was not aware of radioactivity and how this would generate extra energy to heat the interior of the Earth. Had he known of radioactivity he could have added the heat generated to that already present in the molten magma and thus come to a better estimate of the age of the Earth.
8. Scientific progress takes place all the time. Kelvin's estimate was the best available based on the knowledge at hand. Thus Kelvin was not stupid. When the new discovery of radioactivity took place, better age estimates could take place.
9. Sediment deposited = 1000 m/200 000 years = 5 mm per year.
10. (a) The layer of basalt was deposited before or during Noah's flood. During the flood the layers above were deposited. As the flood waters receded it eroded the valleys thus exposing the cliffs visible today.
    (b) Earth's history includes periods of volcanic activity that could have deposited the basalt as happens to this day. This was followed by periods of deposition to produce the layers above, some of which are hard enough to produce the small cliff. The region is then eroded to produce the valley that allows the cliffs to be exposed.

1.3 Stratigraphy

1. Eon (largest); era; period; epoch (smallest).
2. Too large to fit on a page. For example, even if we had 1 mm = 1 million years, the Precambrian would be 2400 mm = 2.5 m long.
3. While stratigraphy can tell you which strata is younger and which is older, it does not tell you the absolute age unless it can be dated radiometrically.
4. The law of superposition is most useful as nearly all studies of rock sections must use this technique. Law of cross-cutting relations and law of inclusions are used far less frequently.
5. A relative time scale can become an absolute time scale if rocks can be dated using radiometric methods.
6. For example: Geoscience Australia has a large poster that can be viewed.
   The National Geographic Time Scale allows you to click through a number of small screens that show you how the continents have moved and the flora and fauna for each period.
   The Smithsonian Museum of Natural History allows you the visit many pages from the Geologic Time Scale giving you much more detail.
7. A more detailed fossil record in recent geologic history such as the Quaternary allows for finer divisions in the geologic record. Periods such as the Cambrian are so old that a lot of their fossil content has been lost so we have less detail to allow for dating.
8. The Quaternary (1.6 million years) is about half the length as the Tertiary (65 million years) rather than around 2.5 per cent of the length.
9. Figure 1.21 gives a better idea of the length of geologic time while Table 1.2 allows more detail to be recorded.
10. Several examples exist. For example, the end of the Cretaceous is marked by a large asteroid striking the Earth near modern-day Mexico. The tsunami that resulted, and the huge dust clouds generated helped to lead to a mass extinction. At about the same time there were massive lava flows in what we now call the Deccan plateau in southern India.

1.4 Origins of the Universe

1. The edge of the Universe is believed to be 13.7 billion light years from Earth.
2. 100 million = 10^5; 1 trillion = 1 million million = 10^{12}.
3. Hydrogen and helium.
4. The invention of powerful telescopes allowed astronomers to see objects such as the Andromeda Galaxy. Since this galaxy had a spiral structure, and was made up of individual points of light, and moved in a very different manner to the stars in our own galaxy, it must be a separate galaxy.