SURFING

NATIONAL EARTH AND ENVIRONMENTAL SCIENCE

Unit 1 Introduction to Earth Systems

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Contents

Use the table of contents to record your progress through this book. As you complete each chapter, write the date completed, then tick one of the three remaining columns to guide your revision for later. The column headers use the following codes:

?? = Don't understand this very well at all. RR = Need to revise this. OK = Know this.

Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

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.

conctruct 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.

1 Geological Time

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 **geological time** – the vast period of time over which Earth's rocks have formed.

Determining Earth's age

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

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 1.1 Leonardo da Vinci made early estimates of the age of the Earth.

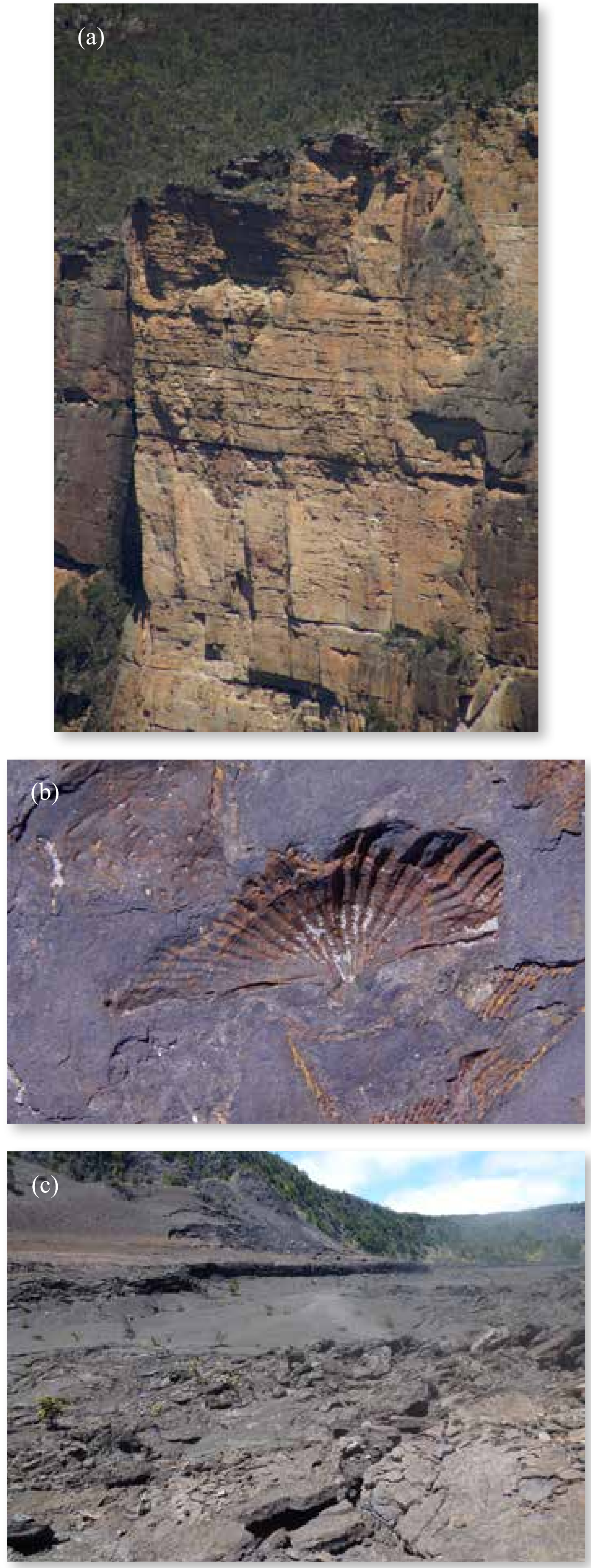


Figure 1.2 How did these form? (a) Layers of sedimentary rock. (b) Fossils in sedimentary rock. (c) Layers of volcanic basalt.

In 1654, the Irish scholar and Anglican archbishop James Ussher (1581-1656) calculated that the Earth was created in 4004 BCE. 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 1.2 (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 1.2 (a)).
- Fossils found in such rocks were buried during The Flood (Figure 1.2 (b)).
- Rocks such as basalt and granite had been crystallised from the waters of The Flood (Figure 1.2 (c)).

Uniformitarianism

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.

Pursuing a different line of evidence, in 1830 Scottish geologist Sir Charles Lyell (1797-1875) determined that 240 million years had passed since the beginning of the Cambrian period, when fossils first became abundant. He arrived at this age by comparing the degree of evolution shown in fossilised marine molluscs over time. Central to this estimate was the theory of **uniformitarianism**: that the rate of geological processes, such as erosion and the deposition of sediments, has been fairly constant throughout Earth's history. This contradicted the popular catastrophism theory. Geologists today believe the processes which shape the Earth are ongoing and generally very slow (uniformitarianism), but acknowledge that there are rare and dramatic events which can cause rapid and widespread change (catastrophism), for example, meteorite impacts and large volcanic eruptions.

Figure 1.3 The Breadknife was formed from hard volcanic rock.

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 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.

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 geological processes for much longer than this. Luckily for Chamberlin, breakthroughs to support his theory were just around the corner.

Radioactive decay

In 1896 French scientist Henri Becquerel (1852-1908) placed some uranium salts in a drawer along with sealed photographic plates. These plates, which normally are only exposed (altered) by visible light, were exposed by the salts even though they were in the dark (Figure 1.4). Becquerel had accidently discovered radioactive decay.

Figure 1.4 Becquerel's original plate that was exposed by the radiation emitted by the uranium salts. The outline of a metal Maltese cross that sat between some of the salts and the photographic plate is clearly visible.

In 1902 Nobel Prize-winning New Zealand-born physicist Ernest Rutherford (1871-1937) outlined his hypothesis of how **radioactive decay** occurs, and in 1904 suggested that radioactive decay of elements within the Earth acts as an additional source of internal heat, thus supporting Chamberlin over Kelvin.

In 1905 American chemist Bertram Boltwood (1870-1927) and British mathematician and physicist JW Strutt (1842-1919) developed a relatively simple radioactive-dating technique to determine the age of certain minerals commonly present in rocks. Their initial results 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.

Presently, the oldest piece of crust ever sampled is from Mount Narryer in Western Australia, dating between 4100 and 4200 million years (Figure 1.5). Because the Earth's crust is continuously recycled and destroyed, we are unlikely to find 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.

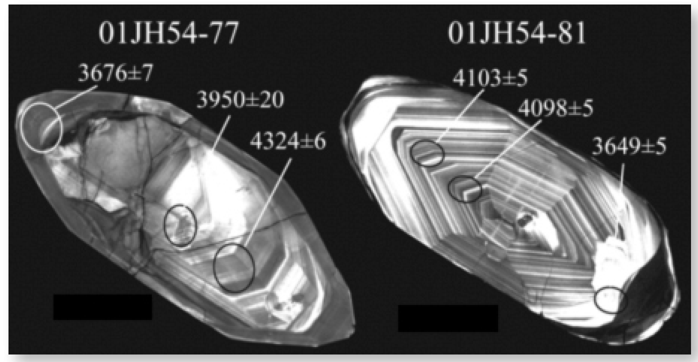


Figure 1.5 Microphotographs showing two tiny zircon crystals from Mount Narryer in Western Australia. The circles show areas where the crystals were analysed using radiometric dating techniques comparing uranium-lead isotopes. The numbers show the estimated age of each section in millions of years. While 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.

The development of our understanding of this time scale is a good example of the way science challenges its theories and modifies them in the light of new interpretations, new evidence and new technologies.

QUESTIONS

1. How does geological time differ from normal time?
2. Identify the location in Australia of some of the oldest known rocks.
3. Explain how the rocks in Figure 1.3 provide evidence for an old Earth.
4. Outline two pieces of evidence from before 1800 that the Earth was more than 6000 years old.
5. Compare catastrophism with uniformitarianism.
6. Explain how the discovery of radioactive decay altered our beliefs about the age of the Earth.
7. Explain why the estimated age of the Earth has become older in the last 50 years.
8. Explain why William Thomson's estimate of the age of the Earth went mainly unchallenged for a period of time.
9. The basalt in Figure 1.2 (c) was formed during a volcanic eruption in Hawaii. Does this support uniformitarianism or catastrophism?
10. Use both uniformitarianism or catastrophism to explain Figure 1.2 (a).

2 Stratigraphy

Can you believe in **catastrophism** and still make major advances in science? Despite the apparent contradiction, Nicolas Steno (1638-1686) did just that (Figure 2.1). Though 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 2.1 Nicolas Steno made contributions to many aspects of science.

Steno became interested in rock **strata** (layers) and the inclusions found within them. He tried to work out the geological 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 rocks. The rules include the law of superposition and the law of cross-cutting relations.

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 2.2 (a) shows beds of rock where layer B is younger than A, but older than layer C. These same principles work with beds of volcanic rock formed from lava flows or from volcanic ash. Figure 2.2 (b) shows rocks that have been deformed by **folding** and great care is needed to interpret them. The top of the fold is called an **anticline**; the bottom is a **syncline**.

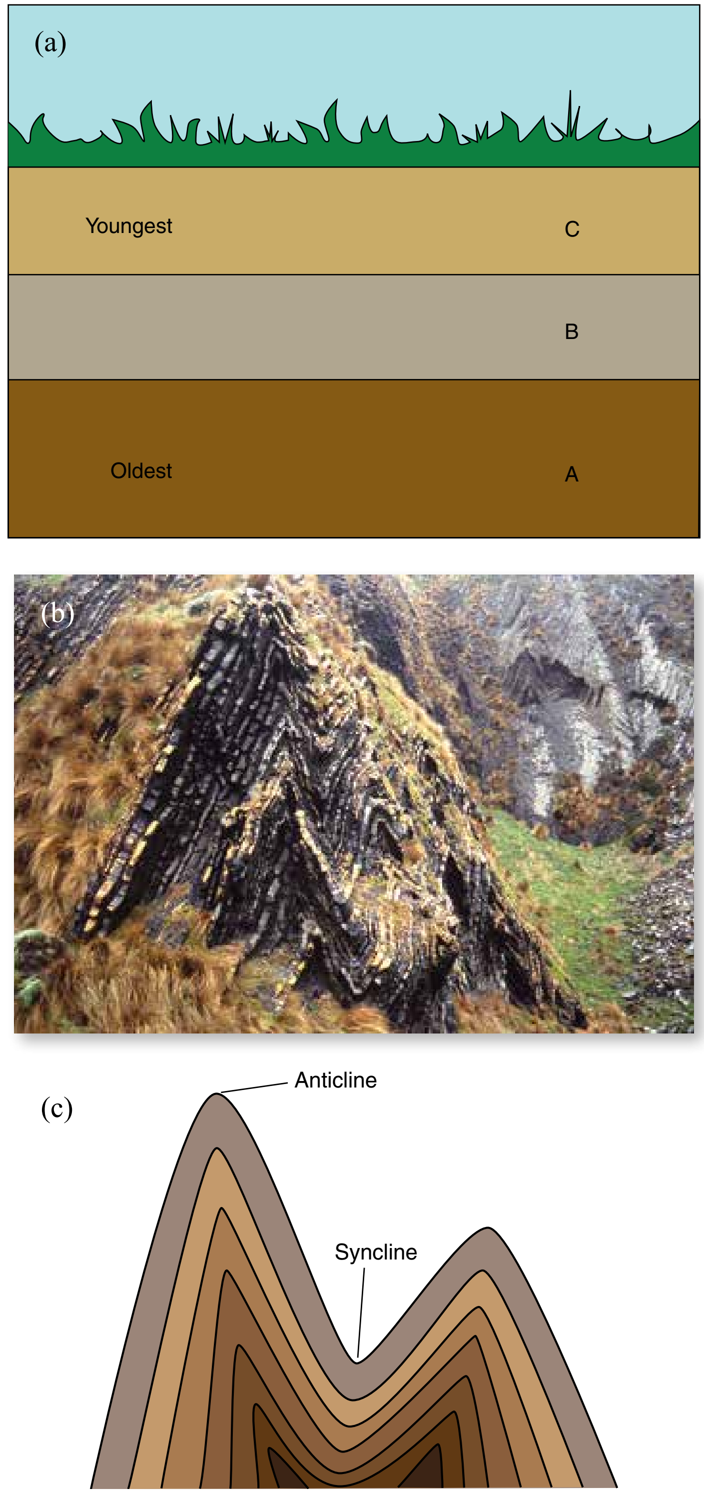


Figure 2.2 Superposition. (a) Sedimentary strata are younger than the ones below them, like layers of icing on a cake. (b) These beds (which were horizontal when they formed) have been deformed into folds. (c) Anticlines and synclines.

The law of cross-cutting relations

When rocks fracture and move relative to each other we say that a **fault** has been formed (Figure 2.3 (a)). The fault must then be older than the rocks that it cuts across. This is called **cross-cutting**.

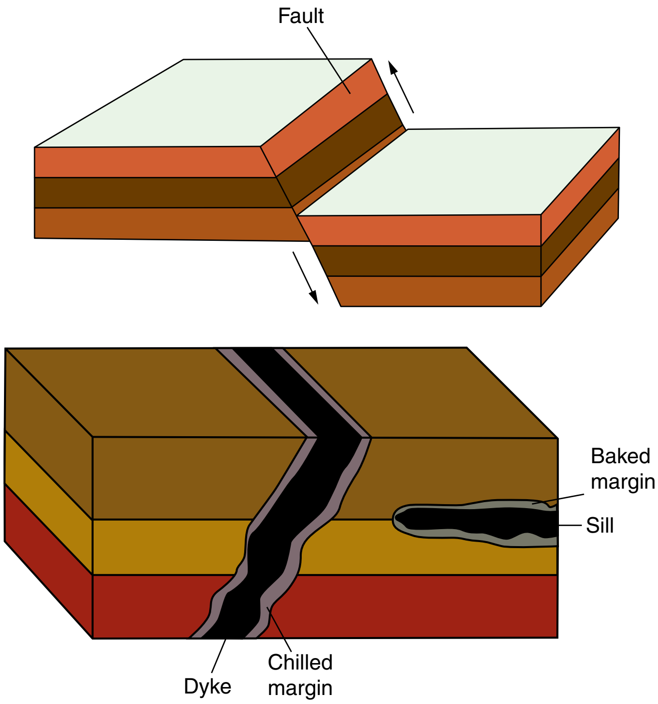


Figure 2.3 Cross-cutting. (a) Because the sedimentary layers had to pre-exist the fault that broke through them, this fault is younger than the rocks it cuts across. Also the matching but displaced layers on either side of the fault are the same age. (b) Both the volcanic dyke and sill are younger than 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 2.3 (b)). This dyke must be younger than the rocks it cuts across. The magma may also form a **sill** if it forces its way horizontally between other rocks (Figure 2.3 (b)). The sill is younger than the rocks that it intrudes.

Correlation

The Englishman William Smith (1769-1839) started his career as an assistant to a surveyor. 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. Not only could he compare the appearance of rocks he found that they had similar collections of fossils.

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 2.4). 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 (Figure 2.6).

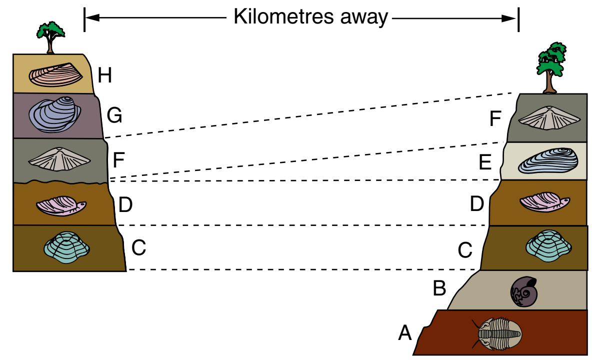


Figure 2.4 Cross-section. The same sequence of rocks and their fossils appeared all over the country.

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).

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 and how it could be used to provide absolute ages for radioactive minerals was the technological breakthrough they had been waiting for. 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 geological cross-section allows for absolute ages to be estimated in years.

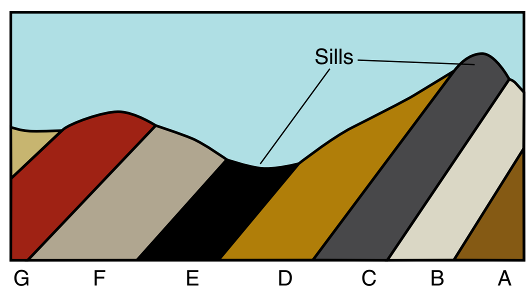


Figure 2.5 Volcanic sill C is dated at 150 million years old and volcanic sill E is dated at 170 million years old. It can therefore be inferred that layer B must be younger than 150 million years old, layer D must be between 150 and 170 million years old, and layer F must be older than 170 million years old.

Even if there are no volcanic layers in a region to give an absolute age, widespread sampling and correlation has taught geologists that the presence of certain fossils indicates the age of the sediments. Such fossils are referred to as **index fossils** and provide scientists with a reliable way to date sedimentary layers in the field.

The following ingredients have combined to give us the geological time scale that we have today (Figure 2.6):

- The progression of ideas and evidence about Earth's age.

- New understanding about how rocks can be ‘read’ to reveal their relative ages.
- Breakthroughs in radiometric dating allowing absolute ages to be determined.
- The field observations of very many geologists all over the world.

QUESTIONS

1. Define the word stratigraphy.
2. Compare the law of superposition with the law of cross-cutting.
3. Both a fault and a dyke cut across beds of rock. How do they differ?
4. Compare anticlines with synclines.
5. How does absolute dating differ from relative dating?
6. Describe what happens during correlation.
7. Explain why index fossils are important.
8. Use Figure 2.3 (b) to determine the order of deposition of the rocks shown.
9. Use Figure 2.5 to determine the order of deposition of the layers shown.
10. Use Figure 2.6 to determine two index fossils used to identify Jurassic rocks.

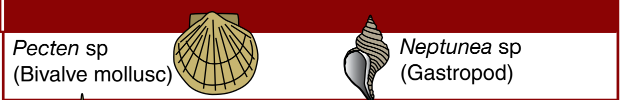
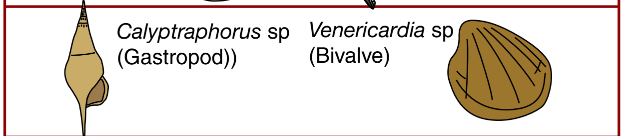
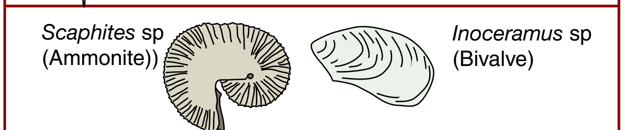
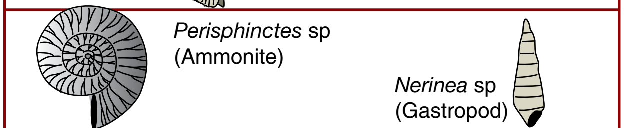
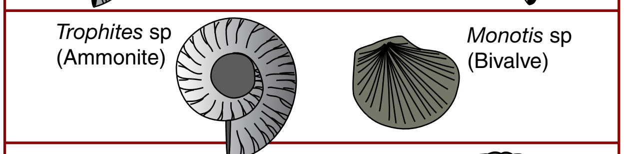
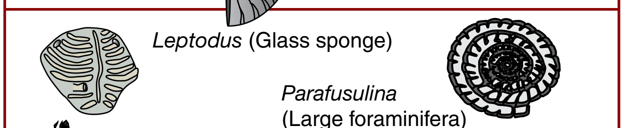
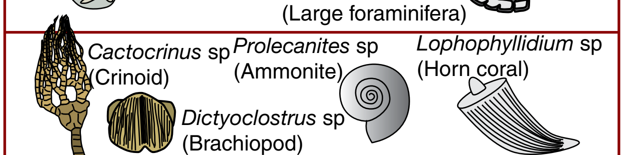
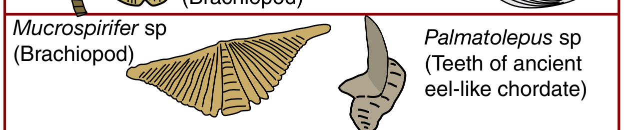
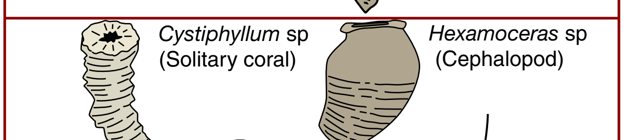
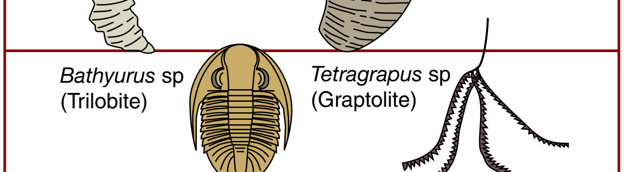
Eon	Era	Period	Age (millions of years ago)	Animal life Examples
Phanerozoic	Cainozoic	Quaternary	1.8	 *Pecten* sp (Bivalve mollusc); *Neptunea* sp (Gastropod)
		Tertiary	65.5	 *Calyptraphorus* sp (Gastropod)); *Venericardia* sp (Bivalve)
	Mesozoic	Cretaceous	145.5	 *Scaphites* sp (Ammonite)); *Inoceramus* sp (Bivalve)
		Jurassic	199.6	 *Perisphinctes* sp (Ammonite); *Nerinea* sp (Gastropod)
		Triassic	251	 *Trophites* sp (Ammonite); *Monotis* sp (Bivalve)
	Palaeozoic	Permian	299	 *Leptodus* (Glass sponge); *Parafusulina* (Large foraminifera)
		Carboniferous	359	 *Cactocrinus* sp (Crinoid); *Prolecanites* sp (Ammonite); *Lophophyllidium* sp (Horn coral); *Dictyoclostrus* sp (Brachiopod)
		Devonian	416	 *Mucrospirifer* sp (Brachiopod); *Palmatolepus* sp (Teeth of ancient eel-like chordate)
		Silurian	444	 *Cystiphyllum* sp (Solitary coral); *Hexameceras* sp (Cephalopod)
		Ordovician	488	 *Bathyurus* sp (Trilobite); *Tetragrapus* sp (Graptolite)
		Cambrian	542	 *Billingsella* sp (Brachiopod); *Paradoxides* sp (Trilobite)

Figure 2.6 The existence of certain plant and animal species is known to have occurred only during specific geological time periods. The occurrence of these fossils in rock strata can be used to date the layer in years.

3 Reading the Rocks

QUESTIONS

1. Figure 3.1 shows a geological cross-section of an intrusion into beds of sedimentary rock.

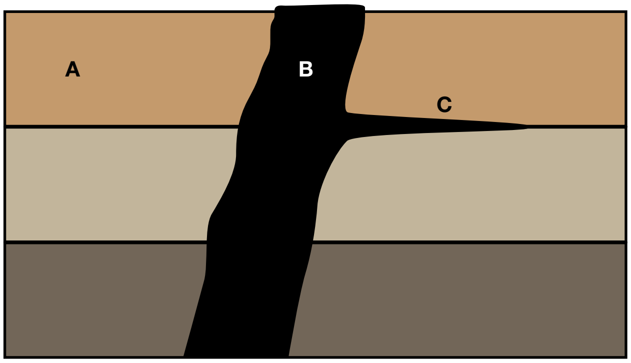


Figure 3.1 An intrusion.

(a) Identify the structures labelled A, B and C.
(b) Determine the order of the geological events shown.

2. Figure 3.2 shows a geological cross-section of folded rocks.

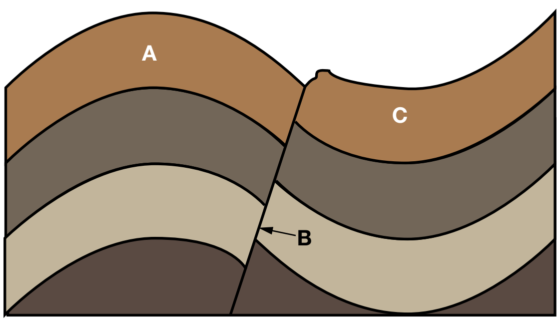


Figure 3.2 Folded rocks.

(a) Identify the structures labelled A, B and C.
(b) Determine the order of the geological events shown.

3. Describe the sequence of events that led to the cross-section shown in Figure 3.3.

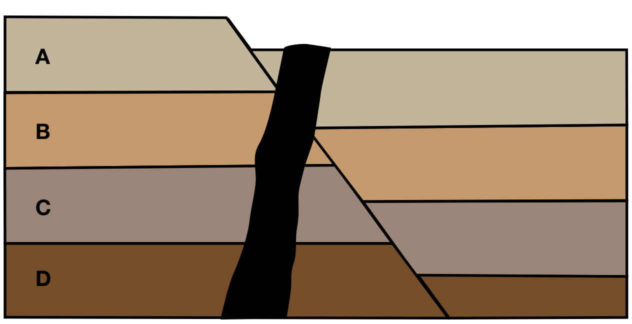


Figure 3.3 Cross-section.

4. Describe the sequence of events that led the cross-section shown in Figure 3.4.

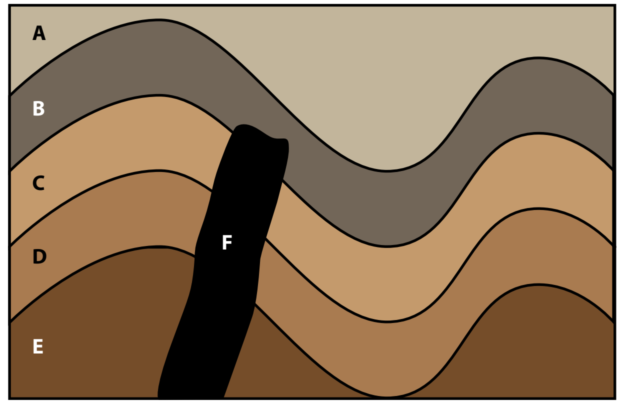


Figure 3.4 Cross-section.

5. Draw a geological cross-section for the following events. Sedimentary layers A, B, C and D are deposited in this order. They are then folded so that one large anticline is formed. A dyke then intrudes one side of the anticline.
6. Identify the geological structure in Figure 3.5.

Figure 3.5 Geological structure.

7. Identify the geological structure in Figure 3.6.

Figure 3.6 Geological structure.

4 Origins of Earth

The story of how the Earth began actually starts with the story of how the Universe began. The term 'universe' means the collection of everything in existence that we know of: all space, all time, all matter and all energy. The Universe is vast beyond our comprehension. It contains between 100 billion and one trillion galaxies, each of which on average contains a few hundred billion stars.

Of all the atoms in the entire Universe, scientists calculate that 90% of them are hydrogen (although because it is the lightest element, it only accounts for 74% of the total mass of the Universe). The Earth has a much lower proportion of hydrogen because most of this gas was lost as our planet formed (more on that later). Most of the hydrogen left on Earth is found locked up in water (H_2O).

Edwin Hubble

Most people know the name Hubble because of the famous Hubble Space Telescope, the first large telescope put in orbit around the Earth in 1990. It was nowhere near the biggest telescope in the world, but by being in space it was free of atmospheric interference and the Earth's rotation. It could peer longer, deeper and more clearly into the Universe than ever before (Figure 4.1). Most people do not know that this telescope was named in honour of American astronomer Edwin Hubble, who made two breakthrough discoveries which forever changed our understanding of both the size and the origins of our Universe.

In 1919, Hubble was hired as an astronomer at the Mount Wilson observatory in California just as a new telescope there was being finished. At the time it was the largest optical (i.e. visible light) telescope in the world. For centuries before Hubble, astronomers had looked through smaller telescopes and observed what appeared to be glowing clouds in space – diffuse, luminous objects with smudged edges unlike the clear points of light that are stars. They named these oddities 'nebulae' and assumed that they were floating around within our Milky Way galaxy along with everything else we could see in the night sky. Prior to Hubble, it was thought that our galaxy was the full extent of the Universe.

Using Mount Wilson's superior telescope combined with the new technique of astronomical photography, Hubble proved that these 'clouds' were in fact made up of individual points of light – stars. He correctly concluded that they are so distant from us compared to the other stars we see that they are separate galaxies existing outside our Milky Way galaxy. This claim published in 1925 sent a huge shock wave through the scientific world. Almost overnight, the Universe as we knew it got a whole lot bigger.

Figure 4.1 The Hubble Space Telescope offered astronomers unprecedented views of the heavens. This image shows a mountain of dust and gas rising 3 light years tall in the Carina Nebula. This pillar of cool hydrogen is being worn away at the top by radiation from nearby stars, while stars within the pillar vent jets of gas that stream from the peaks.

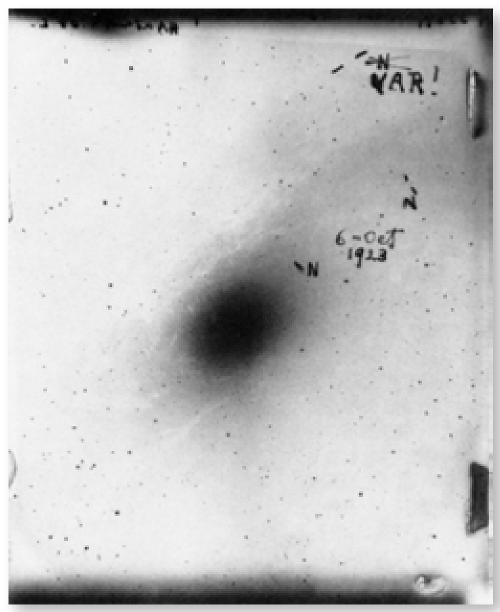


Figure 4.2 This photographic negative taken by Hubble shows individual stars (seen as dark dots) that are visible within a galaxy outside our own. If viewed with a magnifying lens, huge numbers of small individual stars become visible.

This discovery alone would have been enough for Hubble to be remembered in the history of astronomy, but more was to come. After carefully analysing the light from these galaxies, he noticed that the light from most of them was red-shifted by the **Doppler effect** (meaning that they are moving rapidly away from us). Furthermore, the more distant these galaxies are from us, the faster they are moving away (Figure 4.3). The Universe appeared to be flying apart!

The Big Bang versus Steady State

Hubble's conclusion that the galaxies were flying apart was controversial and again quickly confirmed by other astronomers. The next big question was …Why? **Cosmologists** (astronomers specialising in theories of the origin and future of the Universe) were divided into two opposing camps.

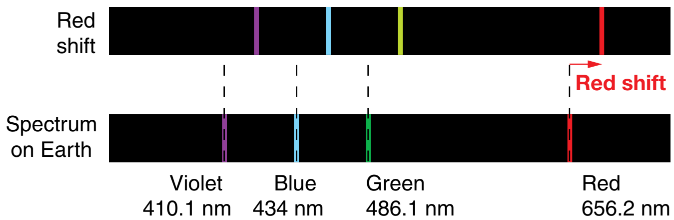


Figure 4.3 Red shift showing how the spectra of stars differs from that on Earth as they move away from us.

In one corner were the **Steady State theory** supporters. These men and women represented the established and ancient view that the Universe was generally unchanging and that it is infinitely old. 'If the galaxies are moving apart' they argued 'then new matter must be continually created between them to fill the gaps. This would preserve the appearance and distribution of matter in the Universe for all time.' This group was led by the eminent British astronomer **Sir Fred Hoyle** and Austrian born **Thomas Gold.**

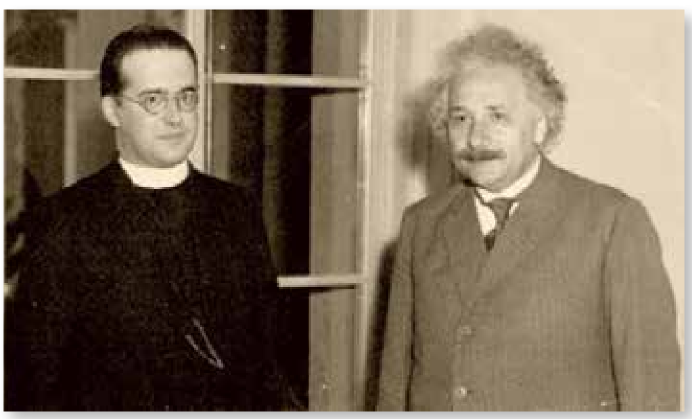


Figure 4.4 Monsignor Georges Lemaître: priest and scientist with Albert Einstein (right). Einstein publically applauded Lemaître's theory of an expanding universe, which used Einstein's new theory of general relativity as its basis.

In the other corner were a group who supported the new idea that if the galaxies are flying apart then they must have been much closer together in the past. If you rewind the observed expansion, you are left with an impossibly small, hot and dense point where the Universe had, for some reason, burst into existence in the distant past. This radical idea was first proposed in 1927 by the physicist, mathematician and Catholic priest **Georges Lemaître**. In an attempt to either explain or ridicule this idea, Hoyle referred to it as the **Big Bang theory** during a radio interview and the catchy name stuck. This theory predicted that the Universe was created at some definite time in the past, and that it would look very different if you viewed it in the distant past or in the distant future. In other words – the Universe is evolving.

The evidence mounts

As both radio and optical telescopes improved, astronomers were able to peer deeper and deeper into the Universe, and therefore further and further into the past. What they found was strange, but it supported the Big Bang theory and made the Steady State theory look increasingly shaky.

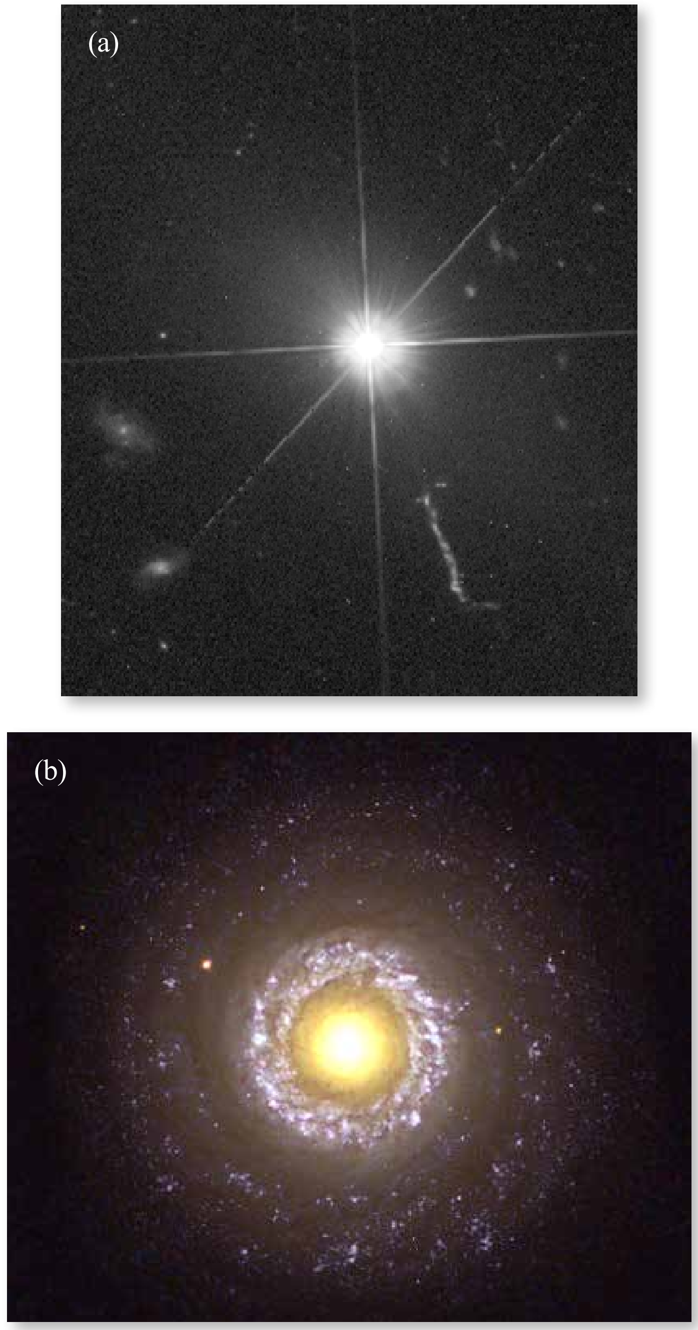


Figure 4.5 (a) Quasar 3C 273 in the constellation Virgo is 2.4 billion light years from Earth and was the first quasar ever discovered. (b) Seyfert Galaxy NGC 7742.

In the 1950s some strong radio signals from deep space were studied and found to resemble stars in that they were a point source rather than diffuse (spread out) like galaxies. They became known as quasi-stellar radio objects, or **quasars** (Figure 4.5 (a)). In the 1960s improved telescopes were able to see the visible light from them, however they were so far away – billions of light years in fact – that they were too bright to be stars. Quasars are astounding because they have the energy of thousands of galaxies squeezed into a tiny space less than 1 light year in diameter. The most distant quasars are around 13 billion light years away, so we see them as they appeared shortly after the Universe was formed. Since no objects like quasars appear in nearby space, the Universe must have looked very different in the past – a direct contradiction of Steady State theory. Astronomers now infer that each quasar is the very active nucleus of a galaxy in the early stages of formation.

The discovery of a new type of galaxy in 1943 also supported the Big Bang theory. These **Seyfert galaxies** are spiral galaxies that are not as distant as quasars, but have particularly brilliant nuclei (Figure 4.5 (b)). They seem to represent a stage in galactic evolution between quasars and normal galaxies like the Milky Way. Like quasars, these are not found in nearby space and so only existed in the distant past (contradicting Steady State theory).

Cosmic microwave background radiation: the echo of creation

Everything gives off energy. Even things that are extremely cold will radiate energy of some sort. In the 1960s a team of physicists from Princeton University theorised that if the Big Bang had happened, that it should have left a heat signature throughout all of space which should still be visible. They predicted that empty space should have a temperature of a few degrees above **absolute zero** (the temperature at which atoms cease to vibrate; minus 273^{o}C) and that this heat should be detectable as microwave energy. They then set about assembling the equipment needed to detect these microwaves.

Steady State theory claimed that the Universe was infinitely old and so empty space would have lost any heat it once had and be at a temperature of absolute zero. This small but fundamental difference of a few degrees proved to be the pivotal piece of evidence on which the two different theories would live or die.

Unbeknown to the team from Princeton, the most sensitive microwave antenna ever built was sitting just a few kilometres away at Bell Laboratories, and was being calibrated to assist with satellite communications. The scientists working with the large horn antenna (**Arno Penzias** and **Robert Wilson**) had a problem: no matter which way they pointed the antenna, they found an annoying and persistent hiss in the microwave signals they were receiving, like static behind a weak radio station signal. At first they assumed that it was interference from nearby New York City, but this was ruled out by further testing. Because the hiss was at such a constant frequency, they then assumed it originated with their systems or equipment. After all the electronics were checked, even the pigeons roosting in the horn were evicted and their droppings cleaned out, but the hiss remained. Penzias and Wilson were left with the conclusion that this weak but measureable microwave radiation was actually coming from deep space in every direction at the same frequency. When they published their findings, the disappointed team from Princeton confirmed that this signal exactly matched their prediction for the heat signal left over from the Big Bang, 'fossilised' in the skies above us.

Figure 4.6 The Holmdel Horn Antenna. Arno Penzias and Robert Wilson shared the Nobel Prize in Physics in 1978 for discovering the cosmic microwave background radiation with this antenna.

As with all new scientific claims, this observation was intensely investigated by other scientists. Its confirmation was the final nail in the coffin of the Steady State theory for most cosmologists. The fact that the Big Bang theory predicted the existence of this background heat made it a powerfully persuasive argument and it remains to this day the accepted cosmological theory by the scientific mainstream. This cosmic background radiation has been mapped in detail (Figure 4.7).

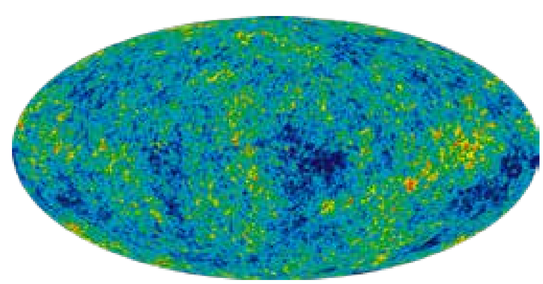


Figure 4.7 This image released in 2008 was taken by the Wilkinson Microwave Anisotropy Probe (WMAP satellite) and represents 5 years of precise mapping of the cosmic microwave background radiation in every direction. It shows tiny fluctuations in the radiation which represent tiny variations in the fabric of the early Universe. Red represents hotter, denser areas and blue represents cooler areas.

The formation of the Solar System

In the aeons after the Big Bang, as the Universe continued to fly 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 still see today). Much of this matter is hydrogen and 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.

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 4.8). Eventually, most of the material was located in a central sphere with a wide disc extending around its equator.

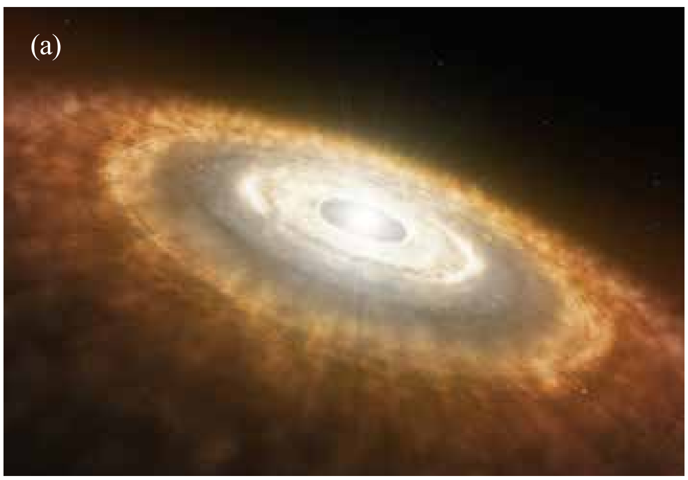


Figure 4.8 (a) An artist's impression of a protoplanetary disc. The centre region eventually ignites as a true star while the surrounding disc of debris forms the protoplanets. (b) A protoplanetary disc as seen through the Hubble Space Telescope. The light coloured background is the Orion Nebula.

Due to the huge internal pressures caused by its collapse, the central 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 4.9). 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.

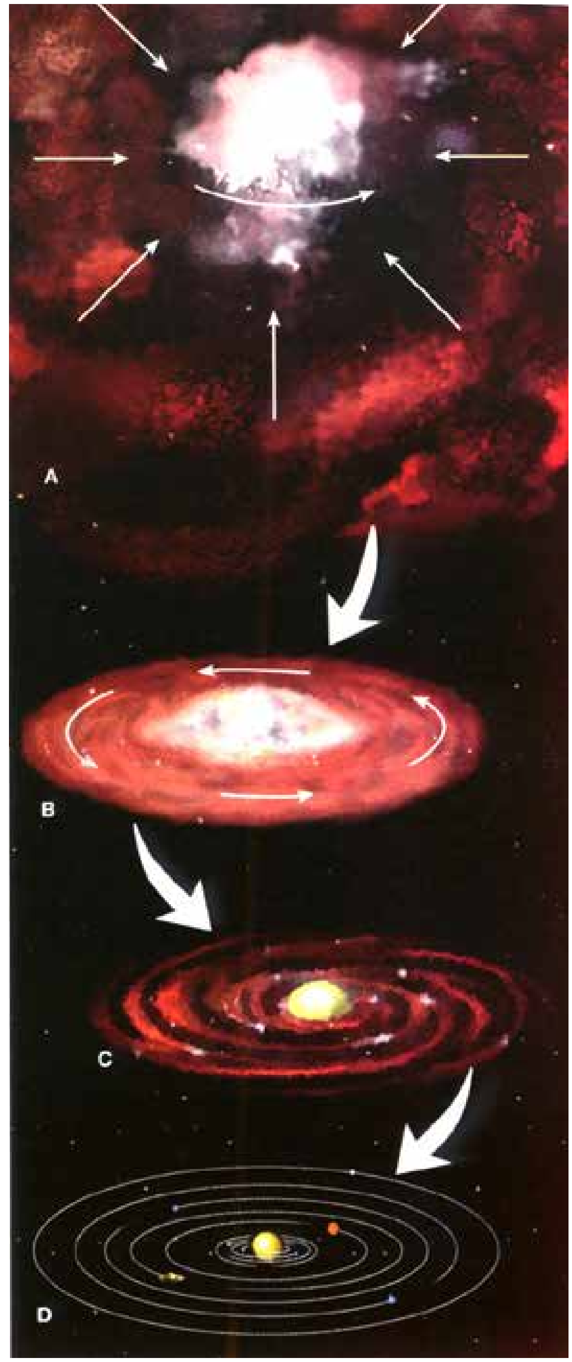


Figure 4.9 Formation of the Solar System. The Earth and other planets are the result of the accretion of dust and gases orbiting the sun.

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 $E = mc^2$. 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 System 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.

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.

Figure 4.10 Artist impression of the collision that led to the formation of our Moon.

These protoplanets would have been constantly bombarded with meteorites as they swept into each other or cleared their orbits free of debris. This bombardment not only increased the Earth's size and mass but 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.

Our Moon is believed to have been born out of one colossal impact between the Earth and another protoplanet the size of Mars (Figure 4.10). 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 signature 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.

QUESTIONS

1. Compare the two different theories regarding the origin of the Universe.
2. The Big Bang theory is accepted by most cosmologists today. Briefly outline the evidence supporting it.
3. Explain the difference between a scientific fact and a scientific theory.
4. Define cosmology.
5. Improvements in technology have played a major role in the development of cosmological theories. Identify at least five examples of technology that have contributed to cosmology or astronomy.
6. Outline the difference between a solar system and a galaxy.
7. Describe the process of the accretion of matter to form stars and planets.
8. Identify the discovery of Edwin Hubble that helped shape our theories about the origin of the Universe.
9. Explain the difference between an observation and an inference.
10. Arrange the following events into chronological order.
    (a) First stars form.
    (b) First life on Earth.
    (c) Moon forms.
    (d) Big Bang occurs.
    (e) First atomic nuclei form.
    (f) First humans.
    (g) First atoms form.
    (h) Milky Way galaxy forms.
    (i) Solar System and Earth form.
    (j) The four forces of nature separate.
    (k) First fundamental particles form.

Answers

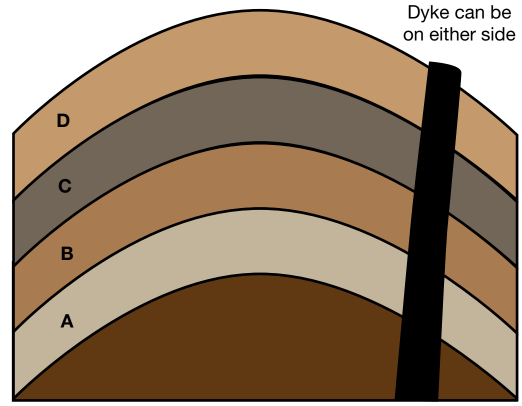
1 Geological Time

1. Geological time covers huge periods of time, often millions of years long. Everyday time covers much shorter periods of time.
2. Western Australia.
3. Normal processes of erosion would have taken millions of years to erode the softer surrounding rocks to leave the hard volcanic rocks.
4. Leonardo da Vinci studied the thickness of sediments in the 1500s. Georges de Buffon used the rate of cooling of the Earth.
5. Both catastrophism and uniformitarianism attempt to explain the geological record. Catastrophism used significant short-term events such as major floods. Uniformitarianism explains the record using much slower geological processes that occur today.
6. Kelvin had assumed that heat was stored inside the Earth at formation and estimated the age based on the rate of cooling. The discovery of radioactivity showed that there was a source a new heat inside the Earth that allowed it to be much older.
7. Exploration of remote regions has allowed even older rocks to be discovered and dated.
8. Thomson was a physicist who made use of mathematics to support his argument.
9. The volcanic eruption is relatively quick and is thus catastrophic. However, this did not occur during a great flood but rather as part of a long series of eruptions over millions of years that have built the island of Hawaii.
10. According to catastrophism, the huge layers of sedimentary rock would have formed during a single major flood. According to uniformitarianism the layers accumulate gradually over millions of years.

2 Stratigraphy

1. Stratigraphy is the science of identifying the relative ages of the layers of rocks.
2. Both laws are used to identify the relative ages of the layers of rocks. They differ in that the law of superposition is used to identify the order the beds are deposited, while the law of cross-cutting helps identify when faults and intrusions take place.
3. A fault is a break across layers of rock so that one section moves relative to the other. A dyke is an intrusion of magma across layers of rocks, with evidence of contact metamorphism along its edges.
4. When beds of rock are folded, the upward folds are called anticlines, while the downward folds are called synclines.
5. Relative dating only allows scientists to determine the order in which layers of rock are formed. Absolute dating allows the use of index fossils and radioactivity to assign an age in years to layers of rock.
6. Rocks in different locations can be correlated (assigned the same age) using index fossils or by matching the characteristics of the rock.
7. Certain fossils are characteristic of certain periods of time in Earth history. They allow scientists to assign rocks in different locations the same age when they contain the same index fossils.
8. From oldest: orange, brown, olive, sill, dyke.
9. From oldest: G, F, E, D, C, B, A
10. *Perisphinctes tiziani* and *Nerinia trinodosa*.

3 Reading the Rocks

1. (a) A = bed; B = dyke; C = sill.
   (b) Three horizontal beds were deposited in order from the bottom up, and then magma forced its way along a weakness to form a dyke and a sill.
2. (a) A = anticline; B = fault; C = syncline.
   (b) Four horizontal beds were deposited in order from the bottom up, and then folded. Finally a fault developed so that the rocks moved relative to each other.
3. Four horizontal beds were deposited in the order D, C, B and then A. Then a fault developed so that the rocks moved relative to each other. Finally a dyke cut across both the beds and the fault.
4. Four horizontal beds were deposited: E, D, C and B in that order. The beds were folded and magma forced its way through these same beds to form the dyke F. Finally sediment was deposited over the top to form layer A.
5. 

6. A series of faults at an angle about 45° to the horizontal.
7. An anticline in a road cutting.

4 Origins of the Earth

1. Differences include age of Universe, size of Universe, evolution of Universe, matter created once (Big Bang) versus ongoing matter creation (Steady State).
   Similarities include both explain observed expansion of Universe, both published in 1948.
2. • Radio galaxies are more numerous than the Steady State theory could account for, therefore the Universe must be changing.
   • Quasars are only found in very distant space which means they only existed in the very distant past. The Universe must therefore be changing.
   • Seyfert galaxies are only found in distant space which means they only existed in the distant past. The Universe must therefore be changing.
   • Background radiation (heat left over from the Big Bang) was predicted in 1948 and detected in 1965. Steady State theory cannot account for this energy.
3. A scientific fact is an observation which is replicated by all other scientists who investigate it, e.g. the Sun rises in the east and sets in the west.
   A scientific theory is a hypothesis or possible explanation which can explain why a set of scientific facts occurs, e.g. the Sun, Moon and stars rise in the east and set in the west because the Earth rotates towards the east.
4. Cosmology is the study of the origin and evolution of the Universe.
5. Optical telescopes, radio telescopes, satellites, computers, internet (e.g. data sharing).
6. A solar system is a 'family' of comets, asteroids and planets with their moons that are in orbit around a star or stars.
   A galaxy is millions of stars (some with their own solar systems) which are clustered together around a common centre of gravity at its centre.
7. Fine particles are clumped together as they collide. The clumps become fewer in number and larger in size. When large enough, they have enough gravity to pull other clumps towards them. Eventually, these form a large number of small planets. When their orbits bring them close, these small planets collide, leaving a few larger planets.
8. Based on observed red shifts, Hubble discovered that most observable galaxies are moving away from us, therefore the Universe is expanding.
9. Observation involves measuring a range of properties or directly viewing a phenomenon. Inference involves deducing from one idea or observation considered as true another whose truth is believed to follow from that of the former.