1
Geological time

1.1 Introduction

Why is geological time so important? It underpins everything we study in geology and Earth Science today and provides a framework for many other sciences. The age of the Earth and length of geological time have probably occupied human thought ever since we became conscious of our surroundings. For centuries, people have attempted to quantify and measure it with varying degrees of success. With a significant degree of certainty, we can now say that the Earth is around 4.65 billion years old, a figure that is, to most people, unimaginably long. Many "creation science" articles and books that talk about creationist stratigraphy, repeatedly claim that we use and misuse – in their view – geological time. So, is our perception of geology, Earth Science, the rock record, and geological time wrong?

Perception of time has changed significantly throughout history, depending on a variety of factors. Some of these will become apparent in the following chapters.

When we look at much of the controversy that surrounds geology and other sciences, we find that the perception and determination of time is frequently at the heart of the problem. However, why should this be an issue? The amount of time available for something to occur usually increases the possibility of it happening or the frequency at which it can take place. If time scales are short, changes and variations become more important; but as time scales increase, it is possible for the unusual to become, if not the norm, at least unexceptional. This is why time has been an almost constant battleground for centuries and why, even now, it plays an important part in how different groups of people think about Earth Science.

For this reason, it is worth spending some time reviewing the historical perspective of time and how, in the past, people have perceived and tried to determine the age of the Earth. This will give us an insight into how different views have developed or changed over the centuries.

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Discussion point

Before you read the following sections, consider your views on the following questions:

Why should the establishment of geological time be so important?
What are your perceptions of geological time and the age of the Earth?
Why should it be necessary to have some idea of the length of the age of the Earth?

1.2 The historical perspective

The Greeks and Romans identified many of their gods with geological processes. As early as the 6th century BC, the Greek philosopher Miletus thought that geological processes were the result of natural and ordered events, rather than the result of supernatural intervention. Equally, another Greek, Democritus, thought that all matter was composed of atoms and therefore formed the basis of all geological phenomena.

During the 4th century BC, Aristotle identified fossil shells as being similar to living seashells and therefore decided that as fossils are found on the land, the relative positions of the land and the sea must have changed in the past. He also felt that for these changes to have occurred, long periods of time would be required. One of his students, Theophrastus, later went on to write the first book on mineralogy – entitled *Concerning Stones* – which formed the basis of this subject through to the Middle Ages.

During the Medieval Dark Ages, people viewed the length of time that the Earth had been in existence as very short and, since the Earth had been made for humans, its historical time frame was man-based. It therefore had a beginning that was "not long ago, and ultimately, an end not far in the future". In other words, they had no real estimates of time but thought that the Earth was fairly young.

The idea that the Earth was only 6,000 years old was based on a combination of the six days of creation and Jesus' words: "one day is with the Lord as a thousand years, and a thousand years as one day", which is recorded in 2 Peter, chapter 3, verse 8, which leads to the age of 6,000 years (and 4,000 years before the birth of Christ). An age of 3952 BC was proposed by The Venerable Bede (672–735) and in 1583, Joseph Justus Scaliger (1540–1609), a French scholar, published *De Emendatione Temporum* in which he calculated the formation of the Earth to be 4713 BC (some publications include other dates, such as 3929 BC). He arrived at this date based on the combination of three known cycles:

1. The Solar Cycle, which refers to the 28-year cyclic behaviour of sunspots;
2. The Metonic Cycle, which refers to the 19-year period it takes for the same phase of the moon to occur in the same calendar month;
3. The Roman Induction, a cycle introduced by the Emperor Constantine for tax purposes, which has a period of 15 years.

Scaliger thought that the creation of the Earth must have been the first time that all three cycles coincided and he calculated that this occurred in 4713 BC, and would not occur again until 3267 AD. His date was used as the start date for the Julian calendar, which was introduced by Gaius Julius Caesar.

One of the first people to attempt to establish the age of the Earth, based on chronologies listed in the Bible, was Sir John Lightfoot (1602–1675). He was a vicar born in Stoke-on-Trent, who eventually became the Vice-chancellor of the University of Cambridge. Using the Bible as a reference, between 1642 and 1644 he decided that the Earth was formed at 9 am on the 26 October 3926 BC.

Shortly after this, James Ussher (1581–1656), who was Vice-Chancellor of the Trinity College Dublin in 1614 and 1617 and Bishop of Armagh in 1625, also calculated the age of the Earth using the Bible (Fig. 1.1).

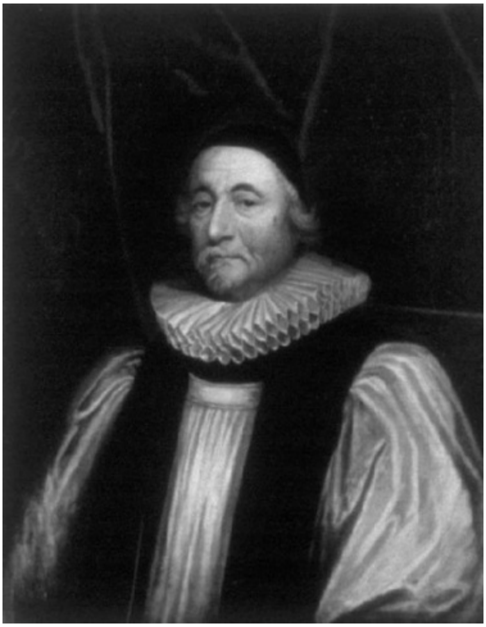

Fig. 1.1 **James Ussher**

Ussher has usually been portrayed as a symbol of authoritarianism and religious dogma, with terms such as “rule of authority”, “early speculation”, and “foolish” frequently being used with regard to him and his work. It is also said that he “pronounced” or “announced with great certainty” his date for the formation of the Earth. However, Ussher was renowned as an eminent scholar in his time. In 1640, he came to England to undertake research, and between 1650 and 1654, he made a detailed study of the Old Testament in which all the generations of people that had lived since the creation of the Earth are recorded. Many books imply that he did this simply by summing their combined ages and then calculating that the Earth was formed on Tuesday, 23 October 4004 BC, at 12 noon (some texts give the date as either the 22nd, 24th, or 26th and also state that Ussher put the start at 9 am, but this is incorrect). Although many later natural philosophers and geologists poured scorn on this estimate, it should be noted that most geologists for the next 100 years did not envisage a time span that was significantly different. This might have been because they accepted his ideas or because they could find no better way to determine it. Ussher and his work are often viewed as science bound up by religion, but his was one of the first serious attempts to organize the ever-expanding amount of information about the Earth into a coherent story and time frame.

In his day, Ussher had a reputation for being moderate, willing to compromise, and a keen scholar. In 1650, he published the *Annals of the Old Testament*, in which he presented his data. This book, which contained his deductions for the timing of the origin of the Earth, was 2,000 pages long and could hardly be regarded as a minor or rushed piece of work.

He represented a major style of scholarship of his time, in which he – working in the tradition of research – took the best sources of information and evidence available to try to determine the answer to a specific question.

Discussion point

Contrary to the usual versions of Ussher’s work, he did not “simply add up the ages and dates given directly in the Old Testament”, but made a valid attempt to estimate the age of the Earth, using what he considered to be the best, most accurate, and faultless data he could find.

So, how did he come up with 12 noon on the 23 October 4004 BC as an exact time for the formation of the Earth?

1. The year of 4004 corresponds to six days of creation, where 1 day equals 1,000 years, which was a common comparison at the time.
2. Why 4004 and not 4000? It had already been established that there was an error in the BC to AD transition, as Herod died in 4 BC. The date could actually have been anywhere between 4037 and 3967 BC.
3. Why 23 October? This is based on the Jewish year that started in the autumn. He thought that the first day would follow the Autumnal equinox.
4. Why more than a month after the equinox? Dates at the time were based on the Julian system similar to that used today, except for one thing – they did not leave out leap years at century boundaries (i.e. divisible by 400). Thus, by 1582, the calendar had ten extra days (Pope Gregory XIII established a new calendar that has come to be known as the Gregorian calendar, in which Thursday, 4 October was followed by Friday, 15 October 1582). However, this was not adopted in Britain until 1752. Therefore, in 4,000 years there would be an extra 30 days.
5. Why midday? Ussher began his chronology at midday as "you cannot have days without the alternation of light and darkness" and as the Bible says, "in the middle of the first day, light was created".

Discussion point

In his book *Eight Little Piggies,* Stephen Jay Gould illustrates a very poignant lesson:

> How many current efforts, now commanding millions of research dollars (or pounds) and the full attention of many of our best scientists, will later be exposed as full failures based on false promises? People should be judged by their own criteria, not by later standards that they couldn't possibly know or assess.

This is an important point that should be taken into account when considering everything that follows.

In his book, *Revolutions in the Earth: James Hutton and the True Age of the World*, Stephen Baxter points out that:

> Even as Ussher was publishing his great work, doubts were raised. During the previous centuries Europeans had begun to travel the world. And they encountered cultures which had their own historical narratives, many of them contradicting the biblical account. The Chinese for example, mocked

the story of Noah's Flood, which was supposed to have occurred around 2300 BC. Chinese written history stretched back centuries before this date, and made no mention of a disastrous global deluge.

After his voyages of discovery, Sir Walter Raleigh (1552–1618) felt that the history of the Earth was considerably older than that envisaged by the Church. Because of this, he and his friends were frequently accused of atheism and heresy, even though when he wrote *The History of the World*, none of these views were expressed.

1.2.1 The march of the scientists

In the early 17th century, natural science was a very popular subject, with many people beginning to study Nature, rocks, and fossils. Many viewed the creation of rocks as the result of Noah's Flood, which followed the Bible's version of history and implied that the Earth could not be very old.

Even so, people like the famous physicist Robert Hooke (1635–1703), who was one of the founding figures in the understanding of earthquakes, did not believe that sedimentary rocks were the results of Noah's flood. Neither did he envisage a greatly extended time scale beyond that proposed by Ussher. He, like many other scientists at the time, viewed the geological history of the Earth as being increasingly violent the further you went back in time. Shortly after the Royal Society was founded by Charles II in 1660, Hooke was appointed Curator of Experiments and most of his geological work was published in 1705 under the title *Lectures and discourses of earthquakes and subterraneous eruptions, explicating the causes of the rugged and uneven face of the Earth; and what reasons may be given for the frequent finding of shells and other sea and land petrified substances, scattered over the whole terrestrial superficies.*

In his book *The Making of Geology: Earth Science in Britain 1660–1815*, Roy Porter reveals that following the formation of the Royal Society, there began a significant change in which wild speculation and theory was gradually replaced by detailed observation, comparison, and description. Fieldwork was also becoming an increasingly important component of natural history.

It was not until the mid- to late-17th century that people began to realize that rocks had not been laid down by Noah's Flood, but had a recognizable continuity, sequence, and distribution that meant that they also had a history. As Porter puts out, "there was a growing realization that strata were the key to Earth history".

Nicholas Steno (1638–1686) (Chapter 2), like Hooke, played an important role in establishing some of the fundamental principles of geology. He used his knowledge of fossils and stratigraphy to establish the geological history of Tuscany. By looking at the rocks around Florence, he determined that the area had been flooded twice. During the first episode, the older strata were deposited. They were then tilted and a second flood deposited more sediments on top of them. He rationalized what he saw with scriptural accounts and suggested that the first flood was that of the second day of creation and that the second flood was that of Noah. With this interpretation, he did not expect to find evidence within the rocks of an extended geological history.

Isaac Newton (1643–1727), the celebrated physicist and mathematician, calculated that the Earth was 6,000 years old based on the Bible, and what he considered other reliable sources of information (Fig. 1.2). As Jack Repcheck says in his book, *The Man who Found Time: James Hutton and the Discovery of the Earth's Antiquity*:

> All Christian churches, their clergies, and their followers – believed that the earth was not even 6,000 years old. This belief was a tenet based on rigorous analysis of the Bible and other holy scriptures. It was not just the devout who embraced this belief; most men of science agreed that the earth was young. In fact, the most famous of them all, Isaac Newton, had completed a formal calculation of the age of the earth before he died in 1727, and his influential chronology confirmed that the biblical scholars were right.

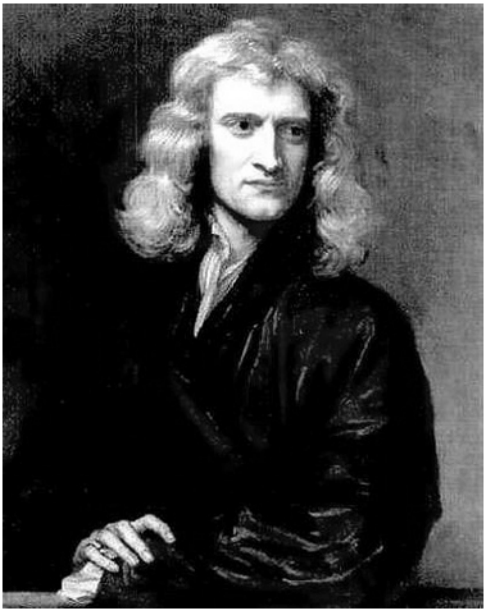

Fig. 1.2 **Sir Isaac Newton**

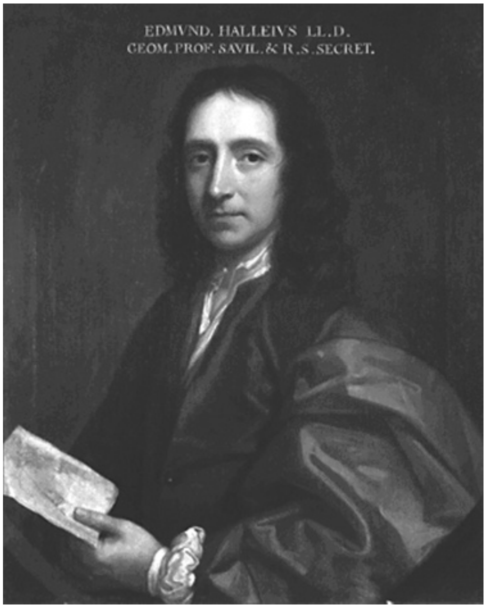

Fig. 1.3 **Sir Edmund Halley**

In 1715, English astronomer Edmund Halley (1656–1742) – who was also a mathematician, meteorologist, and physicist – suggested that the age of the Earth could be calculated from a study of the salinity of the oceans (Fig. 1.3). He thought that if he determined the salinity of the sea, and re-measured it after a period of time, he could calculate how salinity changed with time. From the expected increase in salinity, he felt that he could then back-calculate the amount of time it would take for fresh water to achieve the present salinity of the sea. It is not known whether he actually carried out such experiments.

He then published his theory, titled *A short account of the cause of the saltiness of the oceans, and of several lakes that emit no rivers; with a proposal by help thereof, to discover the age of the World*, in the Philosophical Transactions of the Royal Society of London.

Within this theory, he assumed that the oceans were originally composed of fresh water and that their salinity had progressively increased through the transport of dissolved materials by rivers that flowed into them. He used lakes as a further source of data and categorized them as either those that had inlets and outlets to the sea or those that only had inlets. He used these as examples of the way in which the salinity of the oceans could have formed, i.e. saline water flowing into them that could not flow out again, which would account for the gradual increase in salinity. Halley recognized that there could be several flaws in this argument. For instance, there is not a constant influx of materials, without loss through burial, which would lead to salt being trapped in sediments and rocks that would then prevent it from being dissolved in the sea. He did not, as is usually implied, set out to show that pervious estimates, such as those mentioned above, were wrong, but used similar arguments to those of Ussher.

He is often portrayed as a "hero of geology", because his "scientific methodology" provided a minimum (and not a maximum as has sometime been portrayed) estimate for the age of the Earth. This meant that the Earth was older than previously thought. He also recognized the existence of a second flaw: the oceans may not have consisted of wholly fresh water to start with. He argued therefore that his methodology would provide a minimum age of the Earth, because if there was any salt present in the oceans from the start, his method would reduce the calculated age. This is a crucial argument because he was concerned about Aristotle's ideas that the Earth and therefore time were eternal. This concept also made the idea of extreme events impossible, as his theory relied on a constant change in salinity. (See Chapter 5 for Halley's ideas on magnetism and the structure of the Earth.)

While he was the French Consul in Egypt, at the age of 35, Benoit De Maillet (1656–1738) wrote a book based on his observations and studies of Egyptian records that detailed the flooding of the Nile (Fig. 1.4). He noted that Carthage – a fortress on the seashore that had openings in its basement to let sea water in – stood 1.5–1.8 m above sea level. He estimated, from data recorded over 75 years, that sea level had dropped by 7–9 cm per century. He also noted that similar occurrences were recorded at Acre and Alexandra. De Maillet argued that this data provided evidence for a gradual decline in sea level of around 3 m a century. This could be projected back to a time when the Earth was covered in water and the ancient mountains "emerged from the sea" (a reference to a universal flood). Given the heights of the known mountains, it led him to estimate that the "Earth was immensely ancient", around 2,000 million years old. In order to evade censorship by the Church, he presented the theory titled *Telliamed: or Conversations between an Indian philosopher and a French missionary on the diminution of the sea.* Telliamed, which was De Maillet spelt backwards, was supposed to be an oriental philosopher. It was subsequently circulated clandestinely in 1720, but was not published until 10 years after his death.

Fig. 1.4 **Benoit De Maillet**

> **Discussion point**
>
> We find evidence of sea level change across the country, from flooded river valleys in Devon and Cornwall to raised beaches around Scotland and elsewhere (Fig. 1.5). Without the knowledge of sea level change that we now have, how else would we be able to account for these changes?

The above are examples of estimates of the age of the Earth based on the observation of natural processes. Others also produced estimates based on experiments and scientific theory. These include those by George Leclerc (Fig. 1.6).

George Louis Leclerc, Comte de Buffon (1707–1788), was the keeper of the Royal Zoological Gardens in Paris. As a Newtonian scientist – that is, someone who believed that everything in the universe was measurable and founded on mathematically determined laws – he followed De Maillet's model. He spent 10 years collecting and cataloguing the collections of the

Fig. 1.5 **Two examples of raised beaches, on the Isle of Portland, Dorset (top left and right), indicating a significant change in sea level, and the Isle of Arran (bottom left) with abandoned stacks and cliffs**

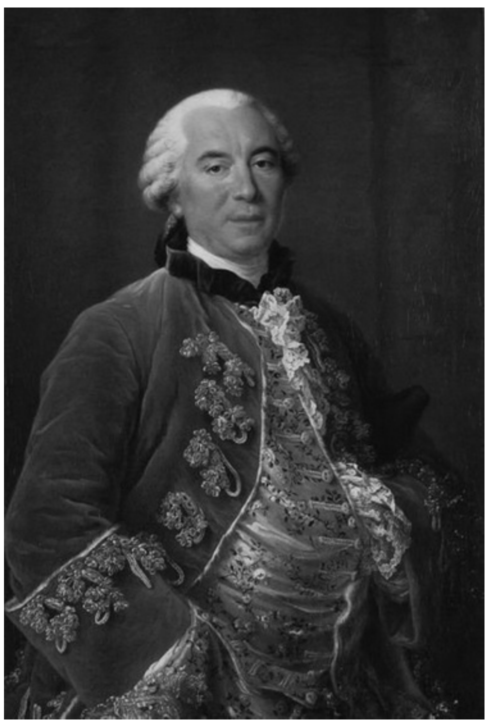

Fig. 1.6 **George Louis Leclerc, Comte de Buffon**

Natural History Museum and set about producing what he estimated would be a 50 volume encyclopedia. The first three volumes were published in 1749. This ultimately resulted in his 36 volume *Historie Naturelle* (Natural History), which was published between 1749 and 1789. This was the first naturalist account of the history of the Earth and the first account of geological history that was not based on the Bible. He only used observable or quantifiable causes to explain natural phenomena.

Another important publication was his *Époques de la Nature,* published in 1778. In this, he proposed that a comet collided with the sun, causing 1/650 of its mass to break away and form the planets.

He proposed that the history of the Earth could be divided into seven epochs, based on different stages of cooling, the first of which saw the Earth being composed of molten material. The first epoch included the formation of the Earth as an incandescent mass that, according to Douglas Palmer in his book *Earth Time: Exploring the Deep Past from Victorian England to the Grand Canyon*, he called "a 'vitriscible' rocky state as it cooled". It gradually cooled down during the second epoch and cracked to form high mountains. The third epoch saw the condensation of water and the initiation of rain. Organic matter then formed "spontaneously by the action of heat on fluid substances". The fourth epoch saw the emergence of a land surface from beneath the water. Palmer outlines Buffon's view of the historical development of the Earth that included a very interesting insight, given the time in which it was written:

> there was a general flood, which on retreat left fossil shells embedded in its sedimentary deposits. The large quadrapedal animals followed next and to Buffon their global distribution showed that the continents must have been joined as a single mass. The sixth epoch saw the continents separate and finally in episode seven mankind appeared.

Buffon's idea that there must have been a single large landmass that then separated had significant implications that he must have considered at the time (Chapter 8).

Buffon modelled the Earth using ten balls of mixed iron and non-metallic minerals in varying sizes that increased incrementally by 1/2 inch (12.5 mm) up to 5 inches (130 mm), which were made for him in ironworks that existed on his estate in Montbard near Dijon. These were then heated almost to their melting point and allowed to cool. From these experiments, he calculated that, given the size of the Earth, it would take 74,000 years to cool down from its molten state, in addition to 2,936 years for its initial consolidation. The Granite Mountains, he said, were the only parts of the original crust still visible. As the Earth cooled, after 50,000 of the 74,000 years, a rain of nearly boiling water began to fall that covered or nearly covered the entire surface. He also claimed that as volcanoes were only found near the seashore, they were the result of chemical activity in modern times, powered by steam from water seeping into the Earth.

Stephen Baxter notes that when Buffon calculated the age of the Earth as 74,000 years old, his work "created a great furore … The theologians at the Sorbonne condemned him, and Buffon dutifully retracted". However, he was not sincere: "It is better to be humble than hanged". Buffon continued his experiments, and rather than a time span of 74,000 years, he published estimates that were in the order of 3,000 years rather than the 3 million years that his unpublished material indicated he considered to be nearer the true age. This was, as Baxter explains, not "so much from fear of the religious authorities – by now he was too old to care – but because he thought the public wasn't ready for them".

Discussion point

Why do you think that there was such a difference between his published and unpublished figures?

Why do you think Buffon divided his history of the Earth into seven epochs?

In 1756, Immanuel Kant (1724–1804), the famous German philosopher, proposed that the Sun's energy was generated by the combustion of conventional fuel. In so doing, he estimated that, given the size of the Sun, it would burn up within 1,000 years.

James Hutton (1726–1797), studied law at Edinburgh, but preferred chemistry; and ended up studying medicine, which he finished in Leiden in 1749. He never practised medicine and after his father died, he ran his farm in Berwick. In 1768, Hutton moved to Edinburgh and joined a circle of eminent scientists and philosophers that included the inventor James Watt. In 1785, he published a paper on geology in which he summarized his new theory of the Earth. This was attacked in 1794 by Richard Kirwan, who was a follower of Werner (Chapter 3), and in response Hutton rewrote and expanded it into a full account titled *Theory of the Earth*, which was published in 1795 (Chapter 4 and 5), in which he proposed that the Earth was significantly older than previously thought.

Following the work of Buffon, Georges Cuvier (1769–1832), the Chair of Comparative Anatomy in Paris, looked at the fossils in the Tertiary rocks of the Paris Basin (Chapters 5, 6 and 7). Again, as with Hutton, there was no indication of a specific age but it was his view that the Earth had passed through "thousands of ages".

The 19th century is considered the "heroic period" of geology. By 1840, the stratigraphic column – the sequential order of rocks – as we know it today, was virtually complete, which allowed every rock on the Earth's surface to be allotted its relative time position in the sequence (Chapter 3). This led to a change of emphasis with regard to the problems of trying to determine geological time and the age of the Earth: with the establishment of the rock sequence people began to realize that they told a story – the historical development of the Earth.

In 1830, Charles Lyell (1797–1875) – who became one of the most famous geologists – published the first volume of his *Principles of Geology*. In 1867, he tried to calculate the length of geological time since the Ordovician Period (Chapter 3), based on an estimate that it would take approximately 20 million years for a complete change of molluscan species to occur. He noted that the fossil record indicated that 12 such changes were recorded since the start of the Ordovician Period, hence this would represent a time period of 240 million years. (We now know that this is actually closer to 500 million.) Lyell's estimate was totally unverifiable because there was no way of calculating absolute dates at the time, but it was one of the first estimates that talked in terms of hundreds of millions of years rather than thousands or even millions of years.

In 1850, Physicist Hermann Von Helmholtz (1821–1894) thought that the Earth had been formed by the collapse of material into its centre, which in turn converted gravitational energy to light and heat. Using this process as a basis, he estimated that the Earth was between 20 and 40 million years old.

Charles Robert Darwin (1809–1882) studied theology at Cambridge and became a keen geologist. When he published *On The Origin of Species* in 1859, one of the crucial factors that he needed for his theory of evolution to work was an extended Earth history. Lyell's estimation for the age of the Earth and his ideas of uniformitarianism provided the time scale he needed. Darwin estimated that he required a time period of at least 300 million years since the last part of the Mesozoic Era (Chapter 3) for evolution to work. This value is now known to be far too large, as most geologists consider this time period to be about 65 million years.

In 1878, the Irish geologist Samuel Haughton (1821–1897) introduced the idea that you could estimate the age of the geological record by adding together the thickness of all known strata. For over 50 years, this proved to be a popular way of estimating the age of the Earth.

In 1899, John Joly (1857–1933), like Halley, looked at changes in salinity to determine the age of the Earth. He thought that if he looked at the chemistry of rivers he could calculate how much sodium was being added to the oceans each year. He decided that if he could calculate the approximate volume of the oceans, he could estimate the amount of time necessary to achieve their present salinity. Allowing for salt that was blown back onto the land, he estimated that 90 million years had elapsed since fresh water had first condensed on the Earth's surface.

Discussion point

The problem with estimates based on changes in salinity is that the natural system in which it exists is very complex, and the estimates all assume that the oceans originally consisted of fresh water – the product of a universal flood formed by rain water. Another problem was calculating the volume of water in all of the oceans, something that is challenging today and would have been even more so in the 19th century. It is now believed that the salinity of the oceans does not vary with time.

William Thomson (1824–1907), better known as Lord Kelvin, became Professor of Natural History at the University of Glasgow at the age of 22 (Fig. 1.7). He was the co-discoverer of the Law of Conservation of Energy. Kelvin thought that if the Earth worked as a heat machine, it would be possible to determine how old it was. In 1862, he set himself the task of calculating how long it would take the Earth to cool down from its original molten state, and he continued to work on this idea, on and off, for 42 years. He also considered the age of the Sun and its rate of cooling. Based on the heat output from the Sun, Kelvin calculated that it had "shone down on the Earth" for about 100 million years. However, as its heat built up due to collision of smaller masses, it would have only generated a temperature hot enough to sustain life on the Earth for the last 20–25 million years. He also looked at the Sun's energy, which was thought to be generated by gravitational contraction. Due to its size, Kelvin thought that this process would make the sun fairly old – although he believed that it had only illuminated the Earth for a few tens of millions of years. He also thought that if the Sun's energy was more than 10% either side of its present value, life would then cease to exist on Earth.

Initially Kelvin set a wide margin of error, of between 20 and 400 million years, for his estimates of the age of the Earth. By 1897, he had refined these

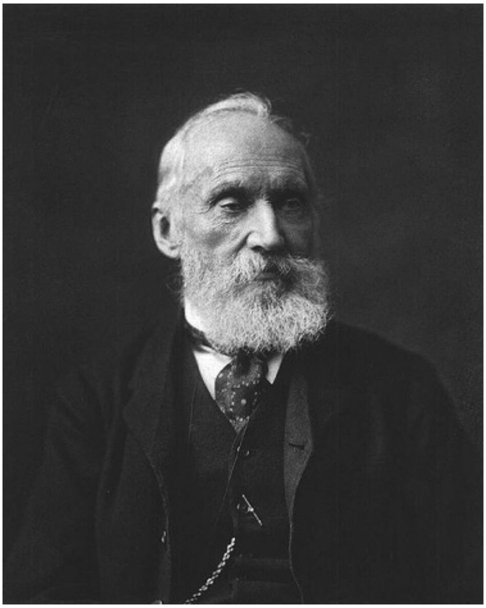

Fig. 1.7 **William Thomson, Lord Kelvin**

down to 20 and 40 million years. He was a very influential scientist at the time and because his calculations were based on precise physical measurements, this rendered his estimate irrefutable. He looked at the uniform increase in temperature with depth in deep mines (as had Joseph Fourier nearly 100 years earlier) to calculate the Earth's thermal gradient; this indicated that heat flowed from the centre to the surface. He reasoned that, as the Earth was gradually cooling down, he could back-calculate the rate of heat loss to determine when it had originally been molten. Even without knowing precise details on the melting points of many of the Earth's rocks and minerals, his estimates were always less than 100 million years. Because of his reputation and scientific credibility, most geologists accepted his estimates – even if they had reservations about the relatively short time scale involved.

Kelvin continued to re-evaluate his ideas and recalculate the age of the Earth until he reduced his estimates down to only 24 million years, at which point various geologists – including Archibald Geikie, who had been studying ancient volcanism in the British Isles – refused to believe him. It is interesting to note that, using his methodology and the data we now have, we would still come up with 25 to 30 million years based on the assumption that the Earth is gradually cooling down.

Discussion point

One of the problems with such a short time scale is that it had serious repercussions for Darwin's theories of evolution. Even Darwin, in later editions of *On The Origin of Species*, was hesitant about talking of a long geological history, because of this evidence and presumably because of the influence of Kelvin as a scientist.

It is important to remember that the estimates above were made **before** the discovery of radioactivity and the realization that this was the source of the Earth's heat and it was therefore not cooling down.

Charles Doolittle Walcott (1850–1927), who is reputed to have had only one week of college training with Louis Agassiz in 1873, later went on to become a famous geologist with the USGS (United States Geological Survey). In 1893, he calculated, by using the total thickness of the known rock sequence in the geological record and typical rates of sedimentation, that the Earth was approximately 75 million years old.

Discussion point

Calculating typical rates of deposition has always been a difficult process, particularly during this period when people continued to find new sections around the world. Average rates of sedimentation vary not only for different periods but also within the same periods. When using rates of deposition, scientists must also take into account the rate of compaction of the sediments.

Even though they were using a completely different method for calculating the age of the Earth, the people who used deposition rates appear to have consciously (or subconsciously) stayed within the estimates of Kelvin.

In 1900, William Johnson Sollas (1849–1936), a geologist from Oxford, estimated geological time as being 18.3 million years.

1.2.2 The atomic age

After Henri Becquerel in 1896 (Fig. 1.8), Marie Curie in 1903 and others had discovered radioactivity, physicist Robert John Strutt estimated the amount of heat that was continuously being generated by radioactive

Fig. 1.8 **Henri Becquerel**

minerals in the Earth's crust (Fig. 1.9). From this, he showed that this accounted for the Earth's geothermal gradient and the apparent heat flow to the surface, without the need for the Earth to be cooling down. This meant that there were no longer any problems with having to stay within or question Kelvin's dates (Chapter 8).

In 1902, Ernest Rutherford (1871–1937) (Fig. 1.10) – a New Zealand born physicist – and Frederick Soddy – an English chemist – published the results of their first experiments with radioactivity. According to most sources, late in 1904 (some quote 1905), Rutherford suggested that alpha particles were released by radioactive decay and that this decay could be used to determine the age of rocks, a technique he named radiometric dating. His first book *Radioactivity* was published in 1904. The same year Rutherford presented the first radiometric date for a rock, a sample of pitchblende, based on the uranium/helium method, at the International Congress of Arts and Science in St Louis. Most sources quote the age as 500 million years, although one source also gives this as 700 million years. (Some sources imply that the original experiment was conducted by Sir William Ramsey.)

Fig. 1.9 **Marie Curie**

Fig. 1.10 **Ernest Rutherford**

In 1905, Bertram Boltwood (1870–1927) – a pioneering American physicist and chemist – developed a technique for determining the radioactive age of rocks that contained uranium. Using this methodology, he determined the age of 26 samples of rock, which produced dates between 92 and 570 million years. Unfortunately, his measurements were flawed and later tests would show that the rocks were in fact between 250 and 1.3 billion years old.

In 1907, Boltwood made the first attempts at constructing a geological time scale using the radiometric dates, the same year that Rutherford, whilst working with Hans Geiger at the University of Manchester, was developing a method of detecting and measuring radioactive particles using electricity. These and other discoveries led to the establishment of radioactive dating, as detailed in a paper written by Arthur Holmes in 1911. In 1910, he had dated a piece of rock from Norway at 370 million years which, as the rock had been formed during the Devonian Period, meant that for the first time he was able to give this geological time period an absolute date. He also calculated the age of some rocks from Greenland, which gave an average age of 3,015 million years.

Whilst Holmes was working at the Strutt laboratory, under the guidance of Robert John Strutt (1875–1947), he estimated that the Earth was 2.4 billion years old and produced the first absolute time scale, which he published in 1913 in *The Age of the Earth*. Douglas Palmer advises in his book, *Fossil Revolution: The Finds that Changed our View of the Past*, that this gave the "first really reliable estimate of a minimum age for the Earth". He then adds that, "Holmes went on to estimate that the origin of the uranium, from which the lead was derived, must be around 4,460 million years ago".

Holmes worked on radiometric dating over a period of 50 years, until he and others discovered which radioactive elements and their decay products (usually referred to as daughter products) could be used as reliable "atomic clocks" (Chapter 2).

In 1929, Rutherford discovered that two such radioactive clocks, uranium-238/lead-206 and uranium-235/lead-207, ran at different speeds. In fact, the uranium-238/lead-206 clock ran six times faster than the uranium-235/lead-207 one. This discovery meant that dates could be determined by comparing the growth of the two different types of lead. When it was finally confirmed that another lead, lead-204, was not derived from radiometric decay, this "primary lead" provided a third clock that could be used in the dating method.

Henry Norris Russell (1877–1957), an American astronomer, obtained a date of 4 billion years for the age of the Earth in 1921. Following the work above, Harrison Brown (1917–1986) and Claire Patterson (1922–1995), two American geochemists, measured the age of the meteorite that formed

Meteor Crater in Arizona and found it to be 4,510 million years old. Patterson also found that a number of other meteorites produced similar dates, which resulted in an average age of 4.55 billion years. This was close to Holmes' estimates for the age of the Earth and is close to the generally accepted age of 4.6 billion years used today. In fact, the oldest known minerals – zircons from Australia – have been dated as 4.4 billion years old.

Discussion point

Cherry Lewis, in her book *The Dating Game: One Man's Search for the Age of the Earth*, recounted the life of Arthur Holmes. In this, she sums up the problems that he struggled with and makes the following comments that could be used to summarize the development of many scientific ideas. She writes:

> Progress on dating the age of the Earth was slow, years, even decades went by without any significant advance being made. But science is like that. What is often not realized when a breakthrough finally occurs is that for years previously a few individuals had been diligently working in the background, thinking and writing about the problems, quietly and persistently pursuing their goal.
>
> … having scrutinized in detail every analysis of uranium, lead, thorium, radium and helium that had ever been published anywhere in the world, now amounting to many hundreds, Holmes determined the age of the Earth.

She describes his work as a labour of love during which he spent years working without flashes of inspiration or miraculous discoveries, but just plain slow-going, hard work.

Stephen Jay Gould suggests that hindsight has frequently been used to pick out themes that seem to anticipate later developments. Similarly, passages are taken out of context in an effort to show how one writer or another had almost (but not quite) put together the conceptual framework that we accept today. Because of this, heroes have been made of those who had "forward-looking" theories and their "unmodern" ideas have been ignored. Rival theories were dismissed as obstacles to the development of science as they were only supported by conservatives who wished to retain traditional values and were deemed to be holding back the development of science.

It is interesting to note that frequently throughout *Time Matters*, we will see that it is often the ideas, or parts of the ideas of the "bad guys", which eventually have an important input to geology as we know it today. Conversely, those of the "good guys" frequently led to comparative deadends. It is also important to see that most of the time the development of knowledge is time-consuming, hard work that is often spread over a long period of time and involves blind alleys, false hopes, and misconceptions.

Lewis also includes Rutherford's description of the time he had "drawn the short straw" and had to present his new dates in front of Lord Kelvin during a lecture at the Royal Institution in London. She also describes another presentation at the British Association in 1921, in which Strutt was presenting Holmes work, where he "again tried to lay the spectre of Kelvin who still rose to haunt the assembly, and again put forward the arguments in favour of radiometric dating". She reports that William Sollas, Professor of Geology at Oxford, was apparently "overwhelmed" by the amount of geological time that was now available compared to that offered by Kelvin, stating that:

> the geologist who had before been bankrupt in time now found himself suddenly transformed into a capitalist with more millions in the bank than he knew how to dispose of, but perhaps understandably, he still urged caution and heeded geologists to substantiate the time being offered by physicists before committing themselves to the reconstruction of their science.

How and why have views of geological time and the age of the Earth been restricted by limited knowledge and/or scientific dogma?

1.3 Geological time and the age of Mother Earth

There are a number of different ways in which the enormity of geological time has been portrayed in a user-friendly way. These include a 24-hour clock, spiral, and linear diagrams. Each has their own merits but I think that a book title *Restless Earth* by Nigel Calder, that was published in 1972 to support a BBC television series, presented one of the best representations. This portrayed "Mother Earth" as a 46-year-old woman, which provided a time scale that was neither too compact nor too large to relate to. Calder's book was published whilst I was doing A level geology at school. I wrote this version of the time scale out and stuck it to the inside cover of my file, together with a postcard geology map of the UK from the Geology Museum in London. I still had it ten years later when I started my geology degree, as a reminder of why I first fell in love with the subject. The following is an adaptation of the *Restless Earth* time scale that I hope puts geological history in to context:

We could view Mother Earth as a middle-aged lady of 46 years old, where each of her "years" are mega-centuries (i.e. 1 year represents 100 million years).

Like so many people, details of the first seven years of her life are almost completely lost, apart from a few vague memories, and a few snapshots. Towards the end of her first decade, we have a better record of some of her deeds recorded in old rocks preserved in Greenland and South Africa. Single-cell life appeared when she was 11 (based on stromatolites found in South Africa) and bacteria developed as she entered her teenage years. Like so many teenagers, much of that period is still a bit of a blur, but as she progressed through her later teens and early twenties, she gained more self-confidence, began to settle down, and got on with living. She experimented with new processes and new forms of life, some of which she would carry through to later years, whilst others, although worth trying out at the time, would be disregarded.

The first organisms containing chlorophyll did not appear until she was 26. They breathed oxygen into her atmosphere and oceans – an episode that has sometimes been termed the Big Burp – which laid the foundation for life as we know it today. At the age of 31, the first nucleated cells developed. By the time Mother Earth was 39 (at the end of the Precambrian Era), multicellular organisms had started to diversify in Australia, Europe, and North America.

Almost everything that people recognize on Earth today, including all substantial animal life, is the product of just the last six years of her life. By the time she was 40, animals with hard parts (bones, teeth, etc.) had developed, as witnessed by the fossils discovered in China and Canada (the Burgess Shale). Fish appeared when she was 41, but the land surface was virtually lifeless until she was almost 42, after which mosses started to invade the hitherto bare continents. Within the next six months ferns appeared, there was an explosion of aquatic life, and insects had arrived on the scene. A year later immense forests of tree ferns covered her body, dragonflies with 3-foot wingspans took to the air, and amphibians and amniotes (egg-layers) roamed her surface. Life, at last, had truly broken free of the water. At the age of 44, she went through another one of her fads when she fell in love with reptiles and her pets included the dinosaurs. Within six months, the first known birds had taken flight, together with bees and beetles. The break-up of the last supercontinent was in progress. It was nearly a year later before she noted the arrival of flowering plants and the planet began to take on the appearance we see today.

Six months ago, dinosaurs went out of favour and she turned her attention to mammals, which largely replaced them in her affections. Primitive tools, found in Ethiopia, indicate that two and a half months ago "intelligent life" began to interfere with her landscape. About ten days ago, some man-like apes, living in Africa, turned into ape-like men. Last weekend, she began to shiver her way through the latest, but by no means the only

Table 1.1 The geological time scale. Each value (×1 million years) relates to the line below the value

Eon	Era	Period		Epoch	Date
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01
		Tertiary	Neogene	Pleistocene	1.8
				Pliocene	5.3
				Miocene	23.7
			Palaeogene	Oligocene	33.7
				Eocene	54.8
				Palaeocene	65
	Mesozoic	Cretaceous		Late	99
				Early	144
		Jurassic		Late	159
				Middle	180
				Early	206
		Triassic		Late	227
				Middle	242
				Early	248
	Palaeozoic	Permian		Late	256
				Early	290
		Carboniferous		Late	323
				Early	354
		Devonian		Late	370
				Middle	391
				Early	417
		Silurian		Late	423
				Early	443
		Ordovician		Late	458
				Middle	470
				Early	490
		Cambrian		Late	501
				Middle	513
				Early	543
Precambrian	Proterozoic	Late			900
		Middle			1,600
		Early			2,600
	Archean	Late			3,000
		Middle			3,400
		Early			3,800
	Hadean				4,600

cold period in her life. Around four hours ago, a new, upstart species of animal, calling itself *Homo Sapiens*, took their first tentative steps in trying to take over the Earth. In the last hour, they invented agriculture and began to turn their back on a nomadic life style. It was only a quarter of an hour ago, that Moses and the Israelites crossed the Red Sea, and it is less that ten minutes since Jesus preached in the same area. The Industrial Revolution began less than two minutes ago, but in that brief time, out of the lady's 46 "years", we have managed to use up a substantial proportion of her resources – many of which she had taken a significant proportion of her life to produce. It is only in the last 10 seconds that we have begun to understand the nature of Mother Earth and the damage we are doing to her and her atmosphere. How many more seconds will it be before we start to treat her with the respect she deserves?

The geological time scale, presented in Table 1.1, will prove useful, not only in relation to the above but also with regard to Chapters 2 and 3.

Discussion point

Reflecting on the geological time scale, is there anything that takes you by surprise?

Is it the fact that we know so little about Mother Earth until she is well into middle age or that life, as we know it, is so recent?

Does it put our current concerns over climate change and the speed of change into context?