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Chapter 4

Major geological events fit into a timeline, beginning with the formation of the Earth

4.1 The origin and development of life

William Smith was a canal engineer who supervised the excavation of boat canals across England in the late 1700s and early 1800s. When cuttings for the canals had to be made through hilly areas, he noticed that the layers of sedimentary rock always formed the same sequence. He also noted that the same layers always contained the same fossils and that the sequence of fossils was always the same. He called this his ‘Law of Faunal Succession’ and this helped him to link together rocks from different parts of the country because they contained the same fossils. This is a method we now call correlation. By correlating rock sequences across the country, Smith was able to produce a geological map of England and Wales (shown in Figure 1.1), the first geological map of a country ever produced (although geological maps of smaller areas had previously been made in Europe).

Smith knew that fossils occurred in a certain sequence in rocks - but he didn’t know why. In fact most people at that time (with the exception of a few scientists) didn’t even question the meaning of the fossils in rocks, believing that all rocks had been formed, with fossils inside some of them, during creation a few thousand years before. It wasn’t until Charles Darwin proposed his theory of evolution by natural selection that a reason for the sequence of fossils in the rock was provided. Darwin published his book, ‘On the origin of species by natural selection’ in 1859, basing it on his reading of other scientific publications and a mass of geological and biological evidence he had collected himself. He realised that when plants and animals reproduce, they produce new young organisms, some of which are better adapted to the environment than others. Through ‘**natural selection**’ the best adapted ones survive and the less well adapted ones die. This means that slightly different, better-adapted organisms develop and, if this continues, whole new types of organisms can form as one species develops into another through evolution. This explains why different rocks contained the different fossils that William Smith had



Figure 4.1: William Smith's geological map of England and Wales, published in 1815, made using his 'Law of Faunal Succession'.

Millions of years ago (Ma)	Some Major Life Events
2	First humans (genus Homo)
65	Major extinction of life on Earth, including dinosaurs
130	First flowering plants
150	First birds
190	First mammals
200	Major extinction of life on Earth
225	First dinosaurs
250	Major extinction of life on Earth, including most marine organisms
315	First reptiles
365	Major extinction of life on Earth
370	First amphibians
420	First plants and animals on land
450	Major extinction of life on Earth
510	First fish
545	First animals with hard parts
1200	First multicellular organisms
2000	First eukaryotes (cells with a nucleus)
3500	First bacteria and archaea (cells with no nucleus)
3800	Earliest life
4600	Origin of the Earth

Figure 4.2: Key events in the evolution of life. In this table Ma means “Millions of years ago”.

observed and why the sequence is always the same, because this sequence of evolution has only happened once.

Since Darwin’s time we have discovered more about the mechanisms of evolution, how parents pass their characteristics onto their offspring through their DNA and how different adaptations can develop, but the principle that Darwin discovered remains the basis of our understanding of life on Earth. The evidence from the rocks shows us the sequence of life on Earth, and the evidence from the DNA of modern organisms (DNA is deoxyribonucleic acid which holds the genetic information of all organisms) shows how this sequence developed.

Some of the key events in the evolution of life are shown in a table in Figure 1.2, but a table like this does not show how these events are spaced out over geological time. The time line in Figure 1.3 attempts to show some of the key life events in this way.

Although we know that the age of the Earth is about 4,560 million years, from radiometric dating, we don’t know exactly when or how life on Earth began. Probable fossils of mats

Millions of years ago (Ma)	Some Major Life Events
0	First humans (genus <i>Homo</i>) (2) First flowering plants (130) First mammals (190) First reptiles (315) First animals with hard parts (545)
1000	Major extinction (65) First birds (150) Major extinction (250) Major extinction (450)
2000	First multicellular organisms First eukaryotes (cells with a nucleus)
3000	First bacteria and archaea (cells with no nucleus)
4000	Earliest life Origin of the Earth

Figure 4.3: Key events of life shown on a geological time line.



Figure 4.4: Two early fossil fish

of simple organisms, forming layers over the sediment surface, have been found in 3,500 million year old rocks - indicating that life on Earth must have begun even earlier. A range of different ideas about how early life might have formed has been suggested. These include, among others, that early life formed in the oceans from the effects of ultra-violet light or lightning on simple organic molecules, and that life formed first in hydrothermal vents on the deep ocean floor through the reactions of iron and sulfur compounds at temperatures over 100 °C.

A key characteristic of life is the ability to evolve. Simple cells with no nucleus (bacteria and archaea) were the first life forms to evolve, producing mats of organisms in rocks 3500 million years old; some of these later formed short pillars of mats called **stromatolites**. These simple organisms with no nucleus, went on to dominate the Earth in terms of numbers. Today they form more than 99% of life and have sometimes adapted to live in extreme conditions, such as with no light, or oxygen or at high temperatures. They live in all environments known on Earth and are particularly important to the weathering that forms soils.

A key evolutionary event was when two simple-celled organisms evolved to work together in a relationship that benefited them both. They became **eukaryotes**, cells with nuclei. Fossils of these have been found in rocks 1600 million years old and possibly of 2000 million years old. One of the first multi-celled organisms to evolve were red algae, which are preserved in 1200 million year-old Canadian rocks. The first organisms that were probably animals were similar to corals and are found as fossils in 580 million year old

rocks whilst the first definite plants were not fossilised until a little later in geological time.

Before 542 million years ago, all organisms had **soft bodies** and so were rarely fossilised and are very uncommon. However, after 542 million years, many groups had evolved **hard parts**, usually to protect them from the environment and predatory animals around them, so we suddenly find fossil life much more common in the rocks. Fossils of the first fish are found in 510 million year old marine rocks (Figure 1.4). Some of these later developed limbs that they could use to drag themselves onto the land and evolved into amphibians, the first fossils of these being found in rocks around 370 million years old (Figure 1.5). A wide variety of amphibians developed, large and small; frogs and newts are common amphibians alive today and like their ancestors, have to return to water to reproduce and lay their eggs.

Around 315 million years ago, the earliest reptiles evolved, with the ability to lay eggs on land and to walk more efficiently (Figure 1.6). Reptiles went on to ‘rule the world’ and evolve into **dinosaurs** before the dinosaurs became extinct 65 million years ago, leaving modern reptiles like crocodiles and lizards.

It took several millions of years for mammals to evolve from reptiles, and the first true mammal fossils are around 190 million years old (Figure 1.7). Soon afterwards, birds also evolved from reptiles and the first bird fossils are found in 150 million year old rocks (Figure 1.8). Meanwhile, flowering plants evolved from non-flowering plants and the first flowers were seen on Earth about 125 million years ago. One of the latest groups to form developed into humans, with the first fossils of the genus *Homo* being found in rocks just 2 million years old. You can illustrate the evolution of life on Earth using the ‘Timeline in your own backyard’ activity from <http://www.earthlearningidea.com>.

This may read as though life showed a steady evolution over time, but this is far from true. There have been at least five major periods of **mass extinction** recorded in the fossil record (Figure 1.2), and probably more before that, when the fossil record was poorer. This is in addition to the many minor episodes of **extinction** that have also taken place shown on the graph in Figure 1.9. In the mass extinction of 250 million years ago ‘nearly all life died’ as indicated by the title of a popular book describing this major catastrophe for the Earth. Mass extinctions are important because, when whole groups or organisms have become extinct, other groups of organisms have the chance to take over the environment in which they lived (their **ecological niche**) afterwards. Thus the extinction of the dinosaurs allowed the mammals to become much more successful and take over many of the ecological niches in which the dinosaurs used to live.

Many theories have been put forward over the years that might account for extinctions, both major and minor. These have included climate change, possibly triggered by widespread volcanic eruptions, and the impact of **asteroids** having dramatic effects across the Earth.

As Darwin suspected, one of the driving forces of evolution has been separation. When groups of animals became separated, as for example, on an island or in a large lake, they evolved without any outside influences and new species developed. When these new species later rejoined the other groups, some were successful and joined or overtook



Figure 4.5: A fossil amphibian.



Figure 4.6: A fossil reptile.



Figure 4.7: A fossil mammal

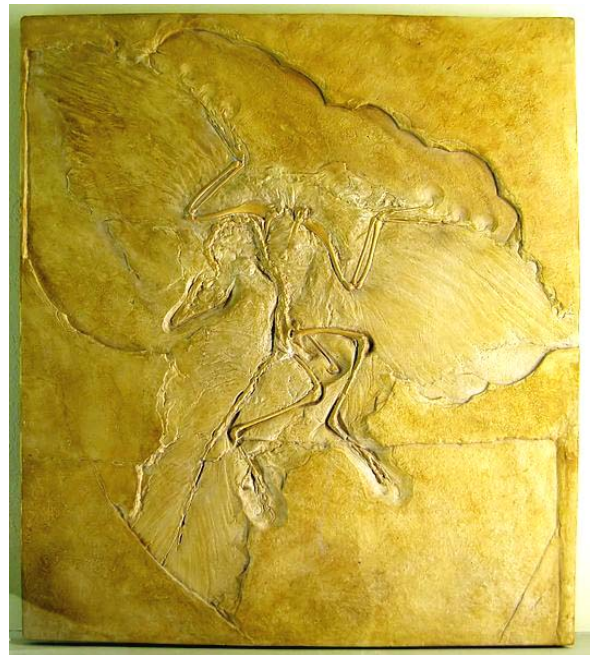


Figure 4.8: The earliest fossil bird that has been found - *Archaeopteryx*.

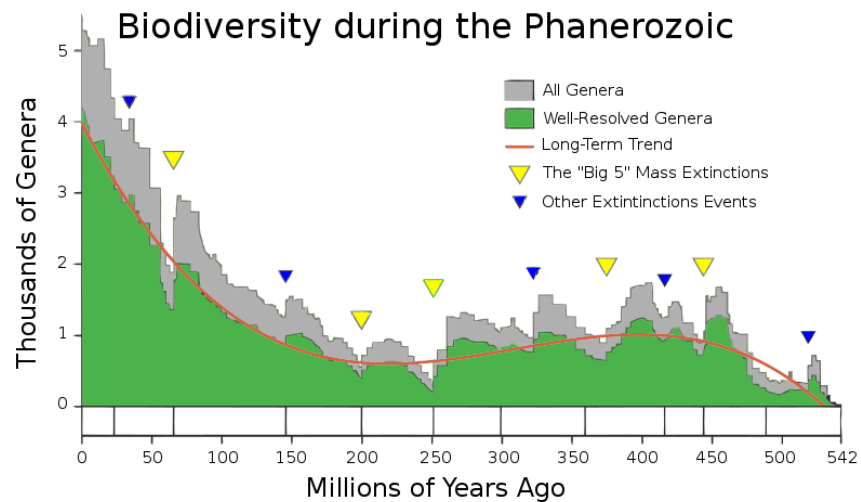


Figure 4.9: The change of biodiversity over time - showing major extinction events.

the other groups, whilst others died out. In the geological past, separation and joining have been caused by the movement of plates, thus plate tectonic movement has been an important component of evolution on Earth. One of the human influences on Earth has been to move organisms around the planet resulting in a 'joining' of groups. This, together with the major human impacts on a wide range of environments across the Earth, has caused the extinction of many organisms in recent times. Some scientists argue that this could result in a mass extinction on the scale of some of the previous mass extinctions on Earth.

Although one way of working out relationships between groups of organisms is to try to find out their evolutionary sequence from the fossil record, a second method compares the features of different groups of organisms to work out the relationships between them. Similar organisms are allocated to a group, called a clade, and the relationships of clades to one another is shown in a cladogram. The cladograms in Figures 1.10 and 1.11 show how early organisms were related and how vertebrate animal groups are linked to one another.

4.2 The development of Earth's continental jigsaw

The first continents were formed around 4000 million years ago by processes similar to the plate tectonic processes we see today, and there is evidence that the early igneous rocks that formed the continents were metamorphosed and subject to sedimentary processes just like continental rocks today. Since these small early continents were made of low density silica-rich rocks, they were too light to be carried back into the Earth by subduction and so remained on the surface to be carried around by early tectonic plates. As they were moved around, they sometimes collided and the new rocks formed in the collision zones 'stuck' the continents together to form larger continents.

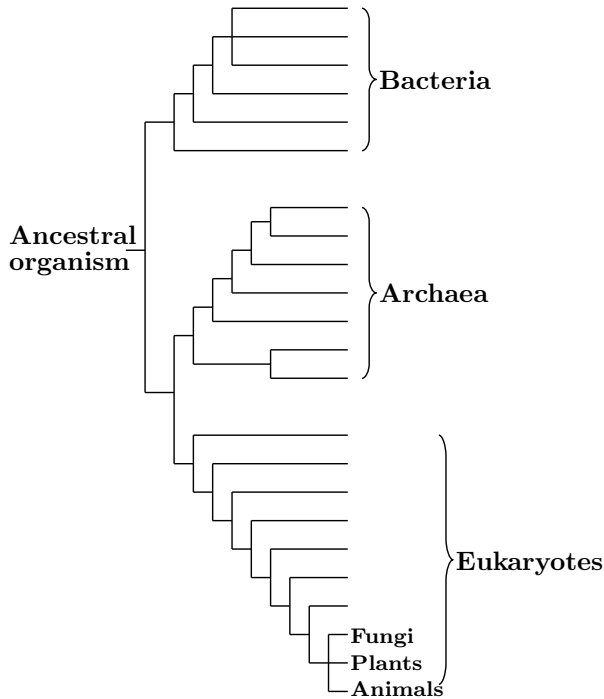


Figure 4.10: A cladogram showing the relationships of the major groups of life on Earth.

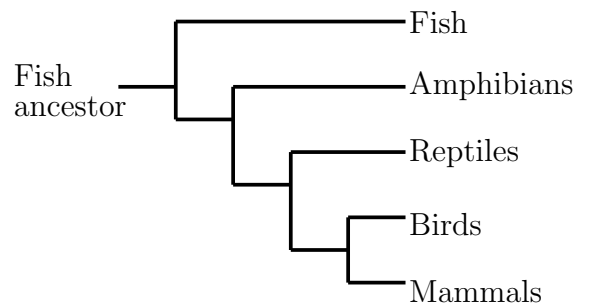


Figure 4.11: The relationships of major animal groups, shown by a cladogram.

Around 1000 million years ago, all the continents had combined together into one huge landmass in the southern hemisphere that we call **Rodinia**. This **supercontinent** began to break up around 750 million years ago and the different continents were shuffled around, but by about 550 million years ago all the major continents that now form the southern hemisphere continents (today's South America, Africa, Australia and Antarctica - with India as well) had recombined into another supercontinent that we call **Gondwana**, whilst the continents that we now identify as North America, Europe and Siberia were all separate (Figure 1.12). As time moved on, 'North America' collided with 'Europe' as the Gondwana continent moved northwards towards them (Figure 1.13)

Between 300 and 250 million years ago all the major continents on Earth had been joined together again to form the largest supercontinent ever seen on Earth (Figure 1.14), that we call **Pangaea**. Then Pangaea began to split apart, forming first the North Atlantic Ocean and later the South Atlantic Ocean, as Antarctica, Australia and India separated from Africa. By around 100 million years ago, all the major continents we recognise today had separated from one another (Figure 1.15).

The continents continued to move, India collided with Asia forming the Himalayan mountain range, and Africa impacted on Europe forming the Alps. All the continents moved

450.00 Ma

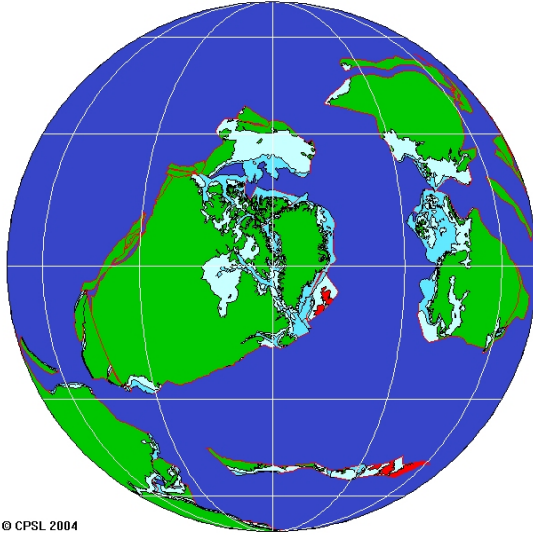


Figure 4.12: The 450 million year old Earth. Separate 'North America', 'Europe' and 'Siberia' with Gondwana formed of all today's southern hemisphere continents on the other side of the globe.

375.00 Ma

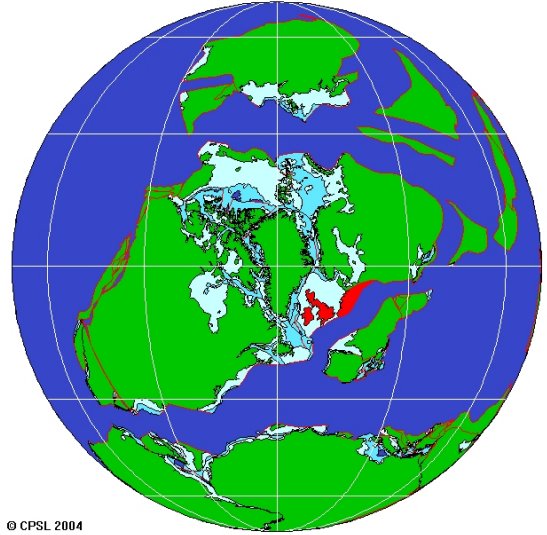


Figure 4.13: The 375 million year old Earth, after the collision of 'North America' with 'Europe'.

275.00 Ma

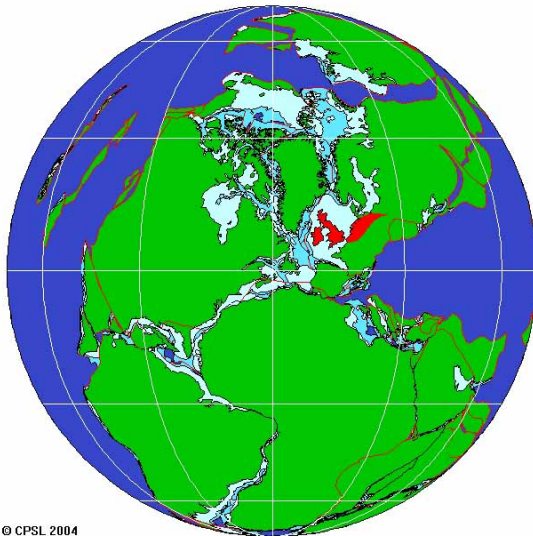


Figure 4.14: Supercontinent Pangaea, 275 million years ago.

100.00 Ma

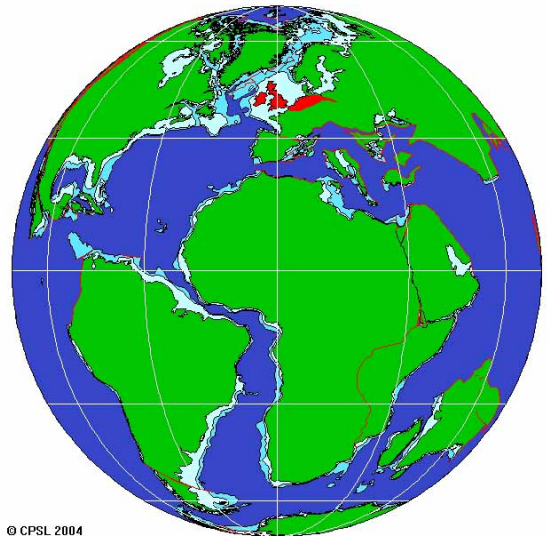


Figure 4.15: Continents on the 100 million year old Earth.

into the positions they have today - but they continue moving, at centimetres per year, so the distribution of continents on Earth will continue to change into the future.

This movement of plates and continents over geological time has had profound effects; oceans have formed and closed, continents have grown and split, and plate movements have produced mountain ranges which were later eroded.

As the plates and continents were moved across the Earth, they encountered different climates in different parts of the globe. So a continent like India, that at one time was near the south pole experiencing polar conditions, was moved north, through temperate and tropical zones and across the equator, to its present position. The sedimentary rocks laid down when it was in each climate zone record the story of this movement over the surface of the Earth. The rock sequence also records evidence of tension, as plates moved apart, and compression, as plates collided, during its long geological history.

As well as all these changes, that are clearly linked to plate movement, there were global changes as well. At times, global sea levels have been much higher than today. These high sea levels seem to be linked to times when new oceans were forming, with active constructive plate margins swelling up and displacing much of the ocean water on to the land.

Great variations in global climate may also be linked to plate activity so, for example, the intense ice ages that affected Earth between 900 and 600 million years ago, may be related to quieter times in plate movement when reduced volcanic activity at plate margins produced less carbon dioxide and the globe cooled. At times during these global cooling events 600 - 900 million years ago, the Earth may have been completely covered by ice - a '**Snowball Earth**' or nearly covered by ice - a '**Slushball Earth**'. Ice ages which did not affect the whole globe, but which nevertheless had important effects near the poles also occurred around 460 and 300 million years ago and Earth today is still experiencing an ice age that began 2 million years ago. These are called '**ice house conditions**', contrasting with the '**greenhouse conditions**' when the Earth was completely ice-free at the poles. One period of 'greenhouse conditions' occurred when Earth experienced extreme global warming 55 million years ago.

All these events build into a picture of the complex evolution of our planet with a number of major 'milestones' along the way (shown in Figure 1.16).

Earth is clearly a very dynamic planet, with the continents experiencing great changes of latitude and altitude whilst also being affected by global sea level and temperature changes. These changes have affected life on Earth by separating and joining populations of organisms whilst creating and destroying environmental niches. Now humans are having an additional impact of global importance that can only have more effects on the Earth in the future.

Millions of years ago (Ma)	Some Major Earth Events
2	Ice age
55	Extreme global warming
65	Major extinction of life on Earth, including dinosaurs
130	First flowering plants
150	First birds
190	First mammals
200	Major extinction of life on Earth
225	First dinosaurs
250	Major extinction of life on Earth, including most marine organisms
300+	Ice ages
315	First reptiles
325+	Supercontinent Pangaea existed
365	Major extinction of life on Earth
370	First amphibians
420	First plants and animals on land
450	Major extinction of life on Earth
460	Ice age
510	First fish
545	First animals with hard parts
600 - 900	Ice ages
1000+	Supercontinent Rodina existed
1200	First multicellular organisms
2000	First eukaryotes (cells with a nucleus)
3500	First bacteria and archaea (cells with no nucleus)
3800	Earliest life
4000+	Earliest continents formed
4600	Origin of the Earth

Figure 4.16: 'Milestones' in the evolution of planet Earth