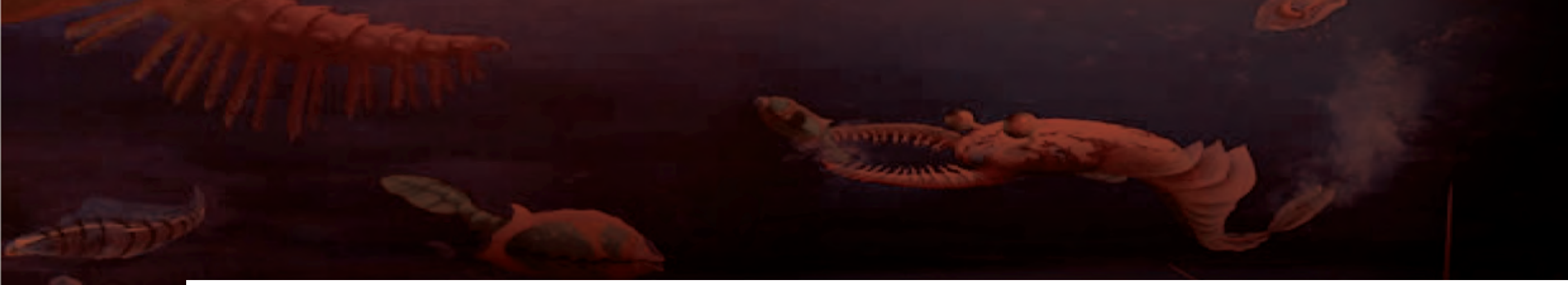

CHAPTER 3

Palaeontology

Key words: Fossil record, palaeontology, evolution, life on Earth, extinctions, fossil groups.

Introduction

Palaeontology is the study of the fossil record through geological time. It is the study of life on Earth and the evolution of all biological groups from their origins until the present day – and it also includes studies of the relationship between life and its physical environment through time. The study of palaeontology, therefore, requires a detailed knowledge of and training in both biology and geology. Palaeontology aims to explain the origins of life on Earth, subsequent evolutionary development and changes, as well as the extinction of biological groups.

The concept of evolution has a major importance for education far beyond its origins as a scientific theory. Evolution underpins the process of biological change and the origins and radiation of the different living organisms that have made up the biosphere through time. Just as the world around us is in a permanent state of change, so is the biosphere and the biological groups, that inhabit the planet's surface. But even a quick look at different types of organisms reveals striking similarities between different species, and palaeontologists and biologists have demonstrated that such similarities can be explained by evolutionary relationships, which can be proved through studying the fossil record.

Although a separate scientific discipline, Palaeontology still has close relationships with other geological disciplines, especially stratigraphy (including biostratigraphy), sedimentology, geodynamics, paleogeography and geochemistry, as well as with most aspects of classical and modern biology, from taxonomy, evolutionary studies, population genetics, to the geographic distribution of species (i.e. biogeography) and to ecology and interrelationships with environments. However, despite these close links with other Earth and life sciences, Palaeontology is has its own unique body of knowledge, subjects of study and research methods. This is the fossil record, and the fossil record, together with the sedimentological and stratigraphical record, is a part of the geological record. Sedimentology is a key facet of palaeontological study as fossils – with very, very few exceptions - are preserved in sedimentary rocks. Although fossils are often referred to as "*petrified organisms"*, this can be misleading, as most represent only the remains of hard inorganic skeletons and shells, or evidence of biological activity such as burrows and footprints. Only a few very rare specimens represent the whole organism, such as insects in amber and mammoths preserved in permafrost. The processes that preserve these remains are called "*fossilisation*" and the branch of Palaeontology that studies fossilisation is called *taphonomy*.

3.1. When and how Life appeared on Earth

Fossils document the origins and evolution of life on Earth over thousands of millions of years. As they are preserved in sedimentary rocks formed at the same time as the organisms they record were living, they can provide information on the age of these rocks - this is the branch of palaeontology known as biostratigraphy - and on the ecology, environments, climate and geography of past periods of Earth history.

The oldest fossils identified so far, date from around 3,500 million years, but chemical evidence of life processes goes back perhaps 100 million years further. These very early fossils represent bacteria, including photosynthetic cyanobacteria (often incorrect know as blue-green *algae*), the simplest unicellular living organisms. During most of this early existence of the Earth, life consisted only of unicellular organisms, initially simple bacteria which are '*prokaryotes'* without a central nucleus regulating the cell, and then, from around 2,500 million years ago, '*eukaryotes*' with a true differentiated nucleus. With the latter the main biological and metabolic processes of life today originated, including sexual reproduction which enabled the sharing of genetic material between individuals, hence providing the opportunity for much greater evolutionary development. This was manifested as the first evidence of multicellular organisms some 1,200 million years followed by whole communities of strange leaf and jelly-fish like animals around 650 million years ago. The first animals with shells and skeletons appeared around 550 million years ago, but it was not until only around 90,000 years ago that our own species, *Homo sapiens* appeared and the history of human civilization is limited to the last 7 to 6 thousand years or so, a time that represents only 0.004% of Earth history.

3.2. Evolution of life

Biodiversity, i.e. the diversity of life forms and biological groups as we see it today, is the result of 1000s of millions of years of evolutionary processes. Why know much less about bio-diversity in the past, however, as the fossil record only provides brief glimpses. The variety of fundamentally different 'designs' for animals (i.e. 'body plans') in the early Palaeozoic Era of geological time (from around 550 million years) was higher than today, although at species level, overall diversity is certainly higher now.

The early evolution of life caused dramatic changes in the composition of Earth's atmosphere. Significant free oxygen was not present in the atmosphere until oxygen-producing cells - such as photosynthetic cyanobacteria - evolved. The diversity of groups preserved as fossils in the fossil record has allowed paleontologists to infer and partly reconstruct the different patterns of evolution that followed through time. Fossil evidence indicates that a wide variety of life forms have existed in the past and that most of these forms have become extinct. Human existence, however, is still very, very brief compared to the span of geological time and the time range of most groups of organisms recorded in the fossil record.

Evolution is the organic process of change affecting all the living organisms that make up the biosphere and leads to changes in numbers and distinct types of organisms through geological time. Both external (environmental) and internal (genetic) factors are responsible for these changes, but the main evidence which shows us that biological groups have changed through time are the fossils that we find. When fossil organisms are compared to living forms, we can see that many things have changed. Some fossils show us organisms that once lived on Earth but have disappeared, such as trilobites, dinosaurs or ammonites; and others reveal the ancestors of life forms that are familiar today, such as clam shells, primitive mammals and early birds.

3.3. How fossils are formed

Fossils are the remains or traces of activity of ancient biological organisms, including animals and plants, and the traces or impressions of living things from past geological ages, or the traces of their activities, such as burrows and footprints. The process of fossilisation is a dynamic, complex process in which the remains of the organism or trace fossil are modified by external, environmental factors (e.g. microorganisms, sedimentary and geochemical processes, etc.) which affect and interact with it from the very moment of death to the stage at which it is recorded as a fossil entity and stored in the fossil record. Fossils have been found in every continent on Earth wherever sedimentary materials, such as clay, silt and sand, have been transported and deposited in sedimentary basins by processes such as water and wind, and hence the remains produced by living organisms can be buried and preserved.
Although it is generally only the hard, skeletal parts of organisms that are most easily fossilised, the reality is that many organic structures produced by animals, plants and other organisms can become fossils under certain conditions. Normally, in oxygen-containing surface environments, organic material will be rapidly destroyed by decay and in oxygen-rich environments, such as shallow marine platform environments, it is most likely only mineralized skeletal remains, will survive – but sometimes even then only as internal molds, where the shell has been filled with sediment or mineral before being dissolved by waters in the sediment after burial. However, in certain oxygen-deficient environments, the organic material of the soft parts can be partly replaced by minerals such as pyrite and phosphate compounds before it rots away entirely.

Fossils of hard mineral parts (such as bones or teeth) were formed as follows:

- The living organism produces remains and/or evidence of its activity during life. These remains can concentrated on or within a sedimentary substrate (i.e. 'accumulation') or can be moved across or within the substrate - which can involve significant lateral transport, including by sedimentary processes such as currents, or with minimal lateral transport (i.e. 'resedimentation'). During these *biostratinomical processes*, the remains will change their original properties (e.g. by disarticulation of skeletons or bivalve shells, fragmentation, infill, encrusting, concentration or dispersion, dissolution, etc.
- Eventually, if the remains are not completely destroyed, they can be buried by sediment accumulating around them.
- Over time, more and more sediment covers the remains and they are subjected to *diagenetic* processes, as the soft sediment is converted into a geological deposit, such as mudrock, sandstone or limestone. These processes can include, dissolution, compaction, early mineralization of any surviving organic material or cementation of cavities or infill of the remains.
- These processes can take place over a relatively long period of time, before the sediments is fully lithified (i.e. 'hardened') to form a rock. For instance the cavities in bone or wood can be filled with minerals deposit from water in the sediment, becoming harder and more rock-like as a result. The process of fossilisation, therefore, typically involves the dissolving and replacement of the original minerals in the remains by other minerals, including where the calcium carbonate shells of some molluscs are replaced by a different and more stable form of calcium carbonate (i.e. calcite replacing the original aragonite mineral of the shell).
- All these *diagenetic* processes can eventually lead to the formation of fossil remains, which can be mineralised skeletal parts (i.e. *permineralised bone*), a cemented infilling of a shell (i.e. *internal mold*) the imprint of the remains in the substrate (an *external mold*) or the consolidated (i.e. *lithified*) impression of the organism's burrow or footprint (i.e. *trace fossils*). Much, much more rarely, however, the mineral can replace and hence preserve certain soft parts, such as calcium phosphate replacing muscle fibres.

- The fossil has the same shape as the original object, but is chemically now a rock, even if some of its original mineral shell or skeleton may remain.

Fossils are generally, but not only, found in sedimentary rocks, as volcanic eruptions can also engulf living organisms in ash or lava. For instance, there are many records of trees preserved in volcanic deposits, although often only as a burnt-out tube. However, there are famous records of animals also being preserved in volcanic deposits, such as some of the Roman populations of Pompeii and Herculanium, preserved in ash flows produced by the eruption of the volcano Vesuvius.

3.4. Some examples of 'Precambrian', Paleozoic, Mesozoic and Cenozoic fossils

Geological history can be reconstructed by observing sequences of rock types and fossils at different localities and then correlating them where their fossil content matches, to build up a composite story of the history of life on Earth. The characteristics of rocks indicate the processes by which they formed and the environments in which these processes took place. Fossils preserved in these rocks provide information about past environmental conditions. Geologists have divided Earth history into time units based upon this fossil record, a discipline of Palaeontology known as *biostratigraphy*:

- The **Precambrian** is a general term for all of Earth history, prior to the first abundant appearance of shelly fossils at the base of the Cambrian Period of geological time around 550 million years ago. Relatively few fossils are found in Precambrian rocks because of this lack of hard bones and shells. The most typical fossils are banded limestone structures formed by prokaryotic cyanobacteria known as *stromatolites.* These are known from the mid Precambrian, i.e. the Archaean Eon. Under certain conditions, microscopic remains of the actual bacterial cells are also preserved, as well as single celled eukaryotes in the later Precambrian (i.e. the Proterozoic Eon). At the end of the Proterozoic, during the period known as Ediacaran, a remarkable biota, including strange leaf-like and jellyfish-like soft-bodied multicellular organisms developed. These were first found at Charnwood Forest in central England in Europe, but are better known from Ediacara in Australia. The apparent lack of any anatomical differentiation has led some palaeontologists, to propose that these animals represent an entirely separate branch of living organisms, the '*Vendobionta'* which apparently did not survive the end of the Precambrian.
- The **Palaeozoic Era** begins with the appearance of organisms with hard parts around 550 million years ago. Marine invertebrates became abundant and diverse throughout the seas of the world at the beginning of this Era, followed very soon by the first vertebrates, primitive fish. Towards the middle of the Palaeozoic, land plants evolved, and the colonisation of land began. Many of our fossil fuels, especially coal, were formed of the remains of the earliest equatorial forests from the late Palaeozoic, which were made up of giant, tree-sized primitive plants such as club mosses, horsetails, and ferns. Invertebrates soon followed the plants onto land, and insects evolved – and vertebrates followed the insects and the first amphibians evolved, eventually giving rise to the first reptiles.
- Into the **Mesozoic**, many new species evolved following a mass extinction at the end of the Palaeozoic. Seed-bearing plants colonised dryer areas of the land, initially dominated by Gymnosperms, including cycads and early conifers, but in the later Mesozoic, the first flowering plants (i.e. Angiosperms) evolved (but did not become dominant until the later Cenozoic Era). Dinosaurs evolved and dominated the land, and giant marine reptiles occupied the seas and others took to the air. The first mammals appeared, but remained small and insignificant whilst dinosaurs ruled the Earth, and the first birds appeared. The extinction of the dinosaurs at the end of the Mesozoic, however, allowed terrestrial and marine mammals to diversify in the following Cenozoic Era.

- The **Cenozoic** is the era of modern life, with mammals, birds and flowering plants very rapidly coming to dominate terrestrial ecosystems and the seas being dominated by the groups of animals which are still very familiar today, such as advanced fish and molluscs.

3.5. Why species go extinct

Extinction is the process in which groups of organisms (ultimately species) die out. If the rate of reproduction of any species is less than the death rate over time, extinction will inevitably result. Extinction is a natural result of evolution and natural selection. Species go extinct when they are unable to adapt to changes in the environment or compete effectively with other organisms. Most extinctions - perhaps up to 95 per cent of all extinctions - occur as a ‘background’ over time. These extinctions are not caused by major catastrophes or dramatic climactic changes, but by small changes in climate or habitat, depleted resources and competition.

3.6. About mass extinctions

A mass extinction is a relatively sudden or rapid, global decrease in the diversity of life. Mass extinctions have occurred periodically throughout the existence of life on Earth. To qualify as a mass extinction, such events or phases must:

- Occur all over the world.
- A large number of species must go extinct.
- Many types of species, not necessarily closely related, must go extinct.
- The extinctions should be clustered over a short period of geological time (note that a few million years is very short in terms of geological time).

The five largest mass extinctions in Earth’s history occurred during:

- The late Ordovician Period (around 438 million years ago): 100 families extinct, including more than half of all bryozoan and brachiopod species.
- The late Devonian Period (around 360 million years ago): 30% of animal families extinct.
- At the end of the Permian Period (around 245 million years ago): 50% of all animal families, including 95% of all marine species (including trilobites) and many terrestrial plants die out.
- The late Triassic (around 208 million years ago): 35% of all animal families die out, including many terrestrial animals.
- At the Cretaceous-‘Tertiary’ (i.e. Palaeogene Period) boundary (around 65 million years ago): About half of all recorded species died out, including the dinosaurs, pterosaurs, plesiosaurs, mosasaurs, ammonites, many families of fish, clams, snails, sponges, sea urchins, and even plankton.

Besides these major extinction events, many minor extinctions phases have occurred through Earth’s history. Today, within the Holocene Epoch of the Quaternary Period, a large number of extinctions are occurring – could this be another mass extinction?

3.7. Why dinosaurs disappeared

As with all other living organisms, many dinosaur species perished as background extinctions throughout the Mesozoic Era. However, despite remaining the dominant animals on land during the Cretaceous Period, the entire group became extinct in the global mass extinction event that took place at the end of that period around 65 million years ago.

Intended learning outcomes:

- Understand, the scope of the science of Palaeontology.
- Describe the process of fossilisation.
- Understand the different types of information contained in the fossil record.
- Understand how fossils can be interpreted by comparison with modern organisms.
- Distinguish the different types of study of the fossil record that are possible.
- Know the main fossil groups from the Precambrian, Palaeozoic, Mesozoic and Cenozoic and how fossils can, therefore, be used to date rocks.
- Know about the five mass extinctions.

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