Only a tiny fraction of all animals survives

A billion animal and plant species are believed to have arisen (and largely gone extinct) at one time or another since the beginning of the Palaeozoic 541 mya. A much greater number of animal skeletons must have been "produced" in the process, which begs the question of what circumstances can prevent the complete decomposition of a living being's body after its death so that components, forms or structures of that body are retained: To date, more than a hundred thousand fossil species have been scientifically documented, but this represents only a tiny fraction of all animal remains that are "fossilized" (or using a broader term, "petrified", i.e. mineralized). Fossils are primarily found in sedimentary rocks (formed by the deposition of material at the surface of the Earth or under water).

When does "fossilization" succeed?

Bird skeletons, such as the ones pictured on this page, can survive intact or virtually intact for relatively long periods of time (at the top a bird skeleton when it was first found and on the right the same skeleton half a year later). However, in the long run, these skeletons will completely disappear as they are exposed to the effects of weathering. In this book, we will occasionally make reference to real fossils, such as the famous primeval bird *Archaeopteryx* (as an example of the "missing link", cf. p. 166) or relatively rare forms of organisms preserved in their original form in amber (cf. pp. see page 55f. and see page 41f.). Fossilization can only occur if the animal body is protected from further decomposition. So the dead remains must have been washed away to oxygen-free zones at the bottom of the Jurassic sea or they must have sunk into an oil-rich swamp (as it occurred to the numerous fossils found in the Messel pit near the German city of Darmstadt). The remains could then have been encased by showers of fine sedimentary lime particles or, at a later geological period, become embedded in oil shale, where they were eventually "petrified" with increasing pressure.

Replica of the "Berlin specimen" of *Archaeopteryx* (Belgrade)

Relative and absolute age dating

As an obvious "rule of thumb", the oldest layers of undisturbed sedimentary rocks can be found at the very bottom and the youngest layers at the top. Thus it is possible to categorize fossils in one layer in relation to those found in another layer. The long half-life of certain elements, such as uranium, thorium, and potassium, allows the absolute age of such rock layers to be determined.

Evolution – a constant process

Evolution – or: How do phylogenetic changes occur?

Evolution is defined as the change of organisms over time. It was recognized very early on that plants and animals had undergone a variety of such changes without knowing what had triggered these changes. It was recognized that offspring differed from their parents and that changes in any one generation are small compared to the differences observed across species. However, it was not until Darwin that the question of what triggered these large-scale changes between species could be answered. Darwin's theory of natural selection provides a causal explanation of how evolutionary change can occur.

Natural selection: Consequences for genetic composition

Natural selection is basically the difference in reproductive success when comparing two individuals from the same species. If this difference is not based on mere coincidence but on the fact that those individuals that are better suited to their environments produce more offspring than the other individuals of the same species. If this behaviour is heriditary, it will have consequences for the genetic composition of the next generation. So, this reproductive advantage, also known as 'fitness', must be hereditary.

Phylogenetic changes

Darwin's theses

In 1859, Darwin set out several theses regarding changes in organisms over time:

- Evolution means the changes that occur within populations of organisms over time. These changes are facts and not theories.
- These evolutionary changes occur in small steps. The extent of these steps can be correlated with the difference between parents and their offspring.
- A rise in the number of species results from the splitting of phylogenetic lineages, which occurs in addition to the evolutionary changes within those lineages.
- The mechanism underlying these phylogenetic changes is the process of natural selection, which Darwin defined as opposed to 'artificial selection' in the breeding of pets and agricultural crops.
- All organisms have descended from one common ancestor. The diversity of organisms is due to phylogenetic developments that have taken place over millions of years following the chemical evolution that has led to the origin of life. Hence, all organisms are related to one another.

The image shows a male *Neurothemis terminata*, a relatively large Southeast Asian dragonfly. Dragonflies already existed in the Carboniferous (especially "giant dragonflies" with a wing span of 72 cm) and they have barely changed since then. Not all dragonflies in the Carboniferous period were giants. Some of them were of "normal size". The giant size of the early dragonflies is sometimes believed to have been due to the higher levels of oxygen in the air (this would also apply to other insects during that period). However, some 150 mya ago, dragonflies seem to have become smaller in size without any significant decrease in oxygen levels. An alternative explanation could be that, with the appearance of the first birds, smaller species of dragonflies began to have an advantage as their larger and slower peers fell prey to birds.

All life comes from the sea

The Galapagos Islands have a strong historical connection with Charles Darwin. This photograph shows the famous rock formation known as “Darwin’s Arch”, situated near Wolf Island.

Below you can see the aquatic life that resides in these waters: a group of eagle rays (*Aetobatus Narinari*) in the foreground, a great hammerhead (*Sphyrna mokarran*) in the back.
All life on this planet began in the sea. The oldest known vertebrates date from the early Ordovician of about 450-470 million years ago. Cartilaginous fishes (rays, sharks) first appeared during the transition from Silurian to Devonian some 420 million years ago. It is no coincidence that the sight of swimming rays may trigger associations with flying. Leonardo da Vinci once said: “Observe the swimming of the fish in the water and you can understand the flight of the bird in the air.”

"Missing links"

Palaeontological evidence

During Darwin's lifetime, evidence to support his theses could be already obtained from palaeontology. Layers of rock serve as windows of time from the past, which can be precisely dated by means of modern methods. Clearly, only the most primitive organisms can be found in the older (earlier) layers of rock. Remains of the earliest vertebrates appear in later (younger) layers and birds and mammals even later.

Vertebrates at a later point in evolution

Even during Darwin's lifetime, these rock layers served as evidence to support that vertebrates had evolved after invertebrates, that birds had not appeared until the different groups of dinosaurs had already established themselves, and that such datable fossils could be used as conclusive evidence of evolution.

The first "missing link"

The discovery of the first primeval bird (*Archaeopteryx*) came in quite handy, as Darwin claimed that there had to be so-called "missing links" for his theses about evolution and natural selection, according to which major animal groups did not evolve independently but are united by connecting links, to hold true. Numerous such connecting links have since been discovered and can thus no longer said to be "missing links".

Scientifically verifiable opposition

Darwin's theses were and continue to be a scientifically verifiable opposition to creation myths, such as the Biblical Genesis and numerous other myths from around the globe, which hold that all species are the product of an individual creation event and have remained constant ever since. These claims have sparked a debate that continues to this day and has relatively little to do with science.

Establishment of the theory of natural selection

Breeders of animals and plants during Darwin's lifetime already knew that changes in traits could be attained by means of selective breeding. They would breed until, by chance, they managed to produce individuals that displayed the desire traits. That is, breeders would wait fo so-called "hot spots" to appear among their "samples" and then use these "hot spots" with the desired traits for further breeding. It is now known that these "hot spots" were actually mutations, i.e. heritable changes in an organism's reproductive cells. Through ongoing selection from one breeding cycle to the next, breeders gradually managed to attain their desired traits. Darwin assumed that similar mechanisms could be found in nature.

The *Archaeopteryx* constitutes a significant connecting link in the evolutionary lineage from feathered dinosaurs to present-day birds. However, as long as these connecting links are not known, that is, as long as they are still missing links, we can do no more than formulate hypotheses. The discovery of the *Archaeopteryx* thus not only revealed a prominent connecting link, but has also given support to the idea that birds have evolved from dinosaurs.