Transitional forms – Transitional forms show a combination of characters of two different groups. Strictly speaking is every organism a transitional form between its ancestor and descendant. It is often difficult to visualize a transitional form between two modern groups. However, this is the wrong concept – one modern group is not derived from another, but rather both have a common ancestor, which might look differently from both.

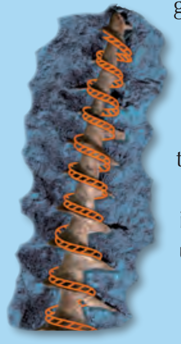
Archaeopteryx

A classic example for a transitional form is the oldest known bird, *Archaeopteryx*. Compared to modern reptiles and birds, this Jurassic animal shows a mosaic of characters. However, considering the fossil record, most of these characters evolved gradually in the ancestors of birds, and it is difficult to tell which of the fossil forms is "still" a reptile, and which is "already" a bird.

The same is true of the evolutionary lineage that leads from mammal-like tetrapods to mammals (Middle Permian to Early Jurassic). Here, a sequence of transitional forms documents the gradual evolution of characters, such as the secondary palate, the secondary jaw joint, the three bones in the middle ear and the highly differentiated dentition, which are commonly referred to as typical mammalian characters. The answer to the question which of these forms is the oldest mammal is thus merely a matter of definition.

Molecular Palaeobiology – Although great progress has been made in palaeontological research, several important questions with regard to the evolutionary history of life on Earth remain problematic, especially those about the relationships of organisms with a poor or no fossil record. Thus, palaeontologists nowadays also use the "genetic fossil record", the inherited genetic information of modern organisms, to reconstruct these relationships. In some cases, such as the relationship between whales and even-toed ungulates, results from genetic analyses have subsequently been confirmed by the discovery of fossils, which were made possible through the predictions from the genetic analyses.

Both ancient DNA (aDNA) of fossil organisms, and the DNA of modern species can be used. However, the utility of aDNA reaches back only 100,000 to 1 million years. To reconstruct the diversification of organisms at the base of the "tree of life" in deep time, the new field of molecular palaeobiology uses comparative DNA sequence analyses of modern organisms. Thus, this field of research can help to solve some of the great enigmas since the times of Darwin: what did the ancestor of all animals look like and how did the great diversity of animals, including humans, evolve from this ancestor?



Fossilrecord and "genetic fossil record"

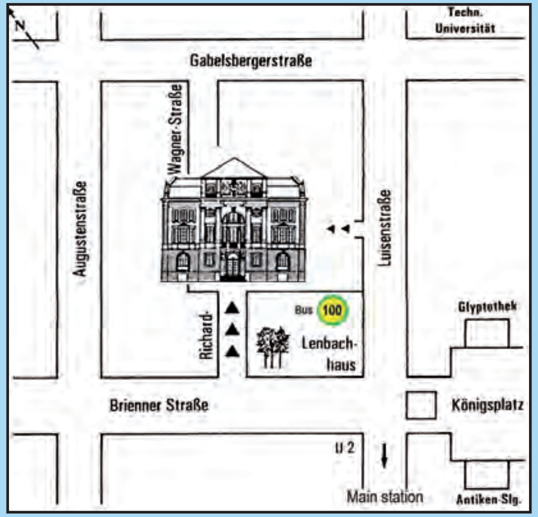
Lineages – Evolutionary lineages encompass generations that gradually change through time. All living species are connected to the earliest organisms by numerous transitional forms. However, most animals and plants are not preserved as fossils and therefore only a few well documented evolutionary lineages are known.

Evolutionary lineage of Steinheim snails

The fossil record depicting the lineage of horse evolution is exceptionally complete and therefore a prime example for evolution in general. Fossil remains of horses from Eurasia, Africa, and North America document that a gradual development from the earliest representatives to the modern horse skeleton occurred that took approximately 55 million years.

The morphological changes that occurred within this lineage are so radical that one would easily refuse a direct relationship between the earliest ancient horse and the modern horse, if not all the transitional forms had been documented. The horse lineage starts with small-sized leave-eating forest dwellers and leads to the long-legged, single-toed grass-eaters that we all know. Apart from the main lineage, several side lineages evolved that do not have any living descendants.

The fresh water snails from Steinheim (South Germany) represent a famous example for an evolutionary transition. 15 Million years ago, a meteorite impact formed a crater, which subsequently became filled with water and formed a small lake that persisted for a long period of time. This lake was colonized by a small snail species, which was common during that time. Subsequently, new species evolved from this stem species. Some of these new species differ considerably from the stem species, and all new species are known exclusively from Lake Steinheim. Shells are abundant in the lake sediments, and numerous morphological transitions are recognizable. In 1866, a few years after Darwin's "Origin", the first phylogenetic tree in the history of palaeontology was published on this example. Similar radiations can be observed in recent lakes that are unusually old.



Palaeontological Museum Munich
Richard-Wagner-Str. 10
80333 München
Germany
Phone: +49 (0) 89 2180 - 6630
Fax: +49 (0) 89 2180 - 6601

How to get there
- S-Bahn/railway station "Hauptbahnhof" (10 minutes to walk)
- U-Bahn: U1 station "Stiglmaierplatz" or U2 station "Königsplatz"
- Bus: museum line 100 station "Königsplatz"

Opening times (entry free)
Monday to Thursday:
8.00 – 16.00
Friday: 8.00 – 14.00

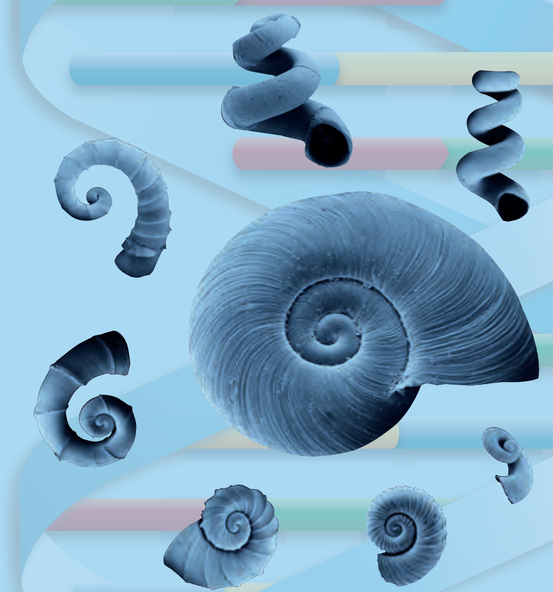
guided tours on wednesday
at 15.00
meeting point "Urelefant"

Saturday, Sunday and Holidays closed
except first Sunday a month
10.00 – 16.00

with guided tours and multimedia-presentations in German

guided tours for groups
by agreement
Tel. +49 (0) 89 2180 - 6630

Tracing Evolution



Special Exhibition

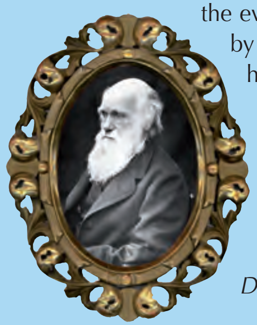
Palaeontological Museum Munich

Bayerische Staatssammlung für Paläontologie und Geologie

Paläontologie & Geobiologie LMU München

Freunde der Bayerischen Staatssammlung für Paläontologie und historische Geologie München e.V.

Darwin, Evolution and Palaeontology – Charles Darwin (1809 – 1882) was certainly one of the most influential naturalists of the 19th century, due to his substantial body of contributions to many different areas of the natural sciences. His most renowned publication is "The origin of species", and he is often regarded as the "father" of the theory of evolution. However, Darwin was not the first to propose the existence of evolution, neither have his ideas remained unchanged to the present day. By detailing the process of "natural selection", he provided a reasonable explanation of how evolution functions. This was pivotal for the general acceptance of the theory of evolution. Fossils are crucial to our understanding of the evolution of life on Earth, as already stated by Darwin: "That the extinct forms of life help to fill up the wide intervals between existing genera, families, and orders, cannot be disputed." We therefore have dedicated this year's special exhibition to Darwin on the occasion of his 200th birthday.



Darwin at the age of 59

A Question of Time – In oder to understand Earth History and the evolution of life, we need an idea of the age of rocks and fossils. Geosciences deal with both relative and absolute age determinations. Absolute dating is based on instable isotopes. Isotopes are variants of chemical elements, which differ from one another in their atomic masses. In time, they undergo a constant, predictible, radioactive decay (breakdown). The proportional abundance of breakdown products and remaining original substances, together with the rate of

Undisturbed sediment sequence

decay, allow for the calculation of absolute ages of rocks and minerals. Unfortunately, most isotopes used in absolute dating cannot be found in fossils or biogenically formed shells and bones. Hence, palaeontologists more often use a relative time scale, which is based on the fact that sediments (including their fossil content) were deposited layer by layer within time. Consequently, sediments become younger up-section in undisturbed and unfolded sequences. The combination of relative time scales and absolute age determinations result in the general Earth history and evolutionary time frame.

Geological processes run on very different time scales. The movement of lithospheric plates amount to several centimetres per year. Sediments are deposited with rates of only a few millimetres in deep sea radiolarian ooze to 5 – 20 centimetres in extensive delta complexes (e.g. Brahmaputra, Mississippi) in 1000 years. Mountain ranges such as the Alps were formed in many tens of million years.

Fossils – windows to ancient worlds – A fossil is evidence of ancient life. Without fossils, we would know nothing about the dinosaurs, the first plants on land, or the vast diversity of life forms that once lived in the oceans but are now extinct. Fossils may represent complete organisms, e.g., an entire, frozen mammoth from the 30,000-years-old Siberian permafrost, or may be incomplete and enigmatic, e.g., a burrow of an unknown 500-million-years-old marine worm. Body fossils reveal the shape of the organisms and encompass hard parts, impressions and steinkerns. Indirect evidence of ancient life such as burrowing and grazing is termed trace fossils. Chemofossils are organic substances such as amino acids or lipids.

Shell of fossil snail
Fusinus Longiroster

Upon death, the soft parts and tissues of any given organism rapidly disintegrate due to mechanical destruction and microbial decomposition. As a result, in most fossils, only the hard parts such as shells and bones or complex organic substances (e.g. Chitin) are preserved. However, physical processes such as currents, water turbulence or involvement of destructive organisms (bioerosion) may destroy even those structures. Hence, the preservation of fossils is commonly related to special conditions.

Generally, the study of fossils allows for the reconstruction of the origin and development of life, as well as climate and environment of ancient environments. This means that fossils not only represent glimpses or snap-shots from Earth history, but also contain important information about the processes underlying past environmental changes, which can today be used in predicting future environmental changes.

Diversity in forests 300 million years ago

Diversity and Extinction – Biodiversity is the variation of life forms within a given ecosystem or for the entire Earth. The total number of plant and animal species today is estimated at approximately 5 million. Since the Cambrian (540 Ma ago), the diversity of organisms has been generally increasing. However, five massive extinction events occurred during Earth history that were caused by catastrophes such as meteor impacts, volcanic eruptions or climate change. These extinction events severely affected the course of evolution. Plant diversity is generally more difficult to assess than animal diversity because plants easily become disaggregated upon death, and thus fossils of complete plants are exceedingly rare. Moreover, plant diversity patterns differ from those of animals. One of the major changes in the Earth's vegetation occurred some 300 Ma ago when the arborescent lycophytes became extinct. Organisms that once dominated the world disappeared, and thus seem to represent the losers of evolution, although they might have been very successful in their time.

Variation, Variability and Speciation – Variation or individual variety is natural and known to occur in all parts of all organisms. The variations/differences in appearance, which include form, anatomy, function, and behaviour (phenotype), are the result of small variations in the genetic code between individuals (genotype), and represent the driving force behind the formation of new species (speciation). Fossils provide information about variability in ancient life forms.

Variation in fossil sea shell
Myophorella Lusitanica

Genetic variability, i.e. differences in the genetic code, between the individuals of one species result from so-called mutations, which represent small alterations or inaccuracies that may occur during the copying of the DNA during cell division. Mutations accumulate especially rapidly in groups of individuals (populations) that are isolated within a species areal, because these populations possess a reduced gene pool compared to other populations that regularly intermingle and exchange genetic material. Isolation eventually leads to the establishment of new genotypes, which, in turn, produce phenotypes that, over time, may become so different from the original phenotype that reproduction between the original and new phenotypes is no longer possible. New species originate! The small changes in the genotype of a population represent evolution at its smallest scale, and this is commonly termed microevolution.

Latimeria

Living Fossils – 'Living fossil' is an informal term used for extant organisms that are strikingly similar in morphology to their ancestors known from the fossil record; examples of 'living fossils' include the coelacanth *Latimeria* and the dawn redwood *Metasequoia*. In several instances, the fossil forms were known long before the discovery of their living relatives. However, 'living fossils' technically is a contradiciton in terms, since fossils, per definition, do not live. While most of the well known examples for living fossils such as the *Nautilus*, the horseshoe crab *Limulus*, or the maidenhair tree *Ginkgo* have a fossil record that can be traced back several 10 or 100 million years, the record holders with regard to morphological consistency are certain cyanobacteria, which appear to have remained unchanged since 3.5 billion years. Nevertheless, the similarities between 'living fossils' and their fossil ancestors are usually superficial and restricted to morphological traits. Like all other living things, 'living fossils' are exposed to evolutionary change as a consequence of mutation and natural selection.