Chapter 8:
Evidence for the theory of evolution

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Introduction to evolution

Evolution terminology

Evolution is the process of cumulative, heritable change in a population over many generations.

An **ancestor** is a species from which other species have evolved

A **common ancestor** refers to an ancestor that is shared by different species. This is supported by molecular evidence: there is a common genetic code in the form of DNA and RNA.

A **theory** is an explanation that has not been proven as fact but is supported by evidence.

Introduction to evolution

Key events in the history of life on Earth

Bacteria, eukaryotes, multicellular organisms

Jawless fish, jawed fish, land plants and anthropods, trees, land vertebrates

Reptiles and amphibians (they become dominant)

Most life eliminated; surviving organisms diversify; dinosaurs dominate; first mammals

Flowering plants; arrival of marsupials in Australia; dinosaurs extinct; Ice Ages; humans

Molecular evidence for the theory of evolution

Comparative genomics

Genomics is the study of the whole set of genes of a species and the interactions of the genes within a genome. The genomes of many species have been fully sequenced. Complete genomes are now available for humans, chimpanzees, koalas and bacteria, among others.

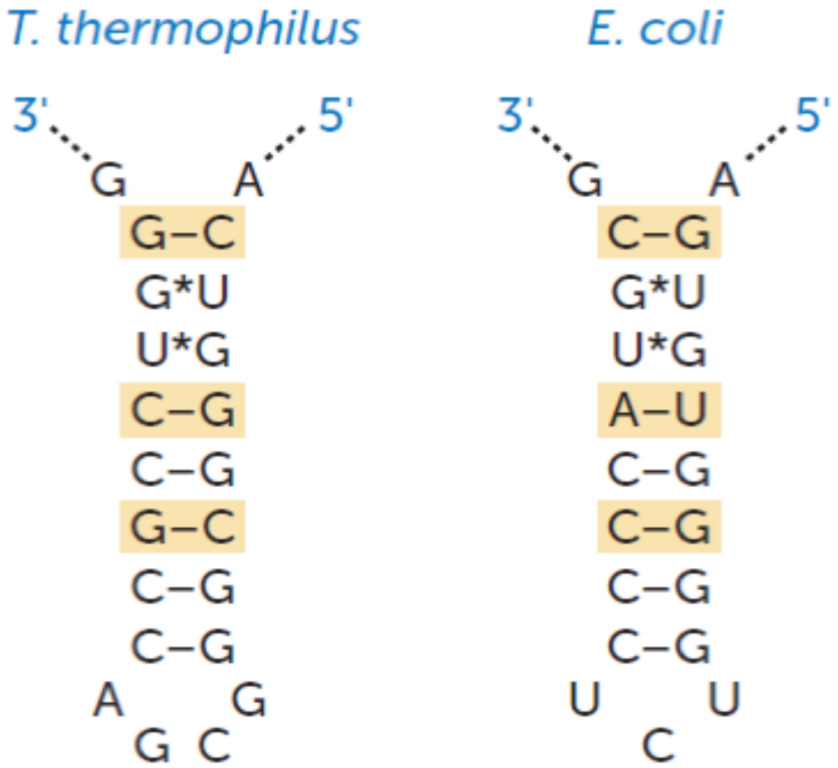
Relatedness is a measure of evolutionary distance. The relatedness of groups of organisms is reflected in the similarity of their DNA sequences. Two species are more related if they have a more recent common ancestor and less related if they have a less recent common ancestor.

Comparative genomics is a field of biological research in which researchers use a variety of tools to compare the genome sequences of different species. The more similar in sequence the genes and genomes of two species are, the more closely related those species are.

Molecular evidence for the theory of evolution

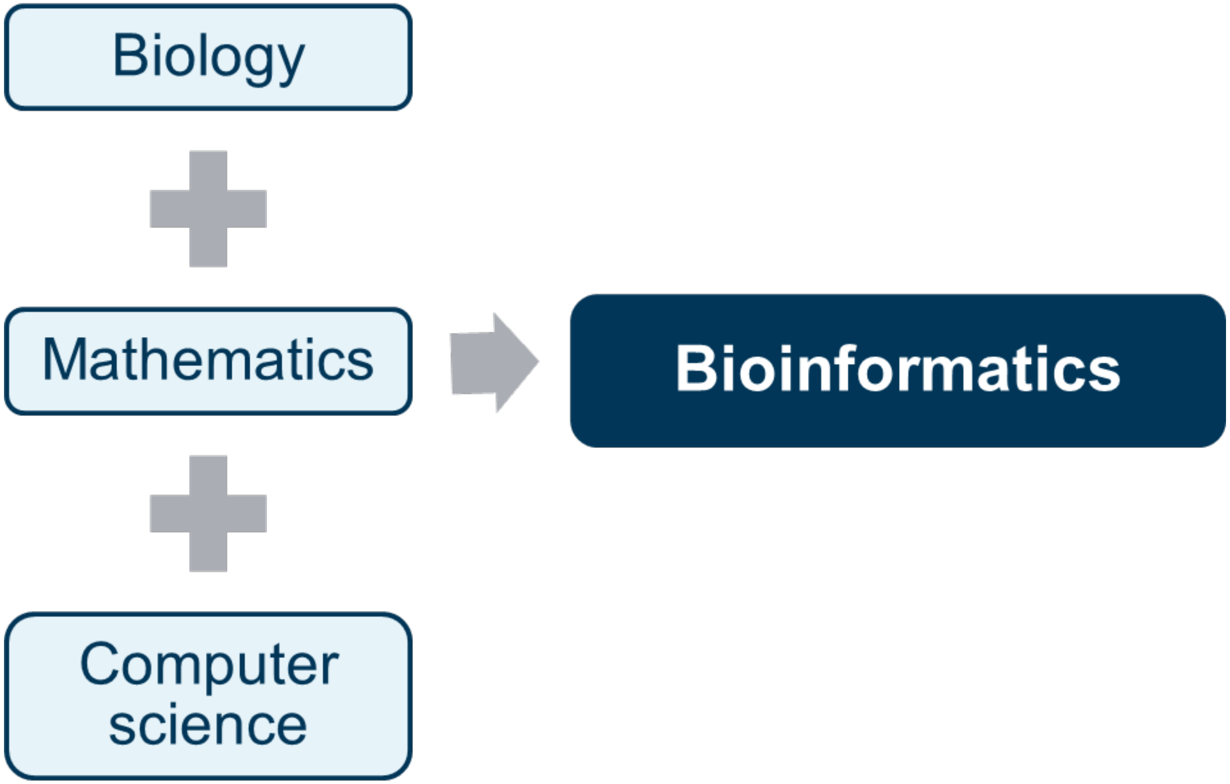
Molecular methods

DNA sequencing (next generation or Sanger) and DNA-DNA hybridisation are molecular methods used by scientists to measure relatedness. Through variation in DNA or RNA sequences, scientists can obtain a measure of the difference between organisms and trace evolutionary relationships. They can, for example, detect subtle differences in base sequences between two microbes.



Molecular evidence for the theory of evolution

Comparative genomics is made possible with bioinformatics



Biology

Mathematics

Computer science

Bioinformatics

Molecular evidence for the theory of evolution

Bioinformatics

Bioinformatics is the digital storage, retrieval, organisation and analysis of an enormous volume of biological data.

Bioinformatics has dramatically increased the size, accuracy and scope of data sets, such as those needed for comparative genomics.

Bioinformatics has provided significant advances in our knowledge of the entire genomes of organisms, and in turn this has revealed yet more evidence of evolution.

Molecular evidence for the theory of evolution

Phylogenetic trees

Evolutionary relationships between groups can be represented using **phylogenetic trees**.

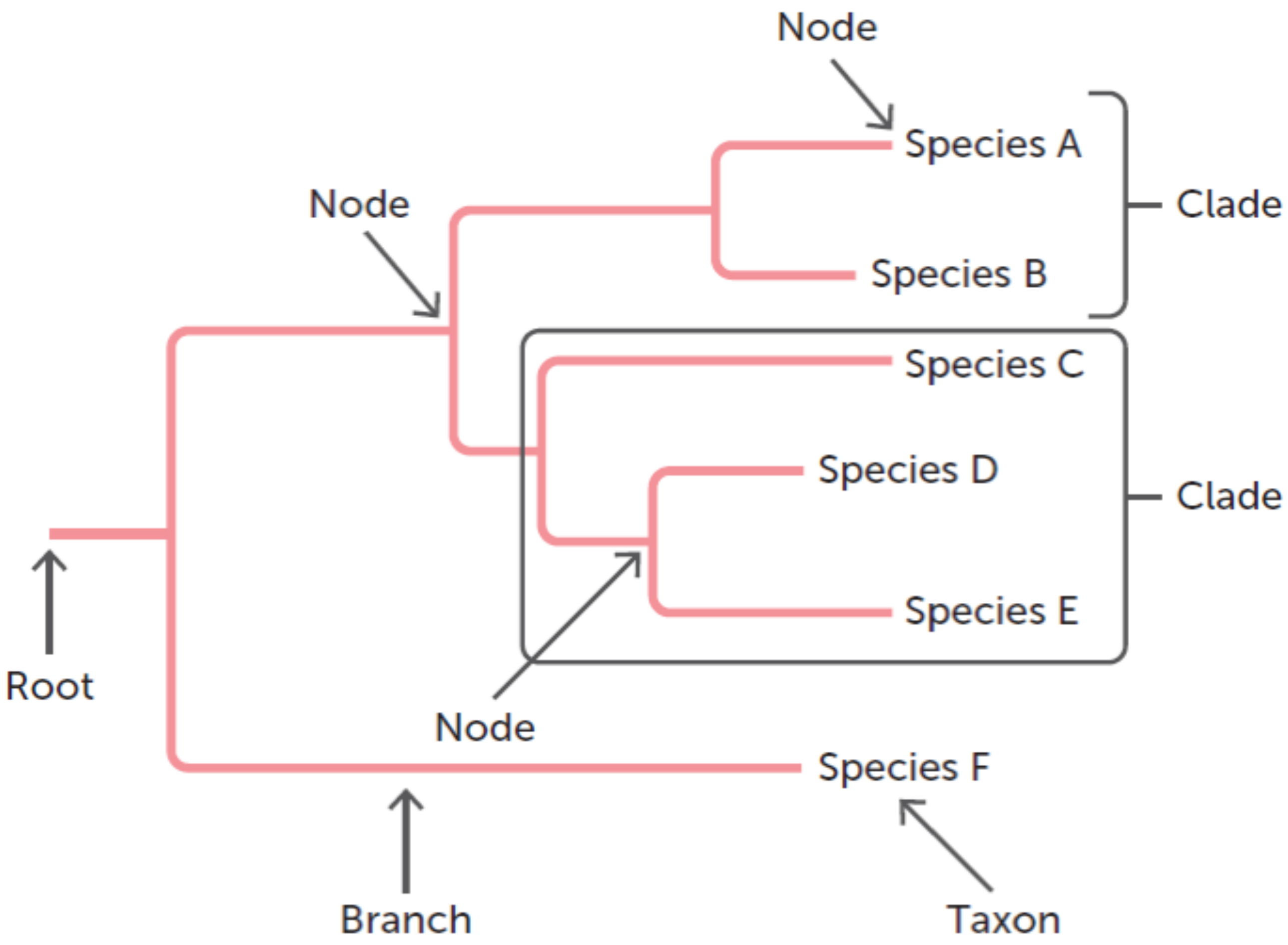
These diagrams show how organisms are related to each other but the tree is a hypothesis, not a certain fact.

A phylogenetic tree can be built using:

- physical information, such as body shape, bone structure or behaviour
- molecular information, such as genetic sequences.

Molecular evidence for the theory of evolution

Parts of a phylogenetic tree



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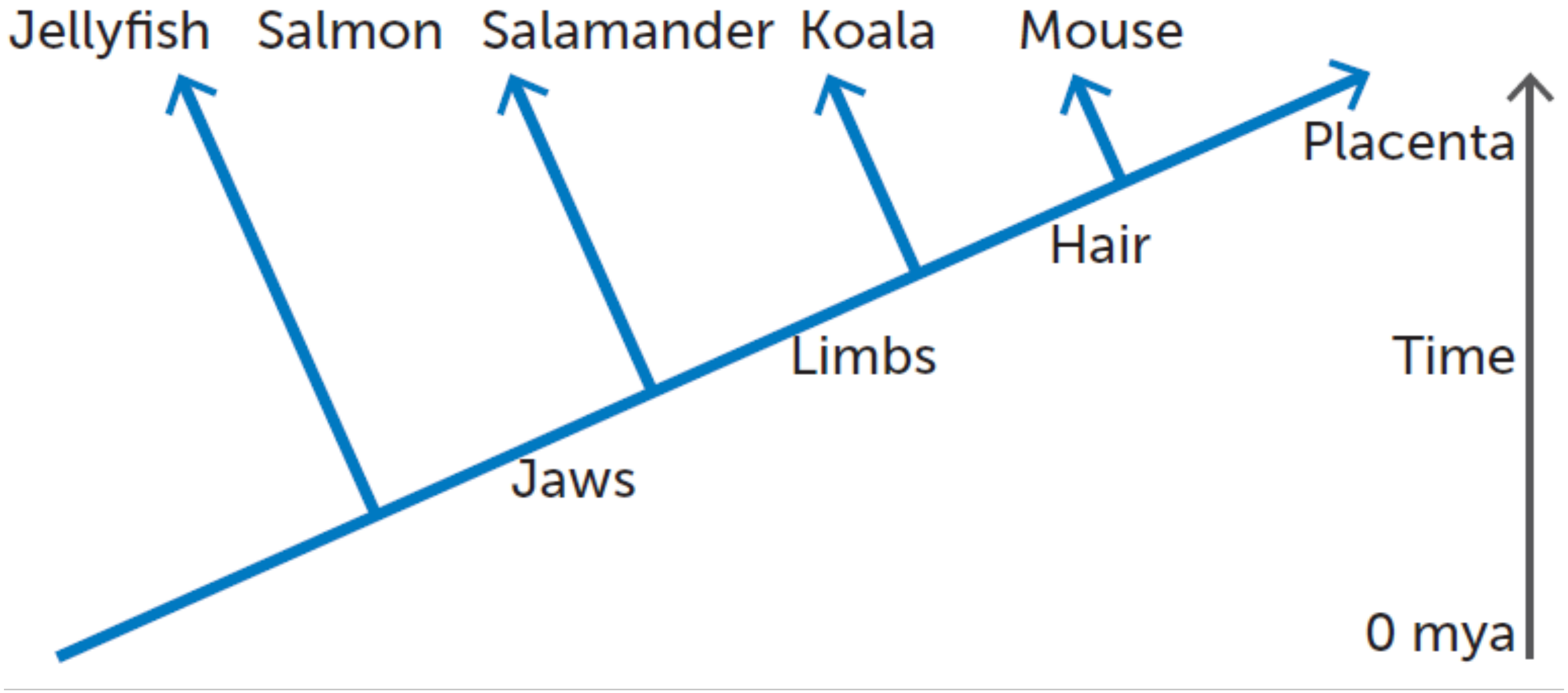
A phylogenetic tree is drawn using a set of hypotheses



Molecular evidence for the theory of evolution

Comparative biochemistry and protein conservation

The amino acid sequence of certain proteins found in many organisms has been analysed across a range of organisms, and the similarities provide evidence for evolution.

Comparative biochemistry is the study of different kinds of proteins (including enzymes) and their fundamental units (amino acids). It involves analysis of the similarities and differences, and the results enable evolutionary biologists to determine the degree of relatedness between species.

Proteins, and the alleles that encode them, are subject to the same mechanisms of evolution as the larger traits that individuals possess. A protein that is well suited to its function will be conserved, while other traits around it may evolve.

Proteins consist of long chains of amino acids, and each protein differs in the number, type and sequence of its amino acids. The number of differences is used to determine the relationship between organisms.

Molecular evidence for the theory of evolution

Comparative biochemistry example:

The differences in sequence of the 146 amino acids that make up the blood protein haemoglobin are an indicator of the closeness of the relationships between humans and other primates.

Primate	No. of differences in amino acid sequence
Chimpanzee	0
Gorilla	1
Gibbon	3
Orangutan	4
Macaque (monkey)	8
Lemur	5

The fossil record

What is a fossil?

Fossils are the preserved remains and traces of past life (many can be found in sedimentary rocks). They provide evidence of past life. These remains can be hard parts, such as teeth, bones and shells, or impressions in the rock where the organism's tissue has decayed.

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The fossil record

The study of fossils

The study of fossils is called **palaeontology**.

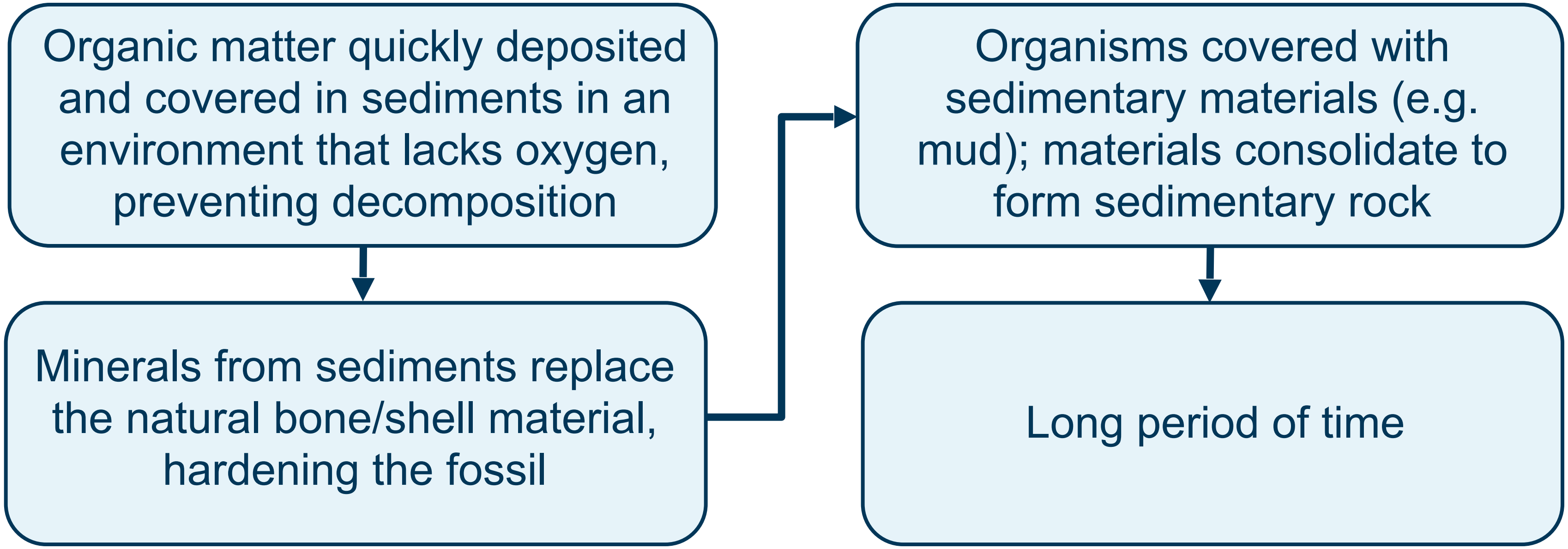
Much of our knowledge of the changes that have occurred in living things over time is derived from fossils. Only a very small percentage of organisms leave fossilised remains. Many fossils are destroyed by natural processes such as weathering and erosion.

Fossils show that there has been a clear change over time from simple to very complex organisms, which is evidence for evolution.

The fossil record is incomplete

The process of fossilisation requires very specific, and rare, conditions. The remains of the vast majority of long-extinct animals may never be found.

Consequently, the fossil record is incomplete and biased toward organisms that lend themselves more easily to the fossilisation process.



Organic matter quickly deposited and covered in sediments in an environment that lacks oxygen, preventing decomposition

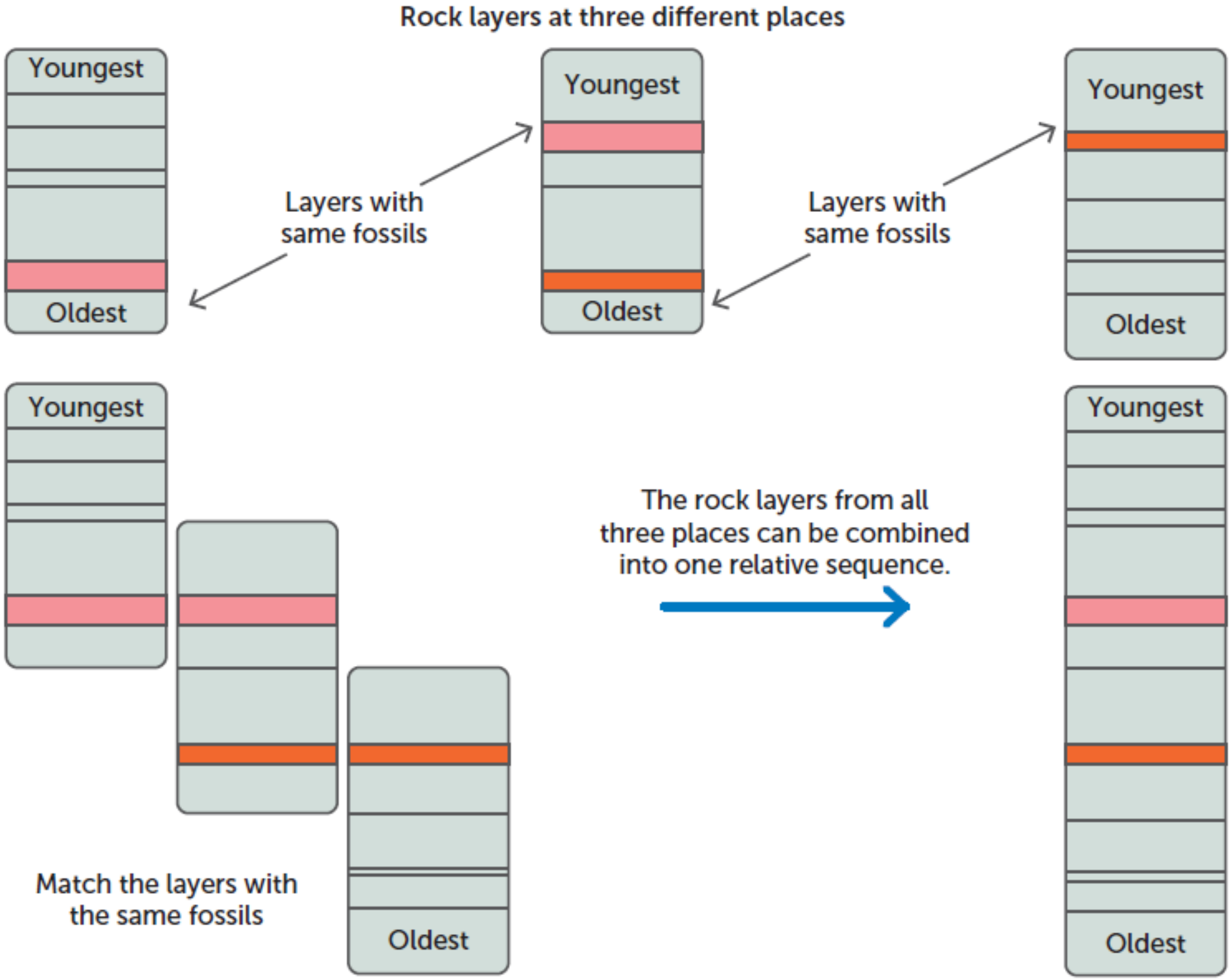
Minerals from sediments replace the natural bone/shell material, hardening the fossil

Organisms covered with sedimentary materials (e.g. mud); materials consolidate to form sedimentary rock

Long period of time

The fossil record

The principle of superposition



The **principle of superposition** indicates that the oldest rock layer is found at the bottom of the rock, with each consecutive layer above being relatively younger.

The fossil record

Transitional forms

The Archaeopteryx was a small flying dinosaur with feathers. It appeared in the late Jurassic period. It shared features in common with both birds and reptiles, suggesting that birds evolved from reptiles. Its reptile-like features include a long-tail, claws, no keel, solid bones, and teeth. Its bird-like features include a wish-bone, feathers and reduced fingers. Intermediate states such as Archaeopteryx are called **transitional forms**.

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The fossil record

Fossil dating methods

Relative dating	Absolute dating
Used to determine the age of a rock, or a fossil contained in the rock, relative to other rocks or fossils found nearby	Assigns a numerical age in years to a fossil or rock
Strata are deposited in a time sequence, with the oldest on the bottom and the youngest on the top. Palaeontologists can assign relative ages to fossils based on the strata in which they are found.	Three main types: radiometric dating, electron spin resonance and luminescence. Most common method of absolute dating is radiometric dating, which uses the known rates of decay of naturally occurring radioactive isotopes present in a rock or fossil.

Comparative anatomy and embryology

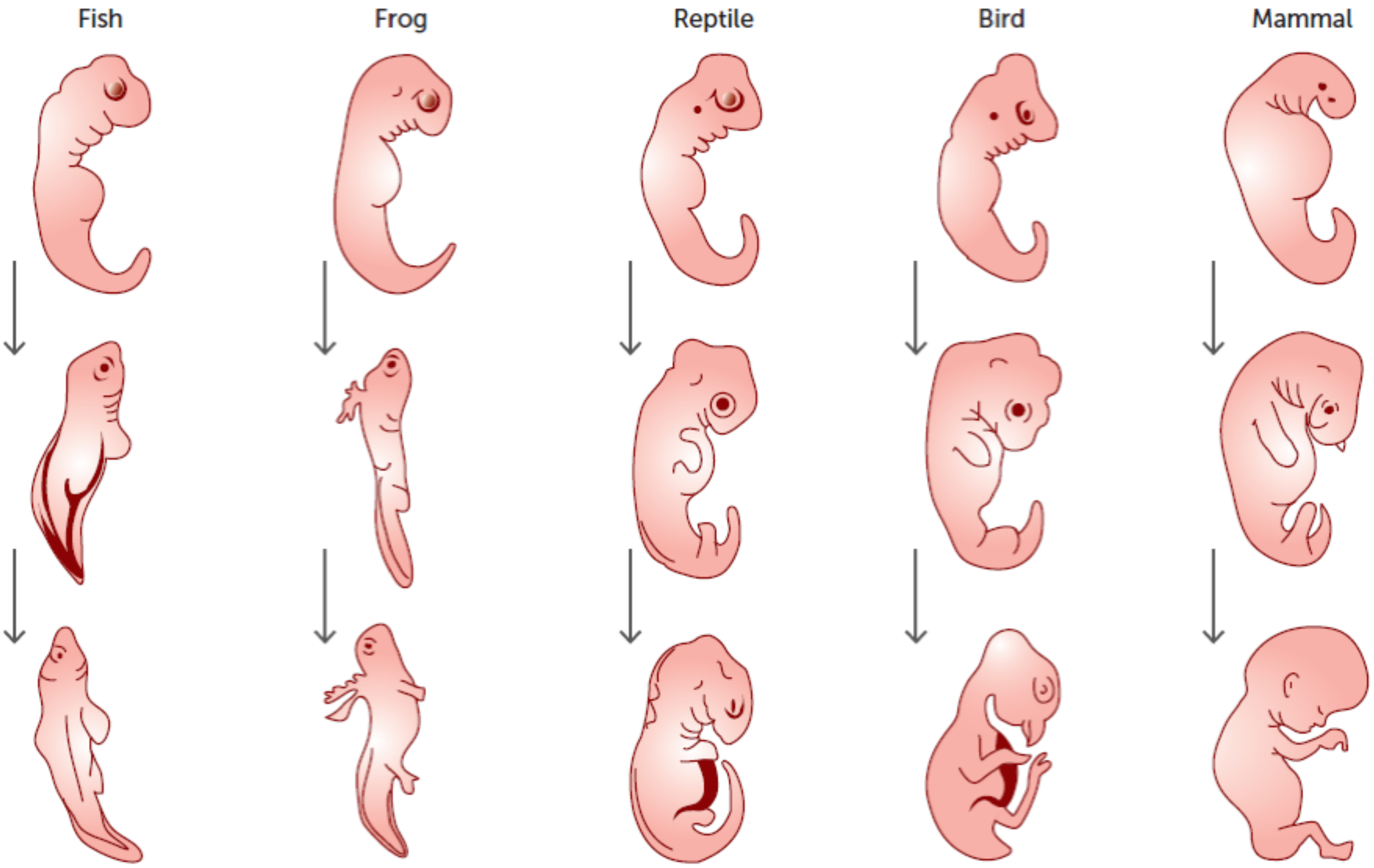
Comparative anatomy is the study of the similarities and differences in structure between different organisms. Structural features are also called **morphological** features.

Comparative anatomy is used to establish evolutionary relationships on the basis of structural similarities and differences, including the comparative study of **embryos**.

Example:

All members of the phylum Chordata have, at some stage of their development, a dorsal notochord (a solid tissue running along the back), pharyngeal slits (which turn into gill slits in fish), a dorsal nerve cord and a tail that extends past the anus. The embryos of the different vertebrates are very similar and show features that are not present in adults. This suggests that these vertebrates evolved from a common aquatic ancestor, such as the crossopterygian fish.

Comparative anatomy and embryology



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Comparative anatomy and embryology

Homologous structures

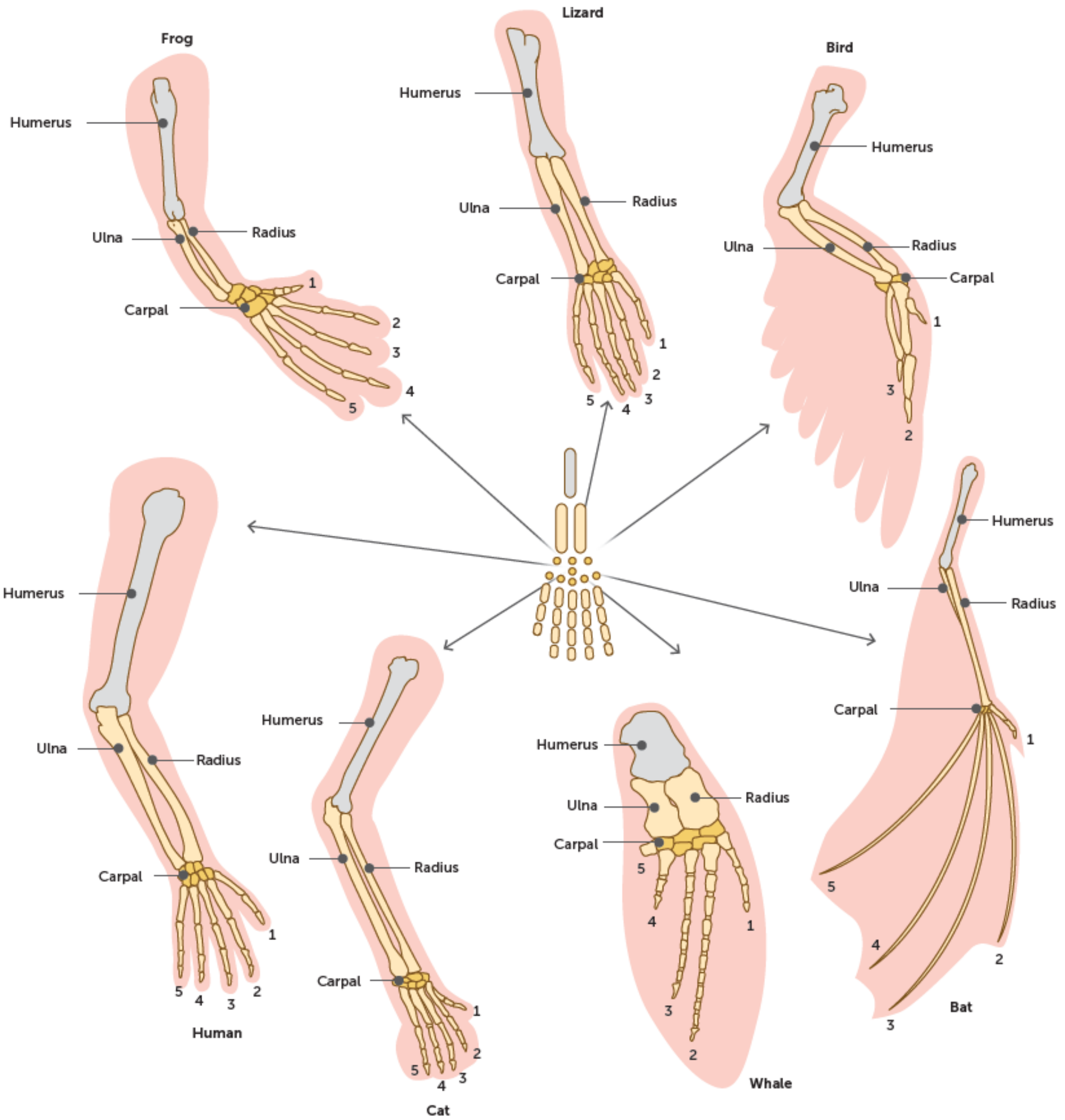
Anatomical structures that are common to more than one species and were inherited from a common ancestor, but have different functions, are known as **homologous structures**.

Homologous structures show the same structural plan but perform different functions due to the different species living in different environments with different selective pressures (conditions).

Example:

The principle of homologous structures is illustrated by the adaptive radiation of the forelimb of a selection of vertebrates. In each group it shows the basic pentadactyl pattern, but it has been modified for different uses.

Comparative anatomy and embryology



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Vestigial homologous structures

In some cases, homologous structures stemming from a common descent can eventually cease to have any functional use for an organism; the structure may not necessarily impede a particular adaptation of an organism, but at the same time the structure no longer serves a ‘useful’ purpose.

These structures are called **vestigial structures**. Vestigial structures can take a variety of forms, including bones, soft tissues, organs, cells or molecules.

Vestigial organs are evidence for evolution, because it is hypothesised that they were once present and functional in their ancestors. Changes in the environment have rendered these organs redundant, so over time they have lost their functionality. They demonstrate the evolutionary divergence of a species from a past behaviour or activity.

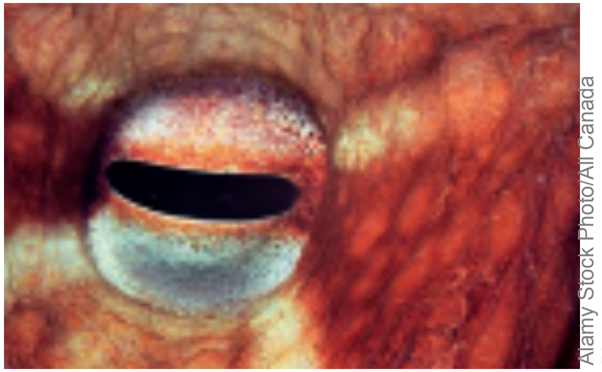
Comparative anatomy and embryology

Analogous structures

Analogous structures are features of organisms that have the same function but not the same basic structure.

Example:

The eyes of octopuses and vertebrates are remarkably similar, even down to fine points of detail. However, in the vertebrate eye, the nerve fibres lie in front of the sensory cells of the retina, whereas in the octopus eye they lie behind them. Because of this, the vertebrate eye has a blind spot where the optic nerve emerges from it, whereas the octopus eye lacks one. The reason for this difference lies in the ways the two eyes developed, which indicates that they are the products of two distinct lines of evolution.



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Biogeography

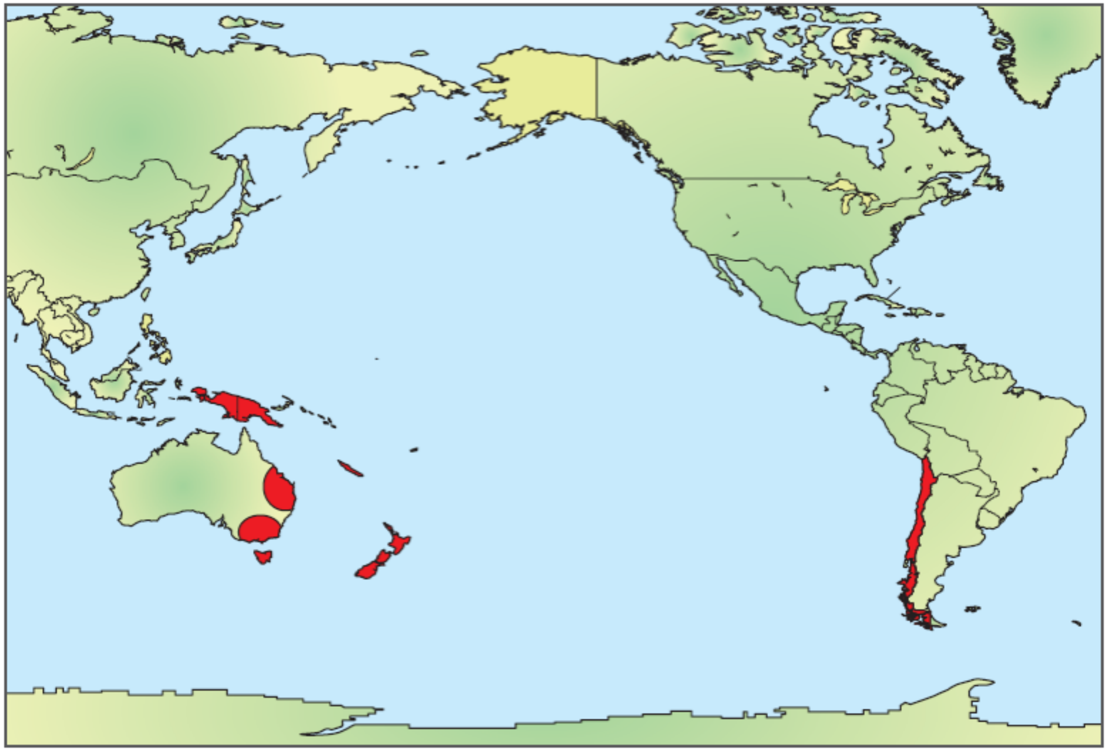
Biogeography is the study of the distribution of organisms and ecosystems across the world and through geologic time.

The fauna and flora of Australia owe their uniqueness to the isolation of the landmass. However, Australia and other landmasses in the southern hemisphere share many plant and animal groups. By looking at the pattern of these distributions today, plus that of the fossils, we are able to reconstruct Australia’s evolutionary history.

Biogeography

Biogeography example:

Southern beech trees, *Nothofagus*, are found as both living and fossil specimens in mainland Australia, Tasmania, Papua New Guinea, New Caledonia, New Zealand, Antarctica and South America. The far-flung distribution of *Nothofagus* provides evidence that Gondwana once existed.



Types of evolution

Divergent evolution

Divergence is a pattern of evolution in which differences between groups of organisms accumulate to a critical point that leads to speciation, the development of a new species.

This pattern is usually the result of the dispersal of a single species to different environments; that is, groups from the same species become isolated from one another, stopping gene flow.

The sub-populations are subjected to different environmental pressures, suited to certain structures that can perform functions specific to surviving their unique environment.

Homologous structures indicate **divergent evolution**, because new species will have the same fundamental structural plan, but the structures may be used in different ways.

Types of evolution

Divergent evolution example:

Koalas (tree-dwelling herbivores), Tasmanian devils (ground-dwelling carnivores) and marsupial moles (dune-burrowing insectivores) are related because they have a common marsupial ancestor. However, they show quite different feeding structures that enable them to adapt to different diets.

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Types of evolution

Convergent evolution

Convergent evolution is a pattern that occurs when unrelated organisms evolve similar adaptations in response to their environment.

The results of convergent evolution often show up as analogous structures: adaptations of very different types of structures that solve a problem in a similar way. The structures are genetically relatively different, but their functionality is very similar.

Types of evolution

Convergent evolution example:

Modern anteaters include echidnas (monotremes), numbats (marsupials), and pangolins (placentals). All of these species have an elongated snout that functions as a smelling and digging device, and a long, extendible tongue that can extract ants from crevices.

Analogous structures such as elongated snouts, are similar due to environmental pressures, not because they share a recent common ancestor. Instead, they would share a very distant common ancestor.

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