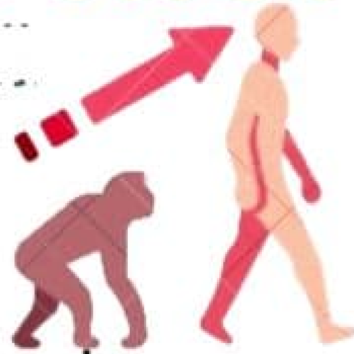
Krishnagar Academy

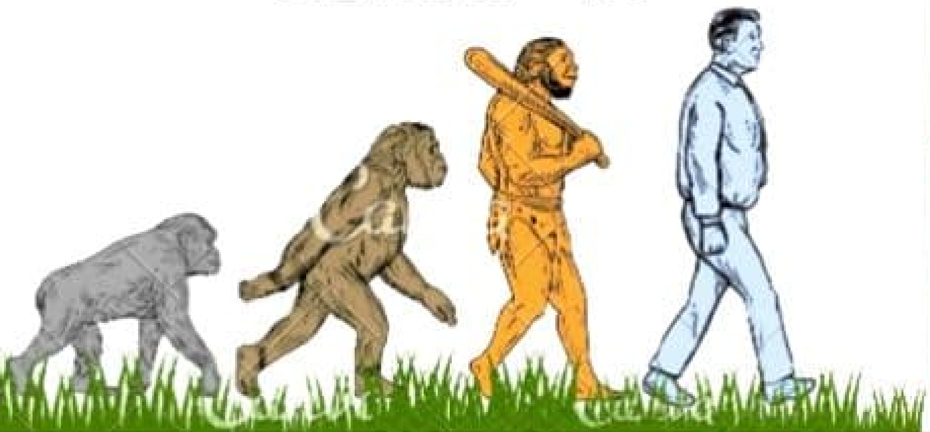
Evolution



chapter-7

BIOLOGY

CLASS 12



Life on the primitive earth was produced by chemical evolution. Biological evolution has resulted in immense variety of organisms over the ages showing variations in size, form and degree of complexity. On the one end, there are simple single-celled organisms and on the other, very complex organisms with billions of specialized, highly organized and cooperating cells. Despite variety, there is a basic unity in the organization of life. There are certain life processes which are common to all organisms : (i) to obtain energy and matter from their environment, (ii) use energy and matter to maintain life, (iii) reproduce to multiply and perpetuate their race, and (iv) respond to external stimulus and adapt to environmental conditions. These similarities suggest that all living organisms have evolved from a common early form of life. Evolutionary change is thus a fundamental characteristic of life.

EVIDENCES OF ORGANIC EVOLUTION

The **evidences of organic evolution** derived from many lines of study indicate that present-day forms have arisen by gradual changes from pre-existing forms, and that more complex forms have been derived or evolved from simpler forms.

The evidences of evolution are largely drawn from palaeontology, comparative morphology and anatomy, embryology, cell biology, biochemistry, molecular biology and geographical distribution of organisms.

Evidences from Palaeontology

The relics of some former living life—plants or animals—embedded in a dug out of the superficial deposits in past geological periods is known as fossil and study of fossils is said to be palaeontology*. Fossils are mostly found in sedimentary rocks. The process of preservation of living beings or their parts in the form of fossils is known as **fossilization**. This is a continuing process. Fossils reflect the history of the past and hence are the true witness of evolution.

Process of fossilization. Fossils not only provide an insight into the structure, traits and behaviour of organisms but also the nature of the environment in that period. The utility of fossils, however, depends upon the degree of their preservation. Majority of the known fossils are imperfect and in most cases only external morphological features are preserved and cellular details are hardly visible. Usually, perfectness of a fossil depends upon the duration and intensity of destructive forces existed before or during the fossilization process.

To explain the process of fossilization two theories have been put forward. **Replacement theory** envisages that fossilization takes place by the replacement of the molecules of original substances of the organism one by one by the molecules of minerals in the soil solution. This replacement occurs due to hydrolysis or weathering of the organic substances present in the body. Several known fossils show such a type of replacement. According to **infiltration theory**, fossilization occurs as the result of infiltration and precipitation of minerals through the cell membrane. After burial, the plant or animal body undergoes partial disintegration and the free carbon released in this process forms carbonates by reacting with infiltrated calcium, magnesium, etc. This process of fossilization depends upon the disintegration of organic substances present in the cell.

Types of fossils. Fossils are of different types. The main types are as follows :

1. **Petrification.** Preserves both external forms and internal structures of animals and plants.
2. **Compression.** Formed as the result of burial of plants or their parts in sediments. These are used to study external morphology of plants.
3. **Incrustation.** External form of plants are preserved but internal structures are destroyed.
4. **Impression.** Formed when an organism or its parts come in contact with soft clay. Extremely useful in study of external features of organisms.
5. **Coal balls.** Plant organs of roughly spherical shape in coal.
6. **Moulds and cast.** Provides external details of body's shape, size and form of organisms in the form of moulds and cast.
7. **Unaltered fossils.** Entire animal body gets preserved in ice, petroleum springs and oil soaked ground.

Computation of the age of a fossil. The time when an organism existed on the earth is calculated by finding out the geological time of the stratum of earth's crust in which the fossils of that organism are found. The age of a fossil is usually determined by analyzing the radioactive substances present in the rock from which it has been recovered. For instance, uranium is transformed into lead through several intermediate stages and one million g of uranium produce 17,600 g of lead in one year. Thus, by estimating the amount of lead in a rock, its approximate age can be calculated. Radioactive carbon dating method is extensively used to determine the age of a fossil. Recently, the transformation of radioactive potassium (K^{40}) to argon and rubidium (Ru^{87}) to strontium has been used for dating fossil-bearing rocks of any age and type. Isotopes with longer half-life periods are of great significance in such calculations. Relatively short periods of geologic time are estimated by measuring the rate at which water falls recede upstream as they wear away the rocks over which they tumble or by counting the annual deposits of clay on the bottom of ponds and lakes.

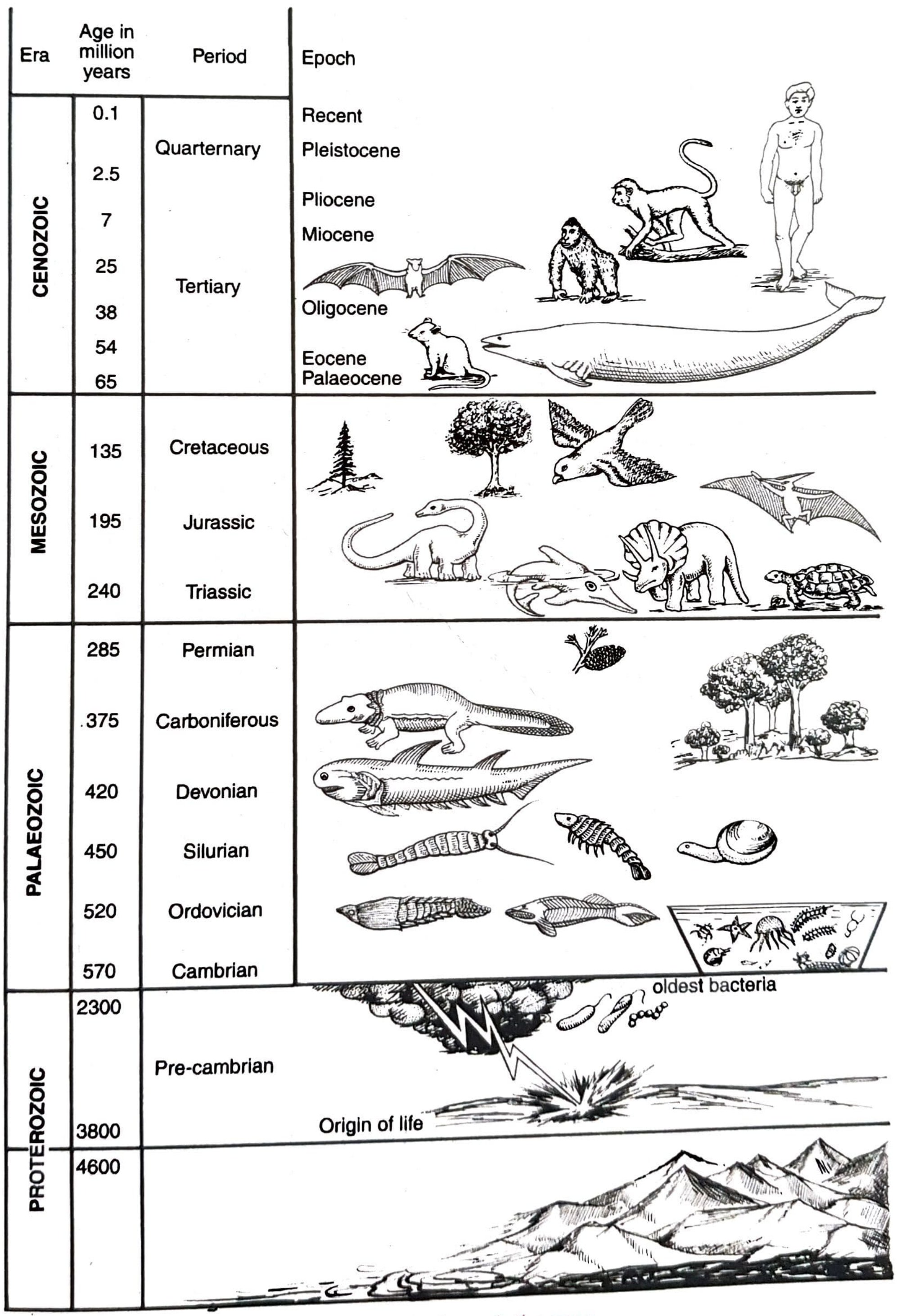


Fig. 1. Life through the ages.

Mass extinctions. Extinction is the permanent loss of all members of a species. Over the last billion years, many plant and animal species have evolved and become extinct at a uniform pace. Well known examples include dinosaurs, sabre-toothed tigers and dodo. Of the estimated four billion species that have evolved since life appeared on the earth, only a few million are still in existence today. There are many instances where a large number of species have become extinct over a relatively short span of time. Such episodes are known as **mass extinctions.** At least five mass extinctions appear to have occurred throughout the history of the earth at the end of Ordovician, Devonian, Permian, Triassic and Cretaceous periods. Even species that are well adapted under normal circumstances may be wiped out as their adaptations become irrelevant under the extremes of environmental stress which seem to be responsible for such extinctions. These major eradications of large numbers of species seem to have cleared the way for the evolution of new and opportunistic groups, and thus had a major effect on the pattern of life on the earth. The most recent mass extinction took place about 60 million years ago when dinosaurs came to an abrupt end. It is believed that the earth was hit by a comet or meteorite around that time, and this resulted in mass extinction of dinosaurs. This view is supported by the presence of very high concentration of the metal iridium as a thin layer below the surface soil. This metal is rare on earth but is present in large quantities in meteorites. Some other hypotheses like **global cooling** have also been suggested for mass extinctions.

Geological time-scale. Geologic time-scale covers the whole span of the earth's history to correlate the events in a proper sequence. The earth crust consists of layers of rocks lying one on the top of the other. Radioactive dating techniques have revealed that the earth is approximately 350 million years old. On the basis of **time**, the geological history of the earth has been divided into five **eras—Archaeozoic, Proterozoic, Palaeozoic, Mesozoic** and **Coenozoic.** Each era includes several **periods** and each period is further divided into **epoch**. Important events of geological time-scale are summarized in Table 1 and shown in figures 1 and 2.

Significance of organic evolution. Palaeontology provides direct evidence of evolution. Different strata in the crust of the earth were formed in different geological periods and have different kinds of fossils which provide the evidence of past life and course of evolution.

EARTH HEADING TOWARDS SIXTH MASS EXTINCTION

Biologists believe that the Earth is now heading towards **sixth mass extinction.** While previous extinctions have been driven by natural planetary transformations or catastrophic asteroid strikes, the current die-off appears to be associated to human activity; a situation designated as an era of **'Anthropocene defaunation'**. Across vertebrates, 16 to 33 per cent of all species are estimated to be globally threatened or endangered. The situation is similarly dire for invertebrate animal life. Large animals-described as megafauna and including elephants, rhinoceroses, polar bears and countless other species worldwide face the highest rate of decline, a trend that matches previous extinction events.

The fossil records provide a complete pedigree or geological history of certain organisms that indicate that evolution has taken place through the series. The fossil series of horse is taken here as an example. The first fossil of this series is the ancestral horse, *Eohippus* (lower Eocene). It was about 30 cm in height and had four digits in the fore limb and three in the hind limb. The first and fifth toes of the hind legs were short and did not reach the ground. From some such Eocene horses other horse-like forms evolved in the Oligocene epoch. Of these, *Mesohippus* recorded a further decrease in the number of digits and it had three digits in each leg. The weight of the body was supported chiefly by the middle (third) digit. It was about 60 cm high. Fossil records of horse-like animals from the Miocene epoch showed a further decrease in the number of functional digits. *Merychippus,* a miocene horse, was 100 cm high, of the size of a small pony, and had three digits in each leg, of which only the middle one reached the ground. The pleistocene horse, *Equus,* resembled a modern horse in all essentials. It was 150-165 cm high and had a single digit in each limb. These evolutionary changes were in response to changing environment from lush vegetation to dry grasslands (*Fig. 3*).

Thus, in the evolution of modern horse in 60 million years the height increased by 135 cm, the head and neck were lengthened, limbs were reduced to one digit, and ulna and fibula were reduced. There was also change in the length of cheek teeth which are used for grazing (eating grass) in the modern forms, while they were for browsing (eating shrubs and leaves) in ancestral forms. With these changes, the modern horse thus evolved is an intelligent, long-legged swift animal suited for open grasslands.

Fossil records also provide **missing links** between the two groups of organisms. An excellent example of such a link is the fossil bird, *Archaeopteryx lithographica*, that lived in the Jurassic period, about 170 million years ago. It shares the features of both reptiles and birds (*Fig.* 4). Its reptilian features are the presence of teeth in jaws, a long tail with free caudal vertebrae, a weak and keel-less sternum, solid bones and elongated lizard-like body. Its avian characters include the presence of feathers on the body, forelimbs modified into wings, four toes in foot adapted for perching; presence of V-shaped furcula, jaws modified to beak and limb bones are bird-like. This suggests that birds have evolved from reptilian ancestors.

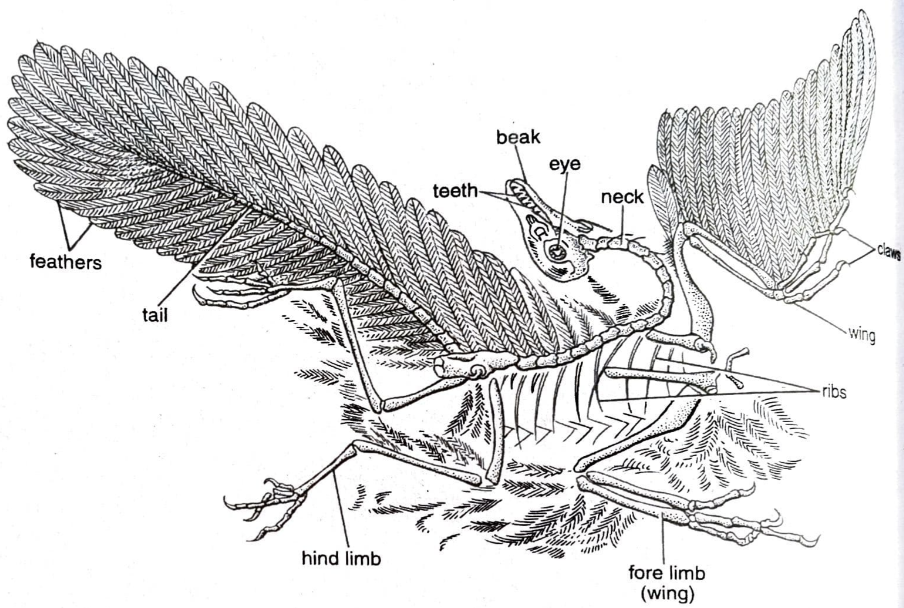


Fig. 4. *Archaeopteryx lithographica*: evidence of origin of birds from reptiles.

Similarly, the palaeontological records of camel, elephant and man can also be taken as evidences of evolution.

Evidences from Morphology and Anatomy

Comparative morphology and anatomy (called **tectology**) of individual organs and organ systems of diverse forms of organisms reveal their phylogenetic relationships and thus provides important evidences of evolution.

Homology and homologous organs. Organs though different in functions but of similar embryogenic origin and development and having similar relationships with adjacent organs are known as homologous organs and this phenomenon is known as homology. Homologies indicate relationships between their possessors. For instance, arm of a man (grasping), leg of a horse (running), wing of a bird or a bat (flying), flipper of a seal (swimming) and forelimbs of cheetah are

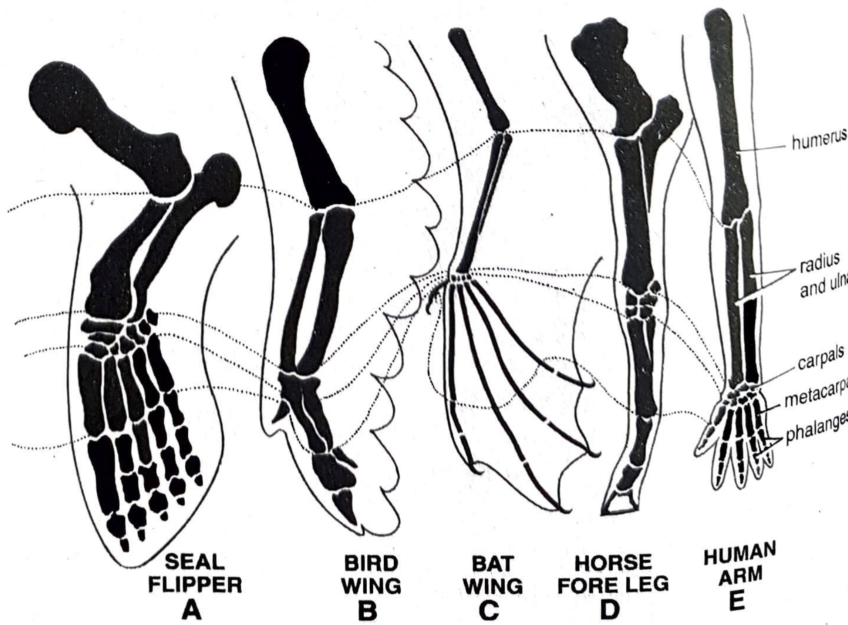


Fig. 5 A-E. Homology in the forelimbs of some vertebrates.

apparently different from one another in structure and function, yet all of them are built on one basic plan, the pentadactyl plan, *i.e.*, all of them have humerus, radius, ulna, carpals, metacarpals and phalanges in their forelimbs and have the same mode of development. Hence these organs are homologous (*Fig.* 5 *A-E*). The differences in these organs can be explained on the basis of adaptation to special conditions. This is **divergent evolution**. Homology indicates common ancestry. Similarly, legs of all insects are composed of the same five parts, *i.e.*, coxa, trochanter, femur, tibia and tarsus, yet they show many adaptive changes in the course of evolution. For instance, grasshopper has simple type of walking legs (the first and second legs) but the hind legs are modified for jumping; the forelimbs of a mole cricket are modified for digging; the legs of hair louse are adapted for clinging to hair, and the legs of a diving beetle are constructed for swimming. Similarly, the mouth parts of insects are variously adapted for licking (house flies), cutting (ants), chewing (cockroaches), sucking (mosquitoes), etc., though they have basically similar structural patterns. Thus these are homologous structures.

Homologies are also found in the systems of various vertebrates. All vertebrates from fish to man, have a dorsal vertebral column consisting of a number of jointed vertebrae. Similarly, all mammals have seven cervical vertebrae, it may be a rabbit with an average neck, a whale with no neck, or a giraffe with a very long neck. Other examples are vertebrate hearts or brains. This constancy is due to common ancestry. Such evidences indicate that the animals having homologous structures must have arisen from common ancestors through successive generations extending over millions of years.

There are many examples of homologous structures in plants also. Phylloclade of *Opuntia* and cladode of *Ruscus* are homologous organs as both are modified stem to perform the function of photosynthesis (*Fig.* 6 *A-B*). Similarly, thorns of *Bougainvillea* and tendrils of *Passiflora* are also homologous as both arise in axillary positions and are thus a modification of the branch (*Fig.* 7 *A-B*).

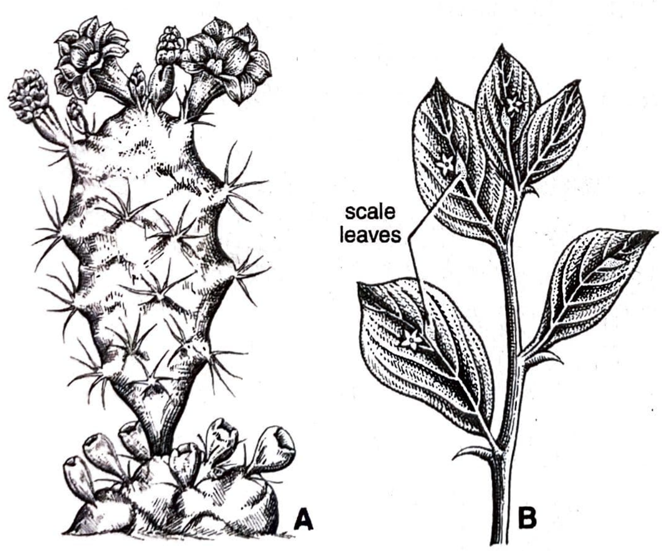


Fig. 6 A-B. Homologous organs : **A.** phylloclade of *Opuntia*; **B.** cladode of *Ruscus*.

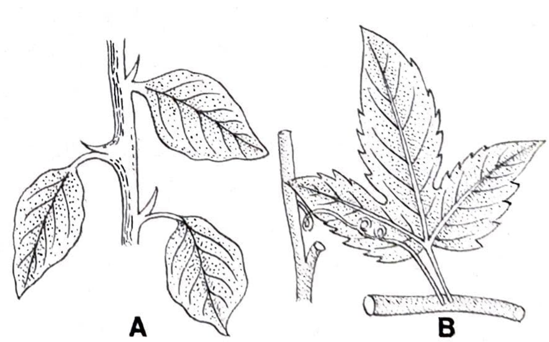


Fig. 7 A-B. Homologous organs : **A.** thorn of *Bougainvillea*; **B.** tendril of *Passiflora*.

The phenomenon of homology is also seen at the molecular level ; the proteins present in the blood of man and ape are similar. Homology is based on divergent evolution.

Analogy and analogous organs. Analogous organs are those which perform the same function, have superficial resemblance to one another, but are of different origin and this phenomenon is known as analogy. Similarity in environment and functions results in a superficial resemblance of two different types of structures. Analogy thus signifies merely coincidence of function. Hence, analogous structures are a result of convergent evolution. For example, wings of insects, birds, pterodactyles (extinct flying reptiles) and bats perform the same function of flying and possess superficial resemblances, but their basic structure is entirely different (*Fig. 8 A-D*). The fins of fish and the flippers of aquatic mammals (whales and seals) perform the same function and also have a close superficial resemblance, but structurally they are different. The gills of fish and crustacea are analogous; and the shape of the body of the fish and whale is also analogous. The stings of honey bee and scorpion perform similar functions and look alike, but they are analogous structures because the sting of the honey bee is a modification of ovipositor and that of scorpion of the last abdominal segment. An another example of analogy is the eye of the *Octopus* and of mammals or the flippers of Penguins and Dolphins.

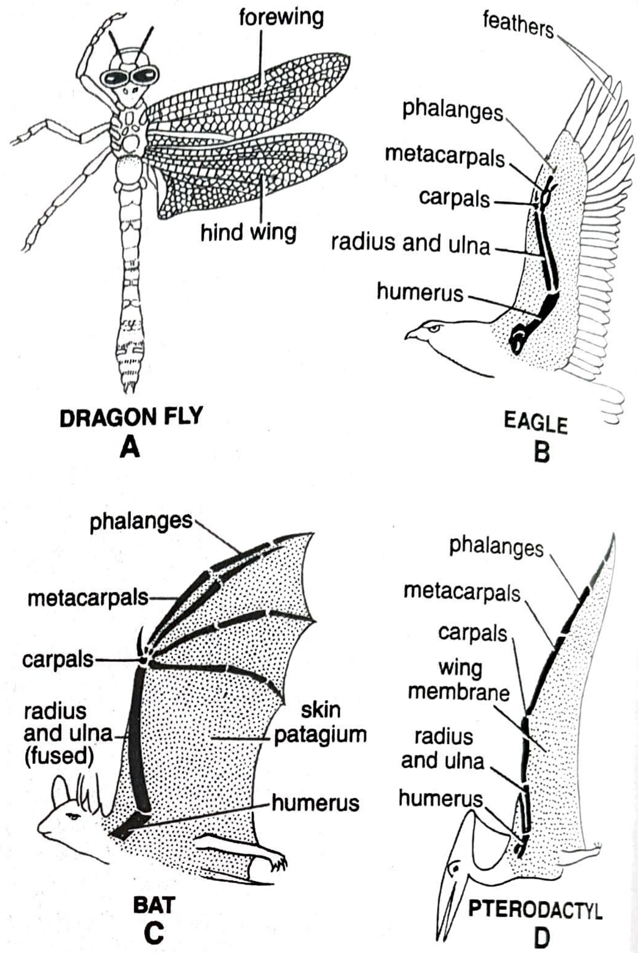


Fig. 8 A-D. Analogy in the wings of an insect (dragon fly), eagle, bat and pterodactyl.

The leaves of plants and cladodes of *Ruscus* or *Asparagus* are analogous structures as they look alike and carry on the function of photosynthesis, but morphologically they are different structures. The tendrils of vine (*Vitis*) and pea (*Pisum*) are structurally and functionally similar but are morphologically different structures. The former is of stem nature and the latter of leaf nature (*Fig. 9 A-B*). Similarly, sweet potato (root modification) and potato (stem modification) is an another example for analogy.

Vestigial organs. Vestigial organs are those organs which are non-functional in the possessor but were functional in their ancestors and in related animals. The presence of vestigial organs provides evidence for organic evolution. These organs were once useful (in ancestors) but now have no function, and yet linger on in a reduced form. Their lingering presence can be explained only by assuming their inheritance from remote ancestors.

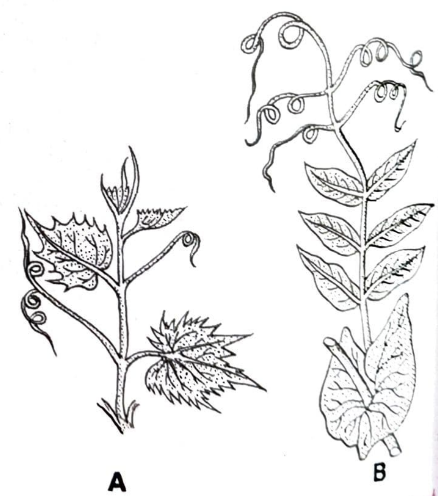


Fig. 9 A-B. Analogous organs : tendrils of *Vitis* (A) and *Pisum* (B).

There are many instances of vestigial organs among animals like splint bones in the feet of the horse, index finger in the bird's wings, functionless eyes of many burrowing animals, rudimentary pelvis and traces of limbs in some snakes (e.g., python) and rudimentary wings in kiwi and ostrich (*Fig. 10 A-C*). Human alone possesses more than a hundred vestigial organs in his body such as nictitating membrane in the eye, vermiform appendix at the end of the caecum, coccyx (tail vertebrae) and tail muscles, non-functional muscles of the pinna, wisdom teeth (third molars), segmental muscles of abdomen, and nipples in males (*Fig. 11 A-E*). These are the remnants of the organs which were functional in ancestral forms, but with the change in environment they were no longer necessary for survival and thus gradually reduced to the vestige.

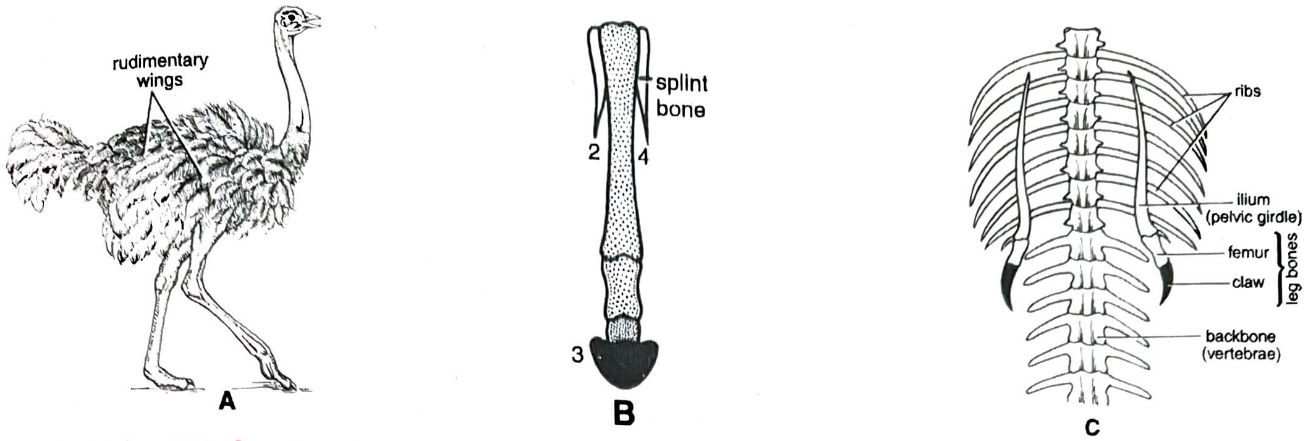


Fig. 10 A-C. Vestigial organs : A. rudimentary wings of ostrich; B. splint bones in foot of the horse; C. vestigial hind limb of python.

There are many vestigial structures which are more developed in the embryo than in the adult. Both pairs of limbs are present in the embryo of the whale but later the posterior pair disappears. The embryo of the whale is densely covered with hairs which disappear in the adult.

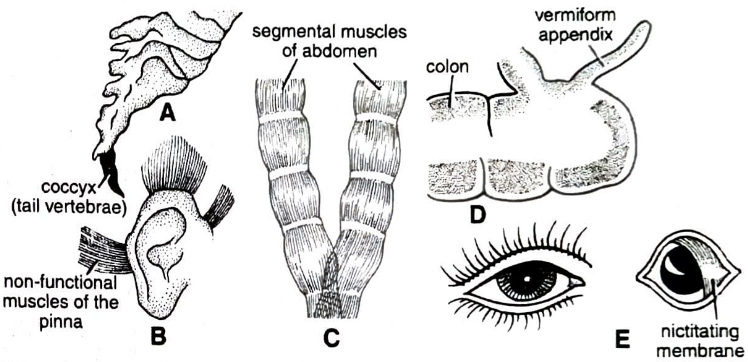


Fig. 11 A-E. Some vestigial organs of man.

Scale leaves of *Ruscus* and those of underground stems (tubers, rhizomes, corms, etc.) are excellent examples of vestigial structures among plants (*Fig. 12 A-B*).

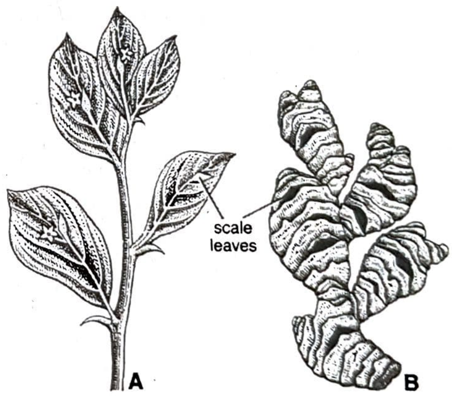


Fig. 12 A-B. Vestigial structures among plants : A. scale leaves of *Ruscus*; B. scale leaves over rhizomes of ginger.

Connecting links. The living animals which possess characters of two different groups of animals are known as connecting links. Such animals establish continuity in the series by proving that one group has evolved from the other. Lung fish and egg-laying mammals are familiar examples of **connecting links.** The lung fish (e.g., *Protopterus*) is a connecting link between fish and amphibians (*Fig. 13*). On the one hand, it possesses paired fins, dermal scales and gills like other fish and on the other, internal nares, 3-chambered heart and lungs for breathing air like amphibians. The lung fish thus provides a stage through which amphibian could evolve. Similarly, the egg-laying mammals like spiny ant-eater (e.g.,*Tachyglossus)* and duck-billed platypus (e.g.,*Ornithorhynchus*) provide a link between mammals and reptiles (*Fig. 14 A-B*). They possess hairs, mammary glands, diaphragm and single aortic arch like mammals and have a large coracoid in the pectoral girdle, lay large eggs (oviparous) with yolk and shell (polylecithal eggs) and have cloaca like reptiles. Other well known examples are *Chimaera* (rabbit fish), a connecting link between cartilage and bony fish; *Peripatus*, between annelids and arthropods (*Fig. 15 A*); and *Neopilina*, between annelids and molluscs (*Fig. 15 B*).

Atavism. Atavism, also known as reversion, is the sudden reappearance of a certain ancestral but not parental structure which has either completely disappeared or greatly reduced. There are many examples of atavistic structures in man like the occurrence of a rudimentary tail in new-borne babies, power of moving pinna, large canines, very long and dense hair and additional mammae (*Fig. 16 A-D*). The reappearance of such features favours evolution.

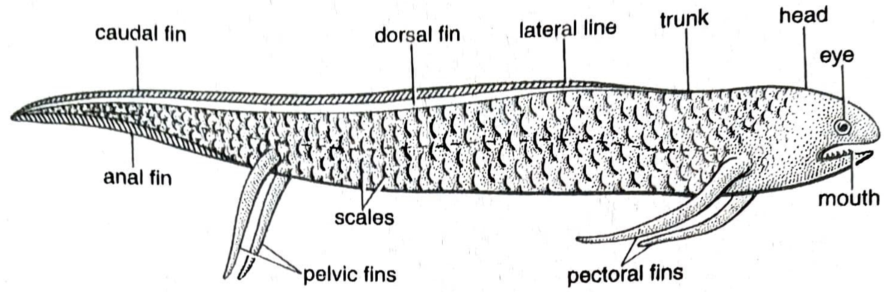


Fig. 13. *Protopterus* : the african lung fish.

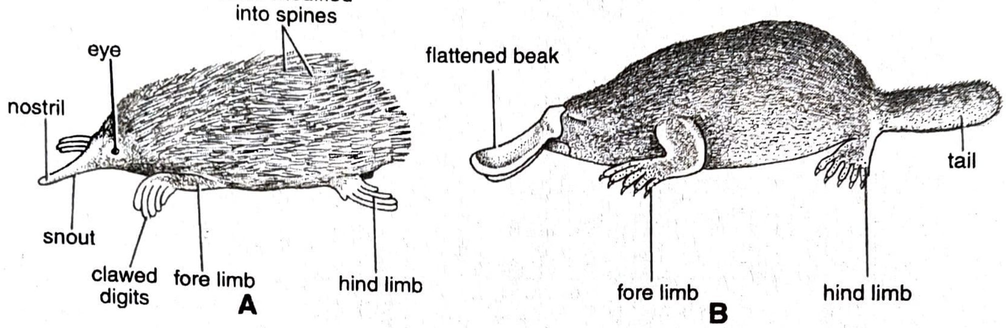


Fig. 14 A-B. Connecting links : **A.** *Tachyglossus* (spiny ant-eater); **B.** *Ornithorhynchus* (duck-billed platypus).

Evidences from Embryology

Embryology, the study of the development of an organism from egg to adult, also provides evidences for the organic evolution. A comparative study of the development shows that the embryos of different vertebrates resemble more closely than their adults and that embryos of higher groups resemble the adults of lower groups. The embryos of fish, salamander, turtle, bird, dog, or human at the same stage resemble so closely that it is difficult to distinguish between them. They have more or less the same structures *(Fig. 17 A-F)*. Such resemblance of structures is a clear proof of evolution and indicates that these forms have evolved from a common ancestor. The earlier stage of development also shows structural correspondence. For instance, every chordate begins life as a single cell (zygote) which by a series of mitotic divisions produces a multicellular blastula that later gives rise to a two-layered gastrula. After gastrula stage, the further development is diversified in different groups of animals.

Embryos of all vertebrates develop notochord and gill-clefts. Notochord is partly or fully replaced by vertebral column in the adults of all vertebrates. Gill-clefts close in the adults of some amphibians and all reptiles, birds and mammals. This similarity in embryonic development indicates evolution of vertebrates from a common ancestor. Similarly, the development of certain organs like heart, brain and ear in vertebrates indicates their common ancestry. The heart, during its development in birds and mammals passes through two-chambered and three-chambered stages before becoming four-chambered. This suggests that both birds and mammals have originated from fish, which have two-chambered heart, through amphibians and reptiles, which have three-chambered and incompletely four-chambered hearts respectively.

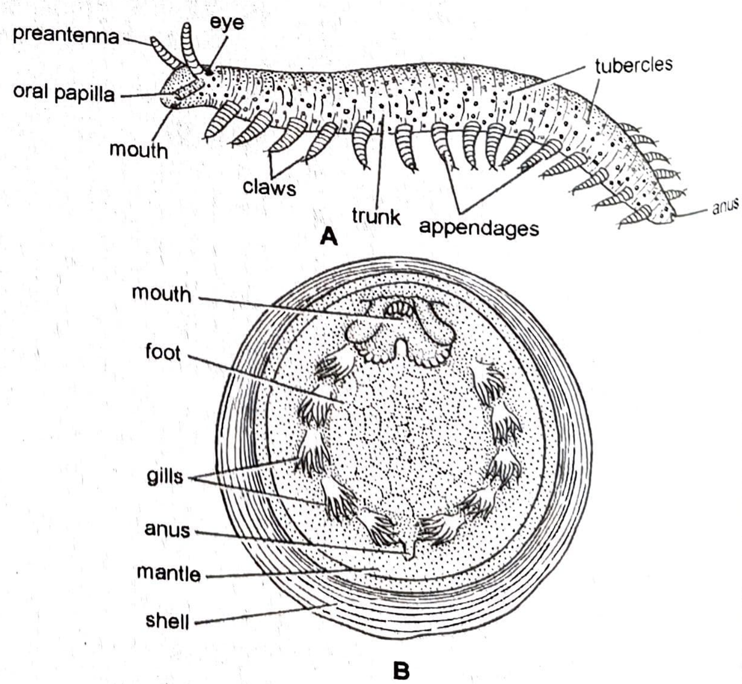


Fig. 15 A-B. Connecting links : **A.** *Peripatus*; **B.** *Neopilina*.

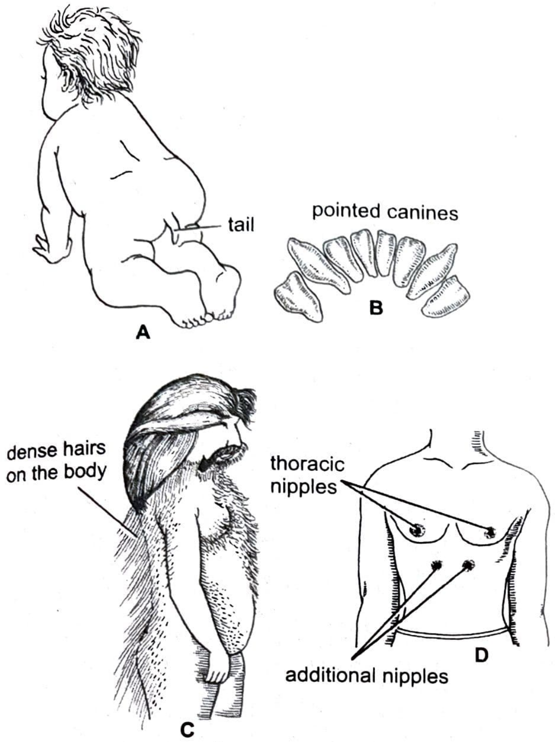


Fig. 16 A-D. Some atavistic structures in human: A. a rudimentary tail in new- born baby; B. large canines; C. long and dense hairs on the body; D. additional mammae (nipples).

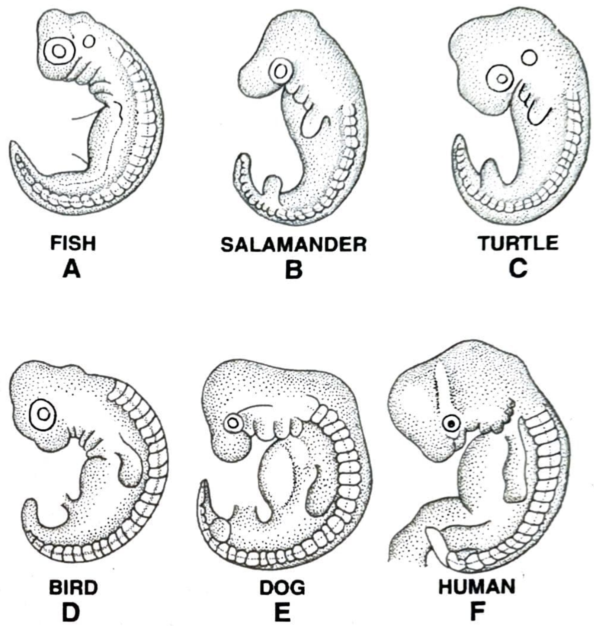


Fig. 17 A-F. Similarities in the embryos of some vertebrates.

Temporary embryonic structures. The embryos of certain animals develop some structures which generally disappear before birth. These structures are known as **temporary embryonic structures**. For example, gill clefts develop in the embryos of all land vertebrates, but are not present in the adult. Gill clefts are useful in fishes as they live in water but they are of no use for land vertebrates but they develop in their embryos as temporary embryonic structures. Similarly, the embryos of all vertebrates develop notochord which is replaced by vertebral column in adults.

Recapitulation theory. On the basis of the developmental history of animals, **Ernst Haeckel** (1866) postulated the famous **recapitulation theory** or **biogenetic law** which states that **ontogeny** (embryonic development of an organism) **recapitulates phylogeny** (evolutionary history of the race). This simply means that embryos in their development repeat the evolutionary history of their ancestors in an abbreviated form. A tadpole of frog is fish-like in the presence of a large laterally compressed tail with tail-fin; gills, first external and then internal; gill-slits and a lateral line system of sense organs which are characteristic of fish (*Fig. 18*). These fish-like features in the development of frog provide a clear evidence that amphibians have evolved from some fish-like ancestors. Similarly, the human infant shows some ancestral simian characters like feet deflected inwards and their soles facing each other, proportionately long arms, power of grasping with hands, and a protruding abdomen with legs joined at an angle to the body with an outwardly thrust bit toe.

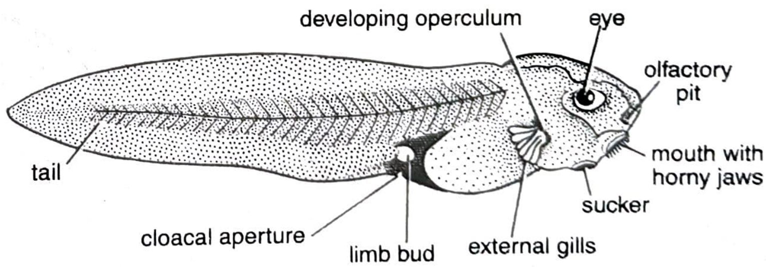


Fig. 18. Young tadpole of frog.

Recapitulation of ancestral form during development also occurs in plants. The protonema, an early stage in the development of the moss and fern gametophyte, resembles the filamentous green algae in structure, physiology and growth pattern. This suggests an algal ancestry of bryophytes and pteridophytes. Primitive gymnosperms like *Cycas* and *Ginkgo* have flagellated sperms. This indicates that gymnosperms have descended from pteridophyte-like ancestors. In angiosperms recapitulation principle is exemplified by *Acacia* which has compound leaves, yet its seedlings possess simple leaves like its ancestors. Similarly, there are no typical leaves on the cactus plant but its seedling has typical leaves.

De Baer (1828) suggested that organs achieve complexity from simpler forms due to their needs. He further states that (i) general characters during development appear before special characters, (ii) from more general, the less general and finally the special characters appear, (iii) an animal during development departs progressively from the form of other animals, and (iv) young stages of animal are like young or embryonic stages of lower animals, but not like adults of those animals.

Evidences from Cell Biology and Biochemistry

The detailed study of the structure of cells by electron microscope has revealed that many of the basic structures of cells, including organelles, are common to most living organisms. This reinforces the idea that living things have a common ancestor. Biochemical analysis of many of the fundamental chemicals of life—DNA, RNA, proteins, etc.—shows that they too are almost universal while many of these chemicals are broadly similar, differences are revealed when the molecules are broken down to their constituent parts. It has been suggested that more the similarities between the biochemistry of different organisms, more closely related they are in terms of evolution. These biochemical similarities have reinforced or clarified relationships proposed on the basis of structural similarities.

Some examples of such biochemical findings are as follows.

(1) Evidence from comparative anatomy and embryology suggests that vertebrates and echinoderms arose from one line of ancestors, and annelids, molluscs and arthropods from another. Biochemical evidence also supports this view. It shows that the **phosphagens** required to provide phosphate group for the synthesis of ATP are of two different types. Phosphocreatine occurs almost exclusively in the muscle tissue of vertebrates and echinoderms whilst phosphoarginine occurs in the other groups.

(2) Blood pigments are important in several animal groups. Analysis has shown that any one group contains only one type of blood pigment—vertebrates and several invertebrates have **haemoglobin**, polychaete worms, **chlorocruorin** and molluscs and crustaceans, **haemocyanin.**

(3) Sequence analysis of the amino acids in particular proteins has allowed relationships within a phylum to be mapped out, for example, mammalian relationships have been investigated by the analysis of fibrinogen.

(4) **Molecular homology.** It is the similarity in the molecular structure of important biomolecules. When the degree of similarity in DNA base sequences or the degree of similarity in amino acid sequences of proteins is examined, the data are as expected assuming common descent. Cytochrome *c* is a molecule that is used in the electron transport system of all organisms. Data regarding differences in the amino acid sequence of the cytochrome *c* show that in a human it differs from that in a monkey by only one amino acid, from that in a duck by 11, and from that *Candida*, a yeast, by 51 amino acids. These data are consistent with other data regarding the anatomical similarities of these animals, and therefore their relatedness.

(5) **Similarity in metabolic processes.** The process of synthesis of proteins and various organic molecules and catabolic process in all the organisms involve the same biochemical reactions.

(6) **ATP.** ATP synthesized during respiration is the energy currency of all living cells.

(7) **Nitrogenous wastes.** In all living organisms, ammonia is the chief nitrogenous waste. In fishes and other aquatic animals it is excreted out in this form, but in terrestrial animals, it is changed into urea and uric acid as to conserve the water.

(8) **Blood groups.** Human beings possess four types of blood groups, *viz.*, **A, B, AB** and **O,** whereas apes possess three types of blood groups, *viz.*, A, B and AB, indicating humans are more close to apes.

Molecular (Genetic) Evidences

Molecular evolution emerged as a scientific field in the 1960's as researchers from molecular biology, evolutionary biology and population genetics sought to understand recent discoveries on the structure and function of nucleic acids and protein. Evolution of enzyme function, the use of nucleic acid divergence as a 'molecular clock' to study species divergence and the origin of non-coding DNA are some important aspects of molecular evolution. Recent advances in genomics, including whole-genome sequencing, protein characterization and bioinformatics have led to a dramatic increase in this field. In recent times, the role of gene duplication in the emergence of novel gene function, the extent of adaptive molecular evolution versus neutral processes of mutation and drift, and the identification of molecular changes responsible for various human characteristics have been emphasized. **Neutral mutations** do not affect the organism's chances of survival in its natural environment and can accumulate over time, which might result in what is known as **punctuated equilibrium,** the modern interpretation of classic evolutionary theory.

Molecular systematics, the study of correct scientific classification from the point of view of evolutionary biology, has been made possible by the availability of techniques for DNA sequencing, which allow the determination of the exact sequence of nucleotides in DNA and RNA. Kimura' **Neutral theory of molecular evolution** states that most mutations are deleterious and quickly removed by natural selection but the fate of neutral mutations are governed by genetic drift, and contribute to both nucleotide polymorphism and fixed differences between species.

The advent of **protein sequencing** allowed molecular biologists to create phylogenies based on sequence comparison, and to use the differences between homologous sequences as a molecular clock to estimate the time since the last common ancestor.

Each protein, with its characteristics rate of change, pinpoints the timing of events in different evolutionary time frames. Changes within the past five million years between closely related species can be timed with this clock. **Russell Doolittle's** fibrinopeptide sequences pointed out the close relationship between chimpanzees and humans.

Cytochrome c provided the first family tree of a sequenced protein, and haemoglobin was used as the first 'molecular clock'. Duplications in haemoglobin and the globin genes span a billion years and are intimately tied to changes in animal life. As animals became land dwelling and shifted their source of oxygen from the water to the air, changes in globin structure were vital.

1. Evolution of proteins. The evolution at molecular level is reflected in protein differences. The proteins can be called **'chemical fingerprints'**, of evolutionary history, because they bear amino acid sequences that have changed as a result of genetic changes. Organisms that bear large number of common amino acid sequences may, therefore, be considered to be more closely related than to those with greatly different amino acid sequences. For instance, **Zuckerkandl** reported about 22 differences between human haemoglobin chains and that of horse, pig, cattle and rabbit and it was, therefore, concluded that human haemoglobin diverged from those of these animals by about one amino acid change per 7 million years.

2. Evolution of nucleotide sequences. McCarthy (1972) and others showed that for each 1% difference in the nucleotide sequences of two organisms, thermal stability of the hybrid DNA molecule is lowered by 16°C. In an experiment, non-repetitive or 'unique' sequences of cattle DNA were hybridized with those of sheep and pig. The reduction in thermal stability was observed to be 6°C between cow/sheep hybrid and 12°C between cow/pig, showing therefore, a significant evolutionary distance between cow and pig than between cow and sheep.

Many of the phylogenetic relationships determined by other taxonomic methods are reflected in the evolutionary relationships between species as determined broadly by DNA-DNA comparisons.

Universal genetic code. The occurrence of DNA as genetic material, the universal sharing of the same genetic code and same codons for amino acids by all organisms shows that they all have evolved from some common ancestors.

Evidences from Geographical Distribution

Biogeography is the study of the geographic distribution of life-forms on earth. According to Wagner's **continental drift theory**, millions of years ago the earth was in the form of a single land mass, the **Pangaea**. Due to geological changes, especially movements of crustal plates below the earth surface, huge land mass broke off and drifted apart into six major biogeographic zones known as **realms** (continents; *Fig. 19*). These are (i) **Nearctic** (North America down to the Mexican highlands), (ii) **Palaearctic** (Asia north up to Himalaya, Europe and North Africa, north of Sahara desert), (iii) **Neotropical** (Central and South America, Mexican lowlands and West Indies), (iv) **Oriental** (Asia, south of Himalaya including India, Sri Lanka, Malay Peninsula, Sumatra, Borneo, Java, Celebes and Philippines), (v) **Ethiopian** (South Africa and Sahara desert, Madagascar and adjacent islands), and (vi) **Australian** (Australia, Tasmania, New Guinea, New Zealand and Oceanic islands of Pacific).

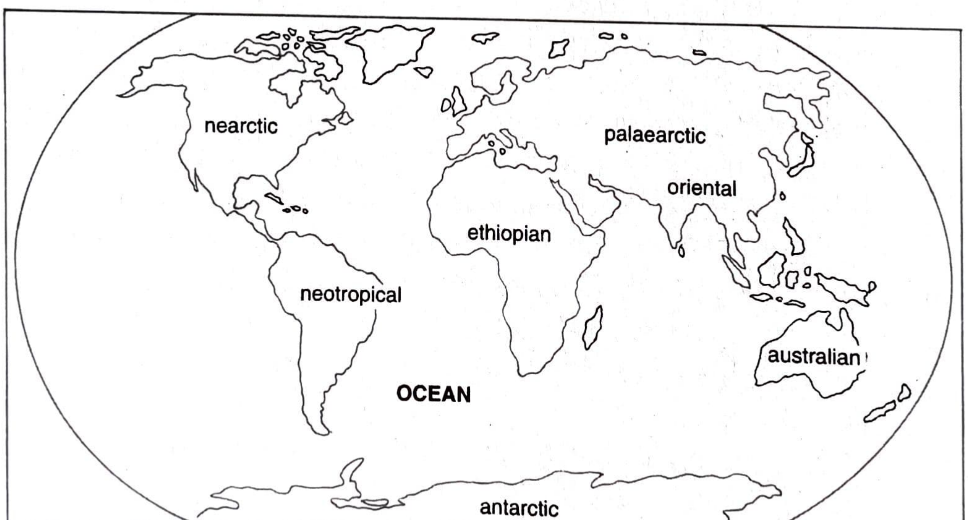


Fig. 19. The biogeographical realms.

The fauna and flora of each realm reflect its past history both in respect to changes in earth surface and the evolution of animal and plant species. As the continents moved away, the seas separated them and acted as **barriers**, which limit the distribution of animals and plants. Due to variable environmental conditions prevailing on the different continents, plants and animals evolved independently in each biogeographical region. The confinement of marsupials such as kangaroos, suggests that Australian continent was once connected with the Asian continent but in the Cretaceous period before carnivorous placental mammals came into existence, it got separated or isolated from Asia where carnivorous placental mammals brought about the extinction of marsupials. In isolation, monotremes and marsupials flourished in Australian continent. The flora and fauna of the Galapagos islands in the Pacific ocean on the west coast of South America resemble those of the South American mainland with which the Galapagos islands were once connected. This divergence in various directions of the isolated fauna is called **adaptive radiation**. Darwin's finches provide an excellent example of adaptive radiation supporting the concept of evolution *(Fig. 20)*.

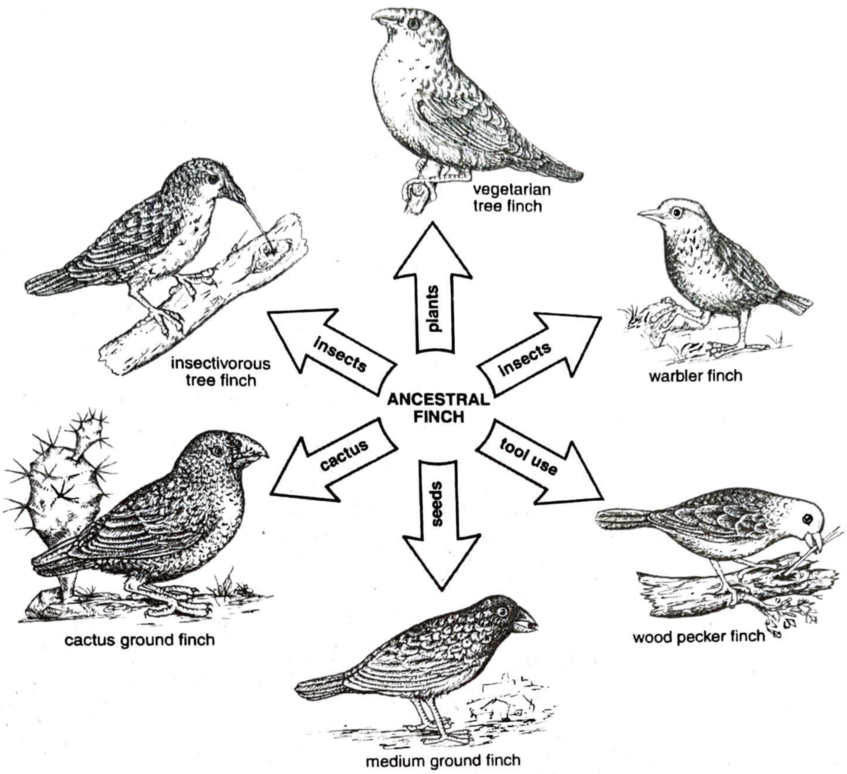


Fig. 20. Darwin's finches.

GALAPAGOS ISLANDS

The Galapagos Islands are an archipelago volcanic islands distributed around the equator in the Pacific Ocean, about 1000 km west coast of South America. The islands have given birth to and seen the death of many species of flora and fauna. The islands became famous around the world after the survey ship HMS Beagle, arrived in Galapagos in 1835 with the naturalist Charles Darwin. These islands were declared a National Park in 1959. The islands are thought to have formed about 19 million years ago by the creation of volcanoes due to the melting of Earth's crust from below by the mantle of the plume. These islands are considered a '**Living Museum**' as they consist of a vast number of endemic and endangered flora and fauna.

DARWIN'S FINCHES

Darwin studied the environmental conditions, fauna and flora of Galapagos islands, a chain of 22 islands in Pacific ocean situated nearly 960 km away of the west coast of South America. He noticed that the Galapagos islands have many endemic species of plants and animals. He was amazed to record that in the islands insect-eating warblers and woodpeckers were absent. Instead, various types of finches, a group of small black birds which were originally seed eating but have assumed insect-eating pattern were present. He observed nearly 20 related varieties of small birds in these islands which differed mainly in the shape and size of their beaks and in the colour of their plumage. These birds are now known as **Darwin's finches**. He also observed that different geographical localities have similar habitats but house different species. In general, bird fauna of these islands shows affinity with American species, but the Darwin's finches differ considerably from American finches. However, a related species of Darwin's finches was reported from South American mainland. **Darwin** thus concluded that the American mainland species was the original one from which different forms migrated to the different islands of Galapagos and adapted to the different environmental conditions of these islands. These adapted forms are considered to be new species.

Discontinuous distribution. Sometimes, closely related species exist in widely separated areas without any representative in the intermediate territory. Such closely related forms are said to exhibit **discontinuous distribution**. Probably such species enjoyed a wide distribution in the past. But, due to various environmental factors, the forms in intermediate regions became extinct. As a result, population of the same or related species are widely separated exhibiting discontinuous distribution. Lung fishes are well-known example of discontinuous distribution. Three genera of lung fishes (*Protopterus*, *Neoceratodus* and *Lepidosiren*) are found in three different continents, *viz*., Africa, Australia and South America respectively.

Restricted distribution. Some organisms are endemic in distribution, *i.e.*, they are confined only to certain areas of the world. For example, egg-laying mammals (prototherians) occur only in Australia.

ADAPTIVE RADIATION

The process of evolution of different species in a given geographical area starting from a point and literally radiating to other areas of geography (habitats) is called adaptive radiation. Darwin's finches represent one of the best examples of adaptive radiation. An another classical example of this phenomenon is Australian marsupials *(Fig. 21)*. A number of marsupials, each different from the other evolved from an ancestral stock, but all within the Australian island continent. Placental mammals in Australia also exhibit adaptive radiation in evolving into varieties of such placental mammals each of which appears to be 'similar' to a corresponding marsupial. For instance, Placental Wolf and Tasmanian Wolf-marsupial show convergent evolution *(Fig. 22)*.

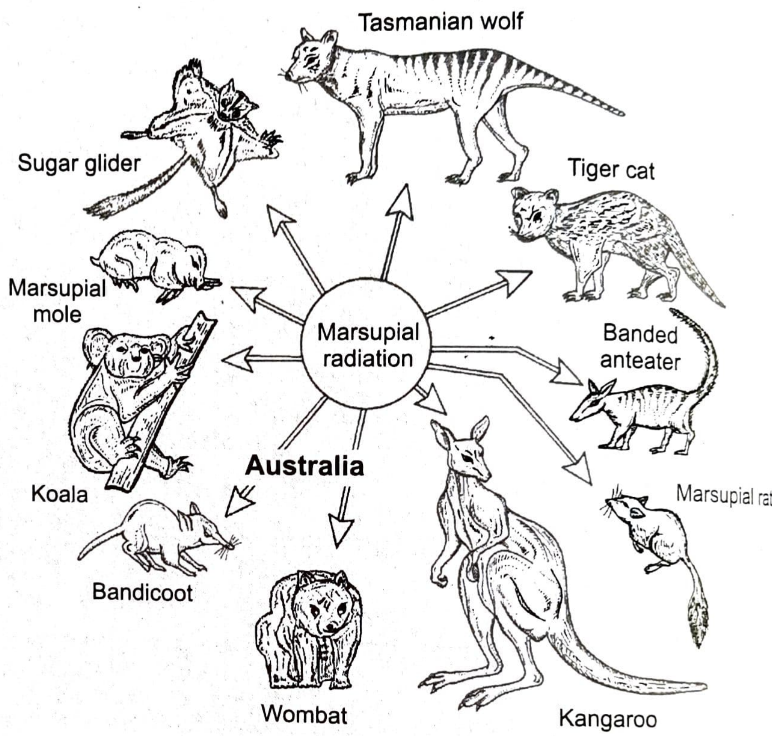


Fig. 21. Adaptive radiation of marsupials of Australia.

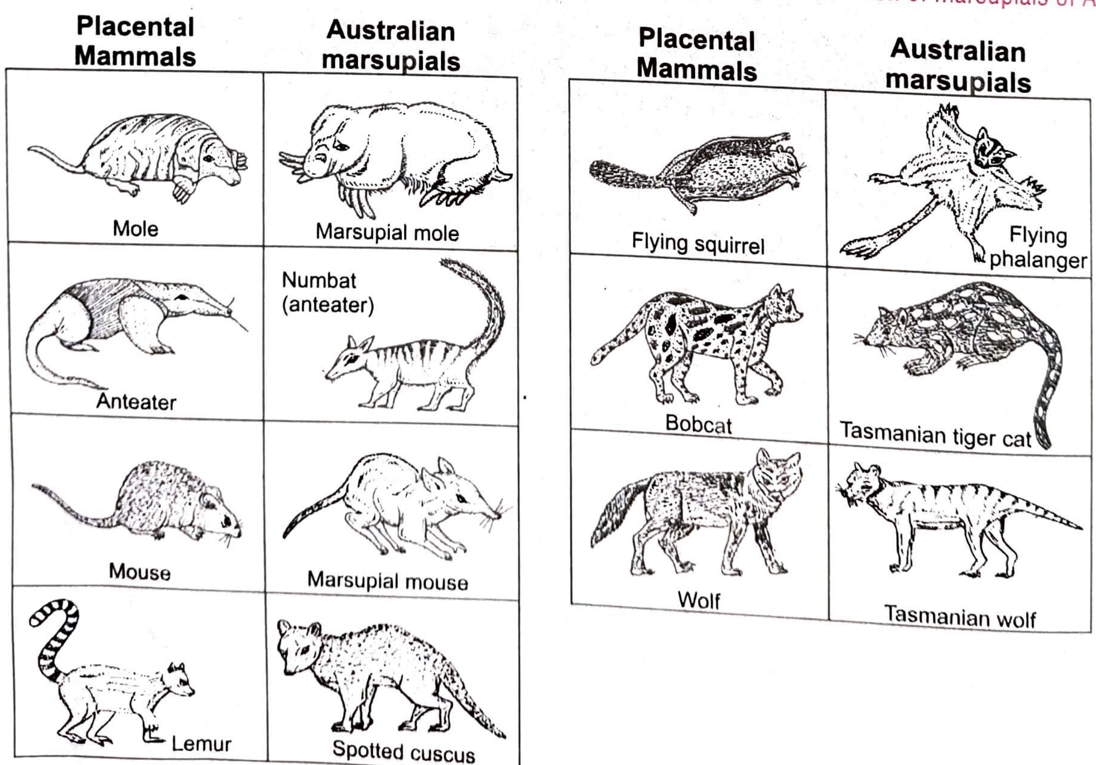


Fig. 22. Australian marsupials and placental mammals showing convergent evolution.

What is a vestigial organ? How does the presence of vestigial organs support the doctrine of organic evolution? **(2000)**

Archaeopteryx is a connecting link between reptiles and birds. Justify the statement by giving two characteristics of each group. **(2013)**

The wing of bat is said to be homologous to the wing of a bird and analogous to the wing of an insect. **(2011)**

Explain the following terms :

(a) Palaeontology **(2000, 01, 02, 04, 11, 13)**

(b) Vestigial organs **(2000, 01, 13)**

(c) Atavism **(2001, 07, 12)**

(d) Geological time scale **(2008)**

(e) Homologous organs **(2008, 14)**

(f) Theory of recapitulation **(2014)**

(g) Darwin's finches **(2003, 08, 12)**

How does palaeontological evidence support the theory of organic evolution? Explain with an example. **(2007)**

What are homologous organs? How do they help in providing evidence for organic evolution? **(2014)**

State three differences between homologous and analogous organs and give an example of each. **(2010)**

What are the important changes in the evolution of the modern horse from the *Eohippus* (ancestral horse)? **(2006)**

Give any two striking similarities in the structure of embryos of all vertebrates. What is the significance of such similarities in the concept of organic evolution ?

How does phylogeny help in building broad historical sequence of biological evolution ? Explain with the help of the example of horse.

What are the evidences of organic evolution ? How comparative anatomy and embryology of animals give evidences of organic evolution ?

What is a biogeographic map ? Locate Galapagos islands