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Learning Objectives

Explain the revolutionary aspects of Darwin's and Wallace's evolutionary concepts.

Understand why natural selection is the driving force for evolution.

Know the experimental evidence that supports the evolution of carbon based life on earth.

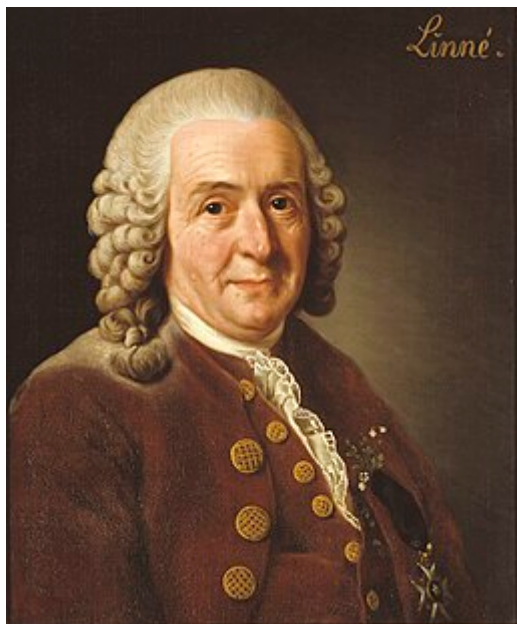
Understand the importance of the early cyanobacteria.

Name (a) the three characteristics that distinguish a cell from a mere aggregation of molecules and (b) the two main characteristics that make Earth so hospitable to life.

Explain the process of continental drift and plate tectonics.

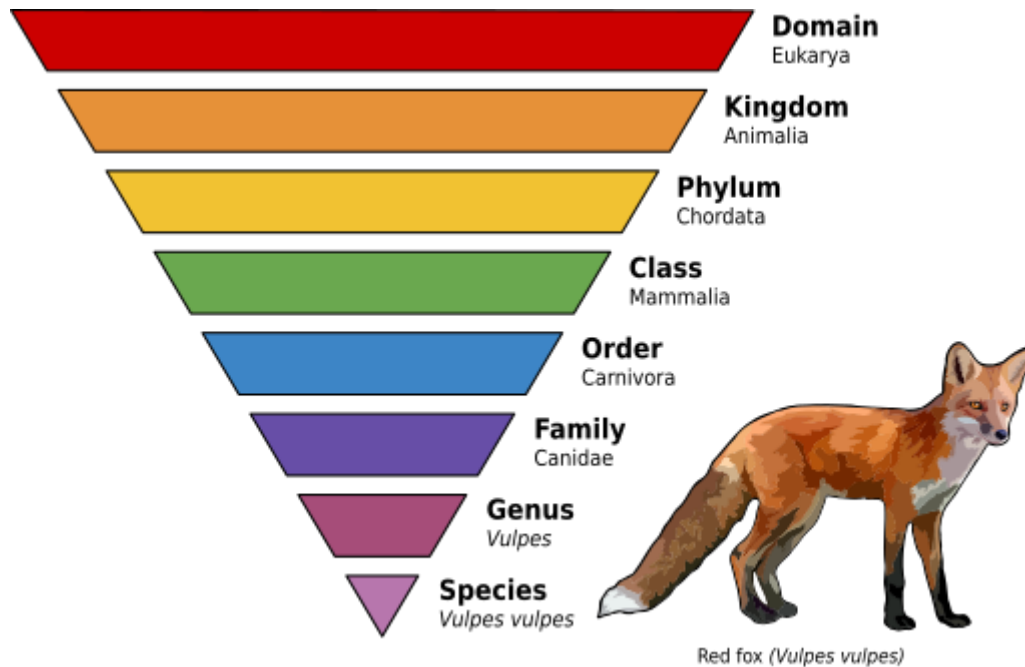
Describe the geological eras of the earth and name the dominant group(s) of animals and plants in each.

Taxonomy: Animal, vegetable or mineral?



Science requires a language of its own to differentiate from colloquial language. In order to study life, scientists must utilize a common precise language to describe organisms. The Swedish physician and scientist Carl von Linné developed a systematic hierarchy to organize life and binomial nomenclature to precisely name organisms in his publication *Systema Naturae*. Linné's **binomial nomenclature** named individual species of organisms using two-part Latin names consisting of a genus and species (*Homo sapiens*). Inspired by this system, he applied this to himself and wrote under the Latinized name *Carolus Linnæus*. A species name must be written as capital Genus and lower case species in italics or underlined to properly illustrate a species name.

Carolus Linnæus was not the first to use a binomial system, but he used it consistently across *Systema Naturae* and is known as the father of taxonomy for organizing life into a nested hierarchy of relatedness. Modern taxonomy classifies organisms from broadest to most specific: **Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species**. These divisions can further be divided by using the prefix super- and sub-.



Hierarchical classification of a Red fox. Credit: [CC-BY-SA 4.0]

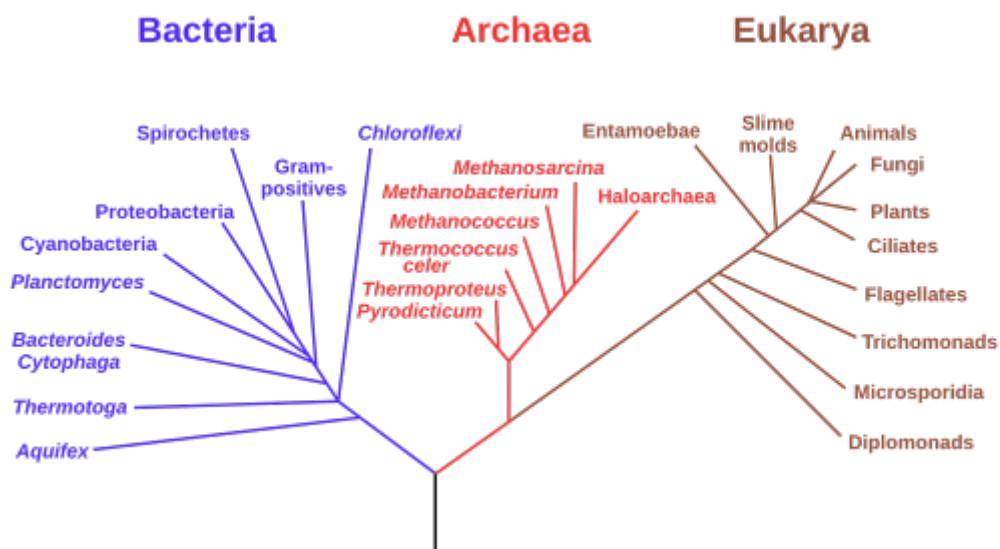
Disambiguation

The precision of binomial nomenclature allows a common language to name organisms without ambiguity of vernacular or regional language. In the US, the word buzzard denotes a carrion consuming bird like a vulture. However, in the UK, buzzard describes an active hunting bird.

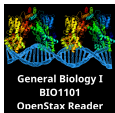


*Pale Male, a red-tailed hawk (*Buteo jamaicensis*). In the United States he is identified as a hawk. In the United Kingdom he is identified as a buzzard. Credit: Jeremy Seto [CC-BY-NC-SA]*

Relationship of all life



Phylogenetic tree of life illustrates the relatedness of organisms and the broad

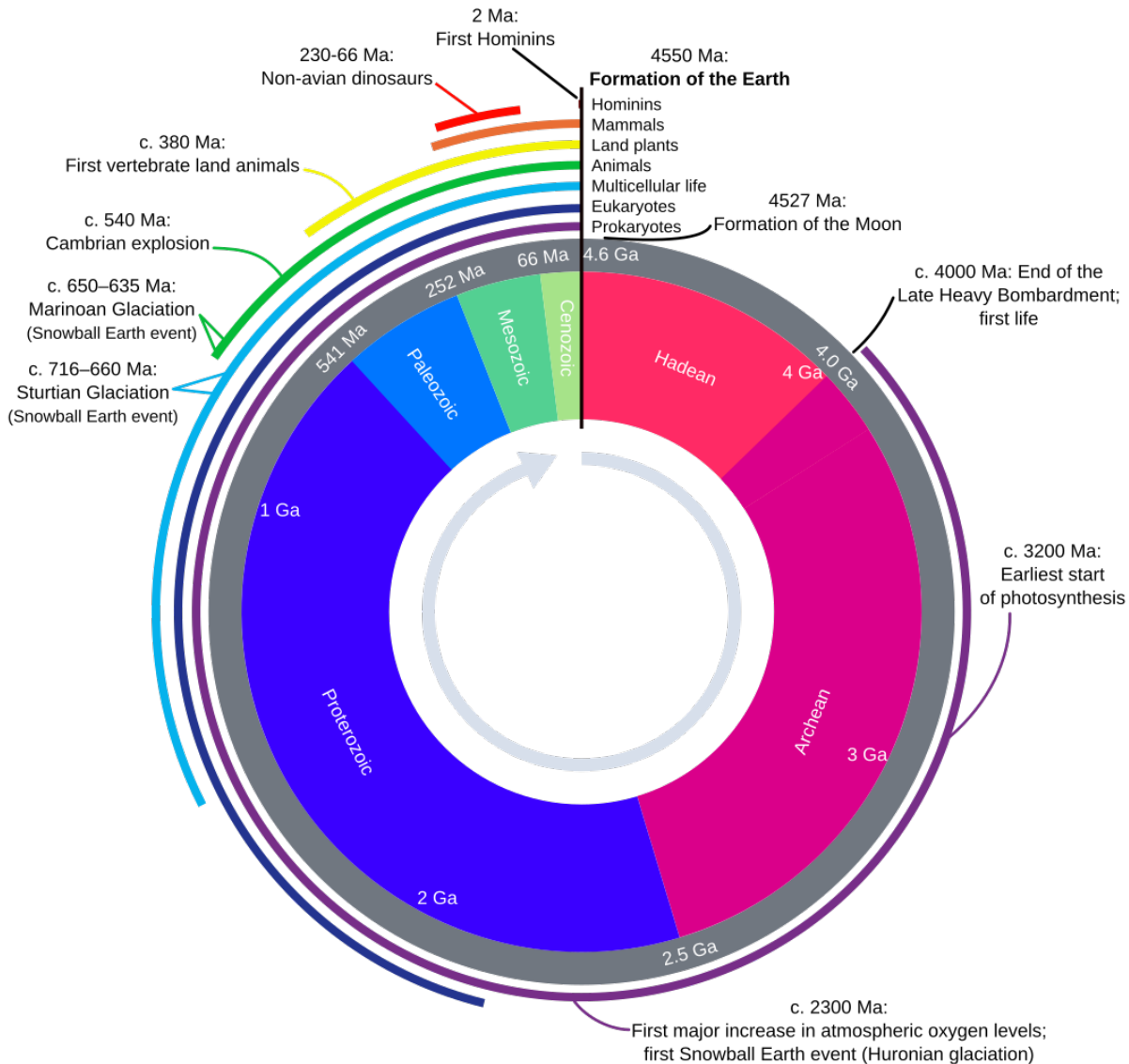


2. Evolution of Life and Taxonomy

categorization into three domains of life: Bacteria, Archaea and Eukaryota.

All life on earth follow the same basic instruction sets and are utilize chemical information transfer in a similar fashion. Three domains exist: **Archaea**, **Bacteria** and **Eukarya**. Archaea and Bacteria are also grouped together as **Prokaryotes** (*pro-* before; *karya-* nucleus). Eukarya (*eu-* true; *karya-* nucleus), or eukaryotes, is a group of of organisms that have nuclei. The second most inclusive or broad category is **Kingdom**. Humans are in the Kingdom of animals. The third most inclusive or broad category is **Phylum**. Humans are in the phylum called chordata. Each level of organization can be further subdivided and you may be more familiar with the subphylum called vertebrata. Within the this division, humans fall in the **class** of mammals. Amongst the mammals, humans are in the **order** of primates. Humans are categorized into a narrower group of organisms in the **family** of great apes or hominids. Within this family, humans fall into the **genus** of *Homo*. Biologists use a method of identifying specific organisms called binomial nomenclature. Binomial nomenclature uses the most specific groupings of taxonomy (genus and **species**) as a two part name. While humans are of the species sapiens, the species name of humans using binomial nomenclature is *Homo sapiens*.

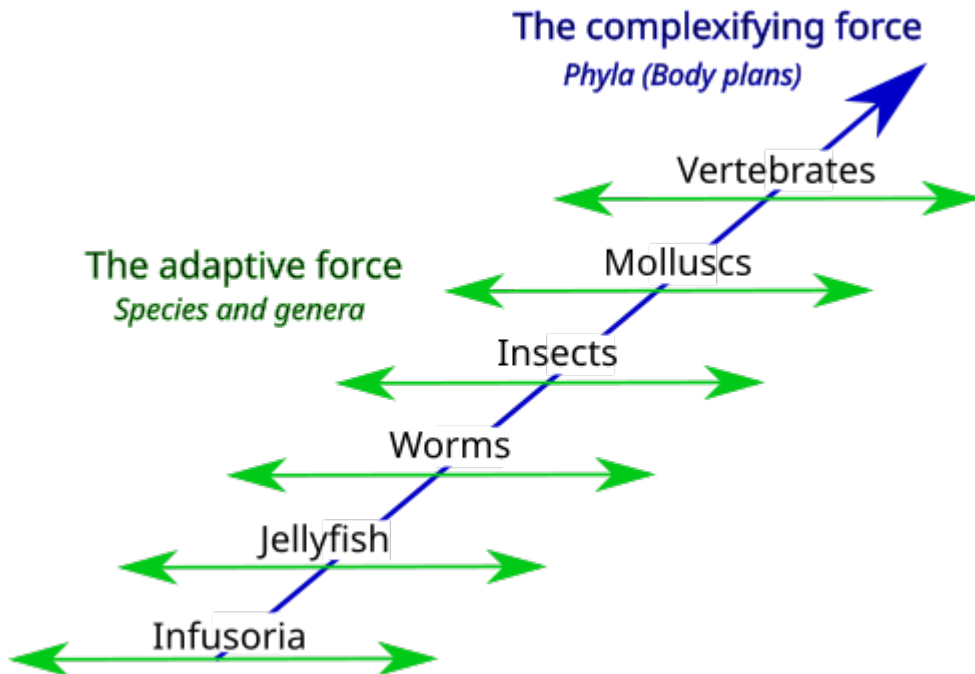
Geologic Time Scale



The age of the Earth is 4.54 Billion years old. This number was determined by radiometric dating terrestrial and lunar samples with additional calibration to meteorites. With this large number of years in mind, there was ample time for historic changes to occur on the planet that encompass geologic, climate and organismal population shifts. One major climate changing shift occurred about 4 Billion years ago as atmospheric oxygen began to accumulate due to the first photoautotrophs. Comparing the geologic time scale to a 24-hour clock, modern humans only arrived on this planet at 4 seconds to midnight.

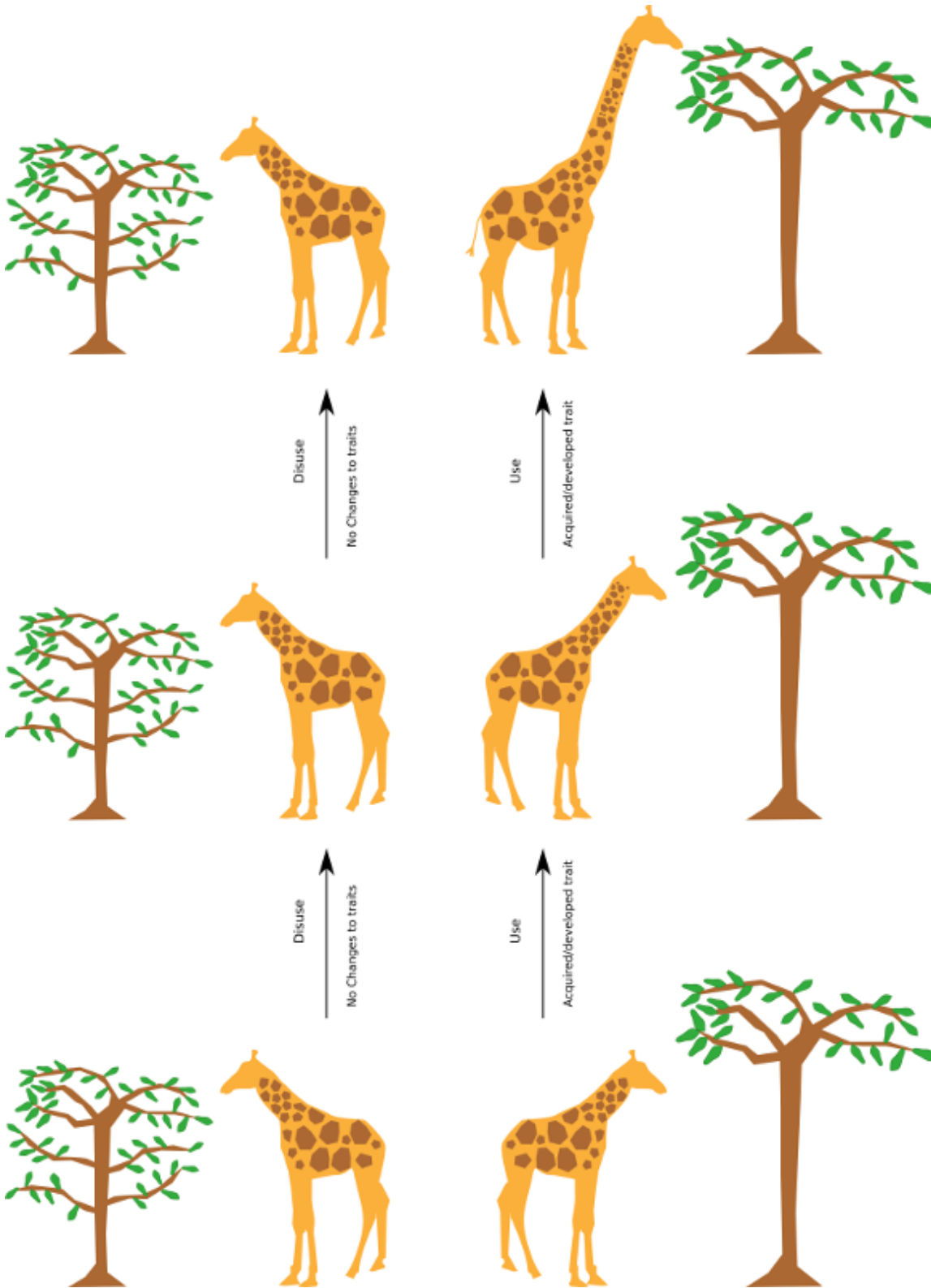
Lamarck's Use and Disuse

The French biologist, Jean Baptiste-Lamarck, discussed the occurrence of different organisms with two forces governing evolution: adaptive and complexifying forces. The complexifying force drives body plans towards the higher taxa while the adaptive force caused organisms to adapt to their circumstances. These discussions in the early 1800s involved two major ideas: use/disuse and inheritance of acquired traits.



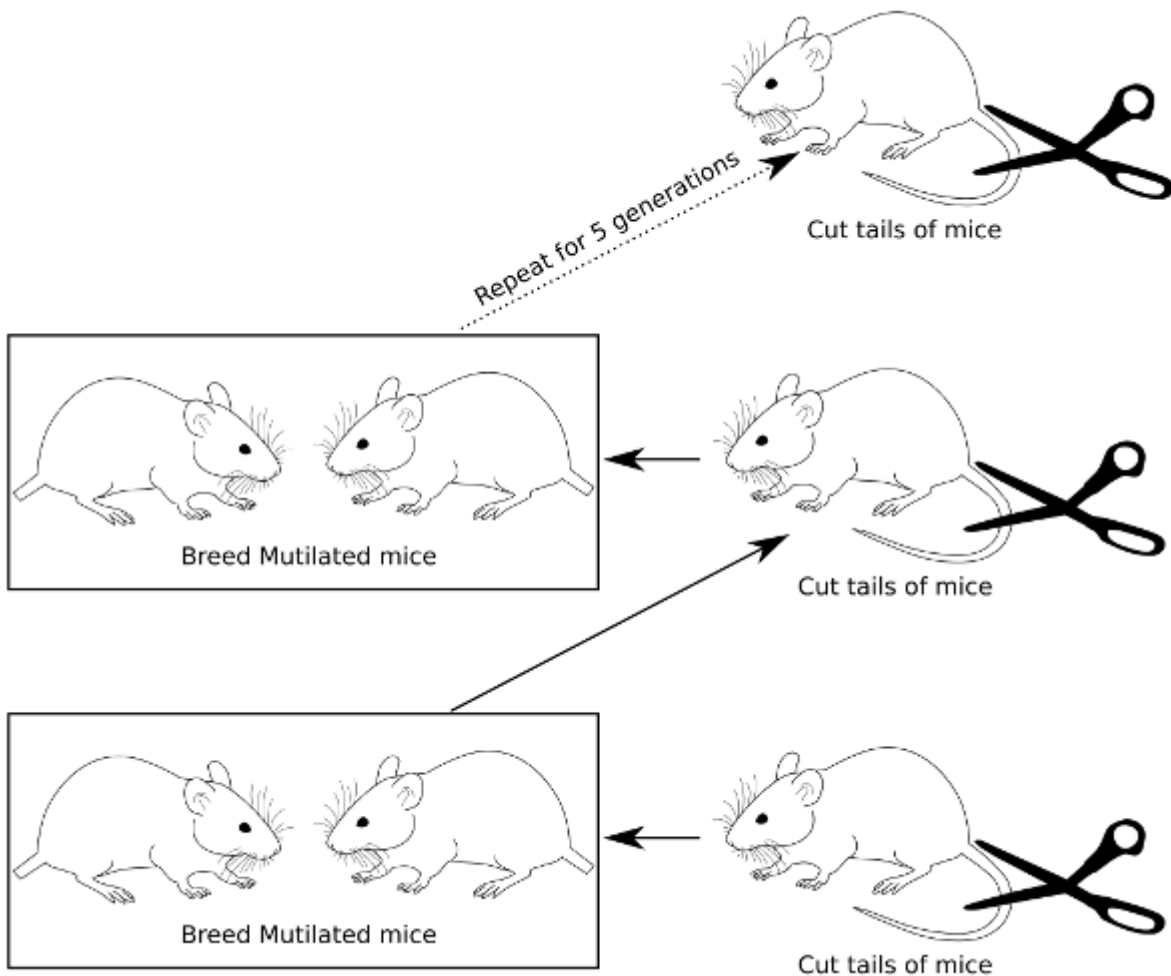
His idea of use versus disuse is exemplified by the case of giraffes. It was thought that giraffes descended from an antelope. As giraffes would reach higher towards trees to acquire leaves, they would stretch their necks through successive generations and inherit gradually longer necks.

2. Evolution of Life and Taxonomy



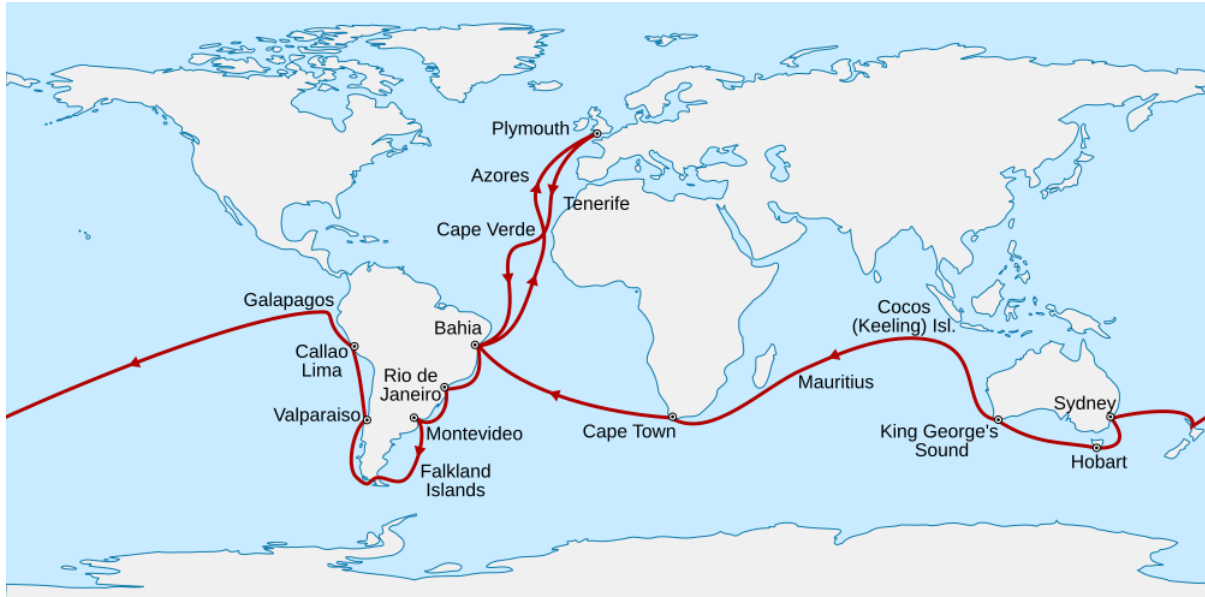
At the end of

the 19th century, the evolutionary biologist, August Weismann tested the ideas of use/disuse and acquired inheritance of traits. Weismann took 68 mice and cut their tails off. After mutilation, the mice were permitted to breed. He repeated the amputation of tails and breeding for 5 generations. If the unused tails were acquired as a trait, then one would think that the tail length over multiple generations would progressively shrink. Weismann found that no shortening of tails occurred, thereby excluding Lamarck's tenets of inheritance of acquired traits from use or disuse.



Darwin and the Voyage of the Beagle

[Introduction to Darwin](#)



Darwin's voyage on the HMS Beagle. Credit: Semhur,Kipala, Samsara and Dave souza [CC-BY-SA

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Charles Darwin was a naturalist who journeyed on the HMS Beagle in 1831. He was heavily influenced by Charles Lyell's *Principles of Geology* which illustrated the evidence that the age of the Earth was greater than 6,000 years old. It was during the second voyage of the Beagle that Darwin came to make observations that would give rise to his idea of **common descent** for all life on Earth and the concept of **evolution** by means of **natural selection**. As Darwin surveyed the natural flora and fauna, he noticed that there were many different organisms that shared similarities. Moreover, on islands that were separated from the continental lands, there was greater separation of these organisms based on their features that illustrated shifts towards adapting to the local environments. While evolution broadly demonstrates the diversity of organisms across geologic time scales is factual, the mechanism of natural selection giving rise to these changes in flora and fauna was proposed by Darwin and Alfred Wallace were revealed by multiple points of evidence that have subsequently been demonstrated through experimental means.

[Darwin's evidence for evolution by natural selection](#)

Variation



Variation of cats due to domestication and artificial selection of desirable traits.

Credit: Alvesgaspar [CC-BY-SA 3.0]

One major aspect of natural selection surrounds the natural diversity that exist within organisms of a species. It is these variations that illustrate the natural starting point for adaptation to specific environments and ecosystems. Darwin observed that organisms often reproduced at a rate greater than the environment could handle and that the individuals who survived to reproduce again were often had features that were best suited for that ecosystem.



Arctic hares have adaptations for its environment: short ears for heat conservation, large paws for walking on snow, seasonal molting for camouflage. In summer, the fur molts and a coat of brown grows in. In winter, a white coat grows in. These features come in a spectrum of variations of sizes and colors. Over many generations, these features have become more stabilized with a narrower range of variation that is suited for the arctic environment. Credit: [Steve Sayles \[CC-BY-SA 2.0\]](#)

Fossils

Paleontology and evolution

The French anatomist/zoologist Georges Cuvier, established the fields of paleontology and comparative anatomy in the early 1800s. He was a staunch creationist who opposed the idea of evolution. Cuvier proposed the idea of **catastrophism** where multiple cycles of creation that gave rise to the diversity of fossils that emerged from multiple catastrophes, like the flood of the Old Testament. Darwin observed that the great age of the Earth (4.5 billion versus 6,000 years) permitted enough time to explain the gradual changes found in fossils at various depths of sediment.



Fossils display successive modifications over geologic time. Credit: JSklmsta [CC0]

Darwin's understanding of geologic time was coupled by a number of other evidence. Contrary to Cuvier's catastrophism, the fossil evidence showed new species appearing gradually and while populations of species had changed, the rates of changes were unequal between different species. Darwin also understood an aspect of heritability as fossils had illustrated that there were no reappearances of species following extinction. The gradual changes often spoke to descent with modification as opposed to catastrophic events.

2. Evolution of Life and Taxonomy

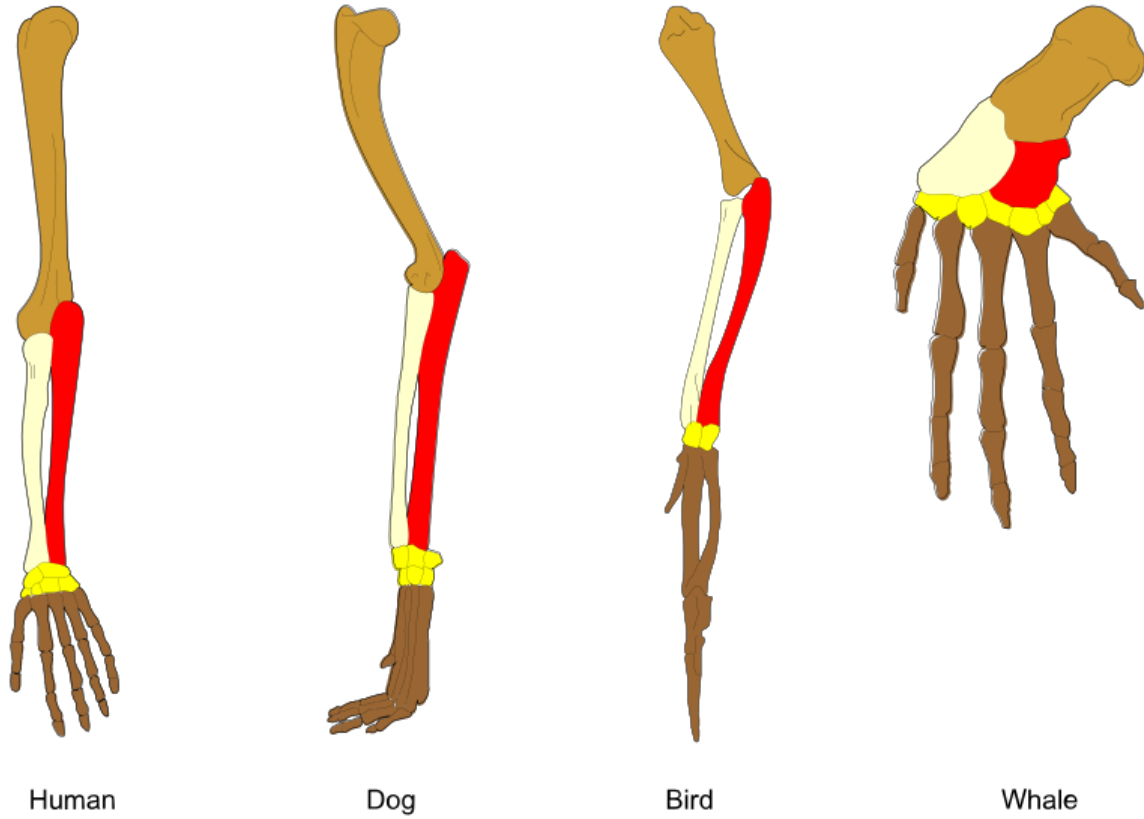


Progression of transitional changes in morphology over time. An image taken in a museum at the Cradle of Humankind, a world heritage site and active paleontological site. Credit: Jeremy Seto [CC-BY-NC-SA]

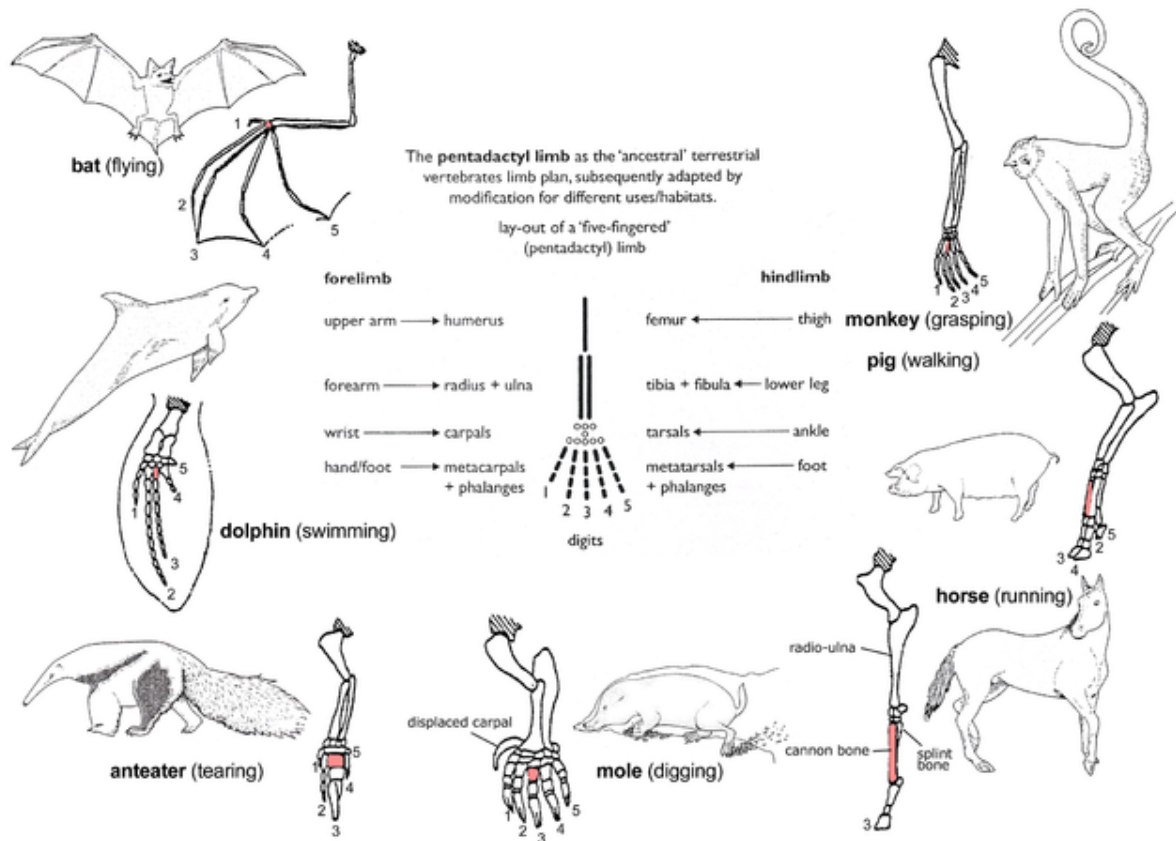


A human **coprolite** (fossilized feces) informs archaeologists and paleontologists of associated flora and fauna that reveal evidence of geologic time. Coprolites can even preserve DNA that can now be analyzed and provide genetic information to scientists. This coprolite yields evidence of health and diet based on pollen granules and presence of parasitic worms. Credit: [Storye book](#) [CC-BY 2.5]

Anatomy & Embryology



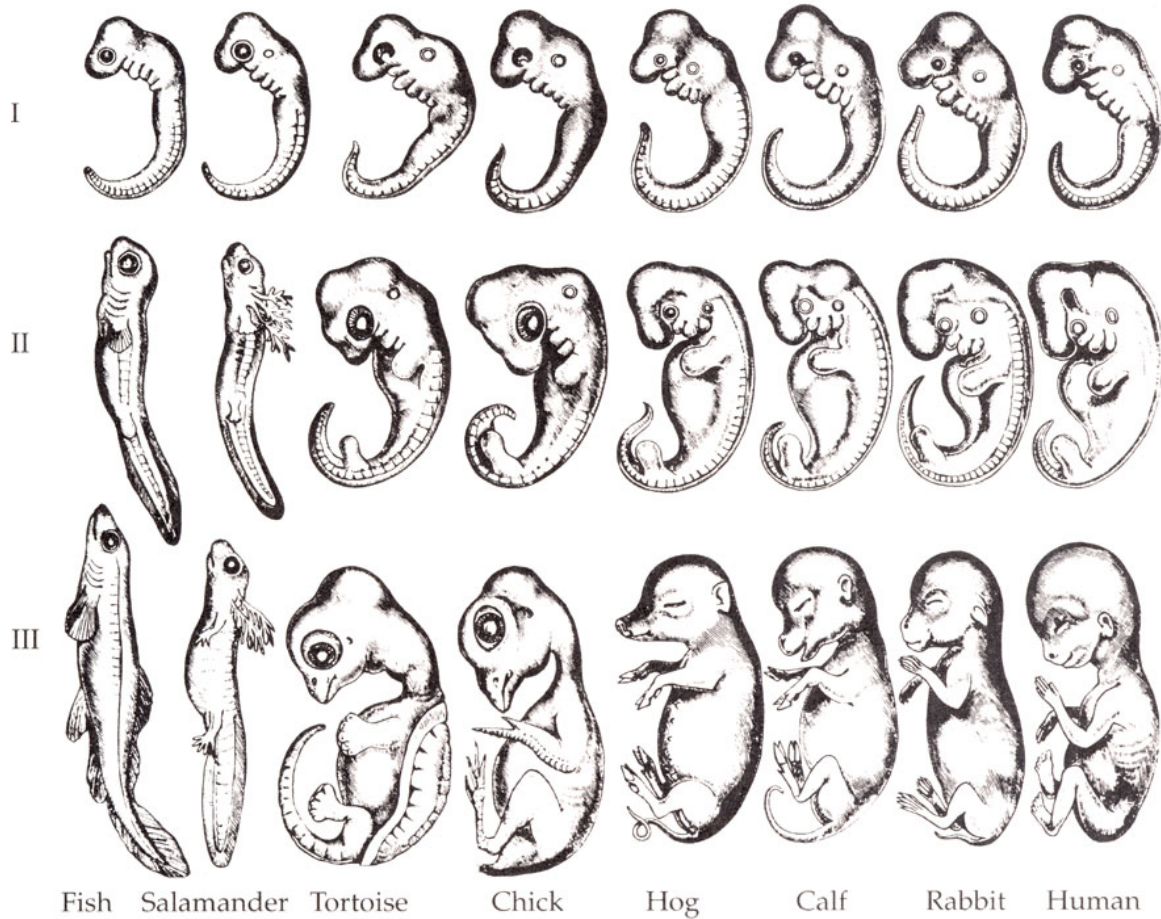
Homologous anatomical parts. Credit: Волков Владислав Петрович [CC BY-SA 4.0]



Adaptations to homologous part suited for differing ecological niches. Credit: [Jerry Crimson Mann](#)

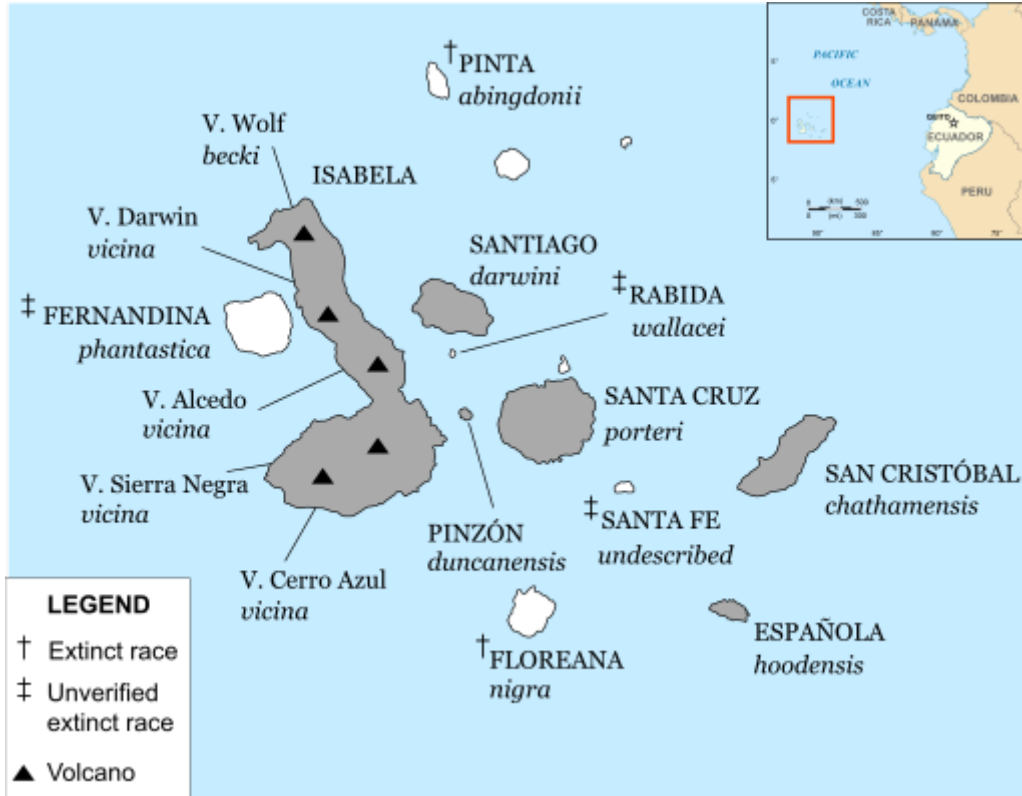
[CC-BY-SA 3.0]

Subsequently, embryology illustrates natural historical features of organisms that share similar lineage. Gill slits on terrestrial vertebrates appear across taxa during development but disappear in higher taxa. These observations gave rise to the idea that "Ontogeny recapitulates phylogeny". Some organisms retain the throwbacks of these developmental times as seen in gills of some salamanders. These developmental throwbacks are called **atavisms**. An example of a congenital atavism in humans is the occasional external tail that can be corrected by surgery.



"Ontogeny recapitulates phylogeny". Organisms sharing common ancestry reveal developmental structures. Credit: Romanes, G. J.; Phlebas; SeventyThree [Public domain]

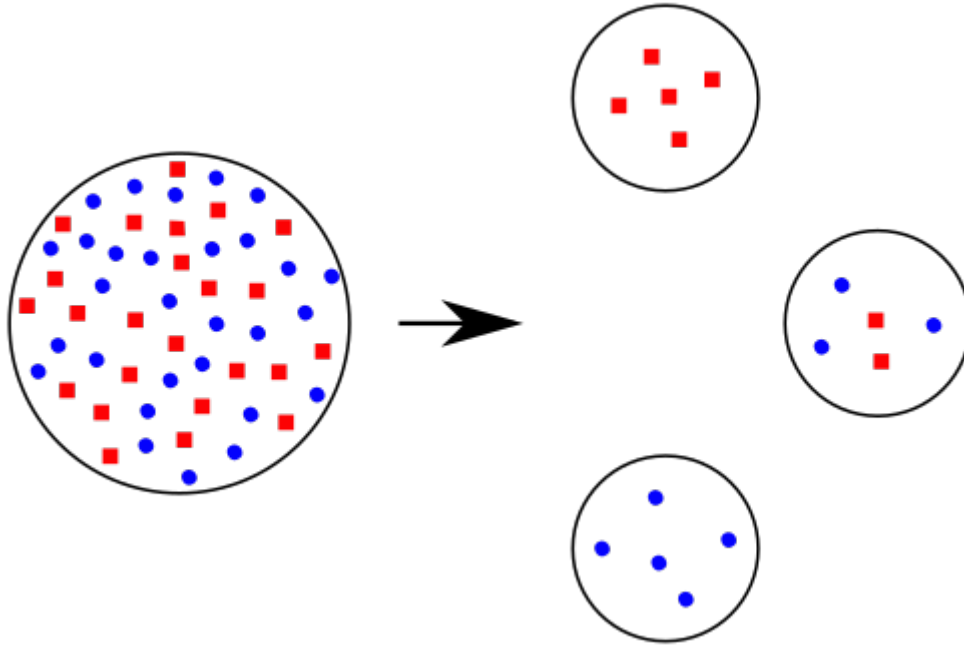
Biogeography



Distribution and isolation of Galapagos tortoises. Credit: Fallschirmjäger [CC BY-SA

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Darwin's visit to the Galapagos Islands off the coast of South America inspired many observations. These islands were relatively close to each other with respect to continental land masses. It was here that Darwin observed similar species to the mainland but in various forms that were specific to each island. Taken together with fossil evidence, some organisms exist in different forms during the same geologic period due to isolation and migration of populations. Migration and isolation would give rise to a founder effect where individuals in the population would not yield the vast array of existing variation.



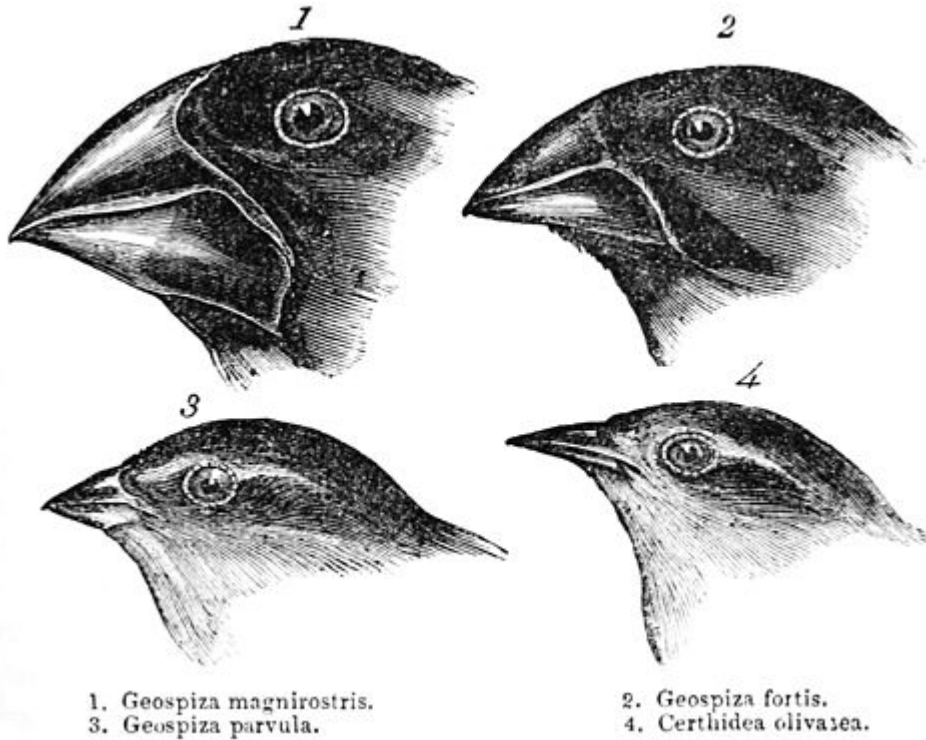
Variation is lost in partitioned populations during migration.

Darwin described the large tortoises that give rise to the archipelago (galápagos is Spanish for tortoise). He observed that each island had distinct species of tortoises with features that were best adapted for the environment. These adaptations were best described by shell shape and neck length that permitted the tortoises to either browse or graze on food, depending on vegetation growth on each island. On the larger island of Isabela, multiple tortoise species existed, but each was confined to a specific ecological niche. This aspect of specialization demonstrated to Darwin that a common ancestor existed that gave rise to different species over geologic time due to isolation in specific environments.



Diversity of tortoises found in the Galapagos archipelago. Credit: Minglex, Mikko Koponen, Mark Putney, Mike Weston, Jeremy Seto [CC-BY-SA]

Darwin also observed the diversity in finches on the islands. These finches would be revisited in the 1970s by the ecologists Peter and Rosemary Grant who performed measurements on finches of the island of Daphne Major that would reveal that rapid evolution could occur in relatively small windows of time based on the changes to environmental conditions.



The Video below illustrates the the combination of evidence collected by the Grants and others to describe the phenomena surrounding natural selection in driving the evolution of the diverse finch species.