Chapter 2

Brief Introduction to Evolutionary Theory

2.1 Classification

Carl Linnaeus (1707–1778)

One of the main goals of early biological research was classification, *i.e.,* the systematic arrangement of living organisms into categories reflecting their natural relationships. The most successful system was invented by the swede Carl Linnaeus, and presented in his book "Systema Naturae" first published in 1735. The system we use today is essentially the one devised by Linnaeus. It is a hierarchical system with seven major ranks: kingdom, phylum, class, order, family, genus, and species.

Specifically, groups of similar species are placed together in a genus, groups of related genera are placed together in a family, families are grouped into orders, orders into classes, classes into phyla, and phyla into kingdoms. When depicted graphically, the Linnean system can be shown in the form of a tree with individual species at the tips, and with internal nodes in the tree representing higher-level categories (Fig. 2.1). Along with this classification system, Linnaeus also developed the so-called binomial system in which all organisms are identified by a two-part Latinized name. The first name is capitalized and identifies the genus, while the second identifies the species within that genus. For example the genus *Canis* includes *Canis lupus*, the wolf, *Canis latrans*, the coyote, and *Canis familiaris*, the domestic dog. Similarly, the genus *Vulpes* contains *Vulpes vulpes*, the red fox, *Vulpes chama* the Cape fox, and others. Both genera (*Canis* and *Vulpes*) belong to the family *Canidae*, which in its turn is part of the order *Carnivora*, the carnivores.

The Linnean system:

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

Note that it is non-trivial to come up with a generally applicable definition of what exactly a "species" is. According to the so-called biological species concept, a species is a group of "actually or potentially interbreeding natural populations which are reproductively isolated from other such groups". This definition is due to the evolutionary biologist Ernst Mayr (1904–) and is perhaps what most people intuitively understand by the word "species". However, the biological species concept does not address the issue of how to define species within groups of organisms that do not reproduce sexually (*e.g.,* bacteria), or when organisms are known only from fossils. An alternative definition is the morphological species concept which states that "species are groups of organisms that share certain morphological or biochemical traits". This definition is more broadly applicable, but is also far more subjective than Mayr's.

2.2 Darwin and the Theory of Evolution

As mentioned, the Linnean system was highly successful. So much so in fact, that in his publications, Linnaeus provided a survey of all the world's

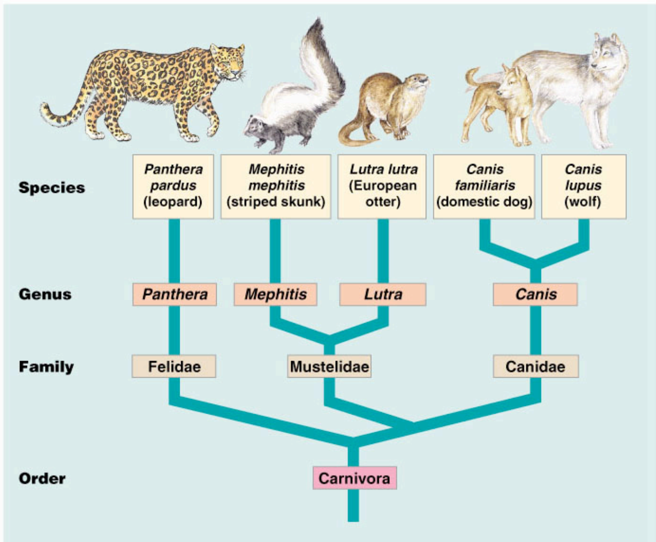


Figure 2.1: Linnean classification depicted in the form of a tree.

plants and animals as then known—about 7,700 species of plants and 4,400 species of animals. Linnaeus believed that God was the ordering principle behind this classification system, and that its structure somehow reflected the divine master plan.

It was not until after the 1859 publication of Charles Darwin's "On the Origin of Species" that an alternative explanation was widely accepted. According to Darwin (and others), the ordering principle behind the Linnean system was instead a history of "common descent with modification": all life was believed to have evolved from one—or a few—common ancestors, and taxonomic groupings were simply manifestations of the tree-shaped evolutionary history connecting all present-day species (Fig. 2.2).

The theory of common descent did not in itself address the issue of *how* evolutionary change takes place, but it was able to explain a great deal of puzzling observations. For instance, similar species are often found in adjacent or overlapping geographical regions, and fossils often resemble (but are different from) present-day species living in the same location. These phenomena are easily explained as the result of divergence from a common ancestor, but have no clear cause if one assumes that each species has been created individually.

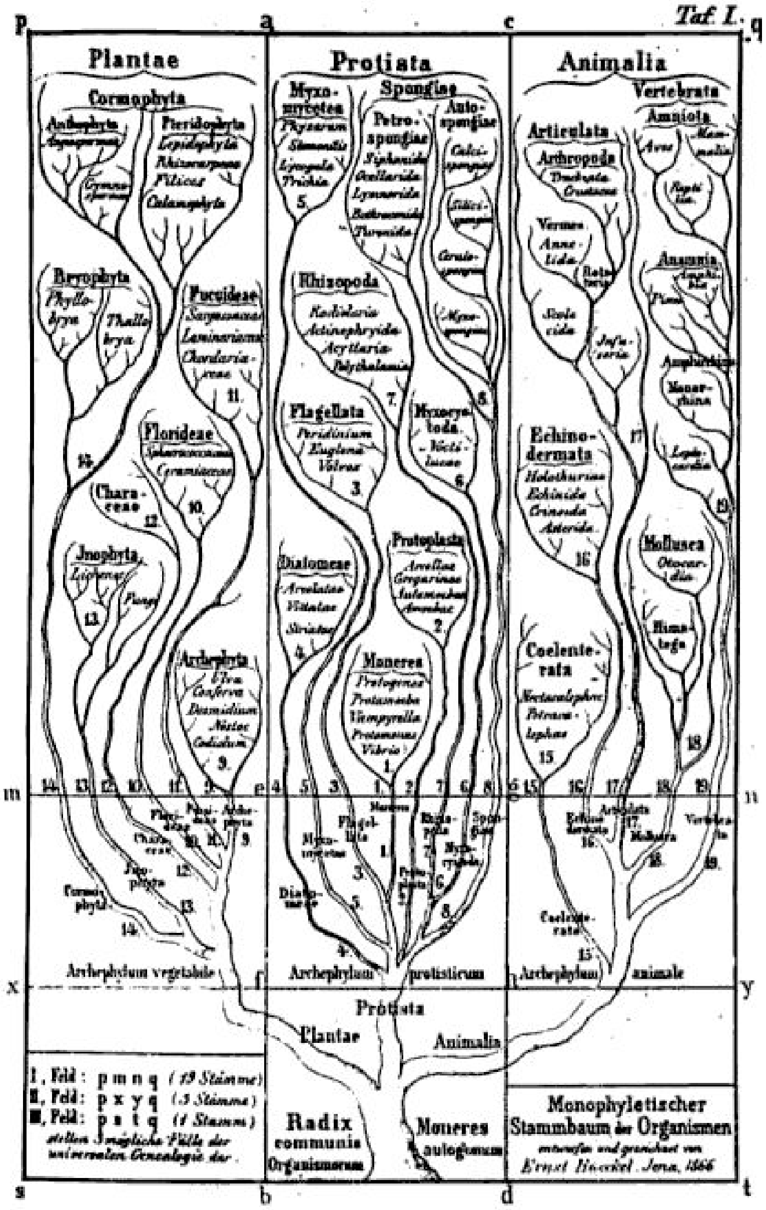
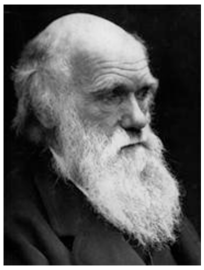


Figure 2.2: The tree of life, Ernst Haeckel, 1866

2.3 Natural Selection

The mechanism that Darwin proposed for evolutionary change is called **natural selection**. This is related to artificial selection—the process of intentional (or unintentional) modification of a species through human actions which encourage the breeding of certain traits over others. Examples include crop plants, such as rice and wheat, which have been artificially selected for protein-rich seeds, and dairy cows which have been artificially selected for high milk yields. The wide variety of dog breeds is also a result of artificial selection (for hunting, herding, protection, companionship, and looks) and illustrates that rather significant changes can be obtained in a limited amount of time (a couple of thousand years in the case of dogs.) You should note that for artificial selection to be possible in the first place, there needs to be naturally occurring and heritable variation in traits of interest: it is only possible to breed high-protein grass sorts, if there are some grass plants that produce more seed protein than others, *and* if that trait is inherited by their descendants.



Charles Darwin (1809-1882)

Darwin suggested that a similar process occurs naturally: individuals in the wild who possess characteristics that enhance their prospects for having offspring would undergo a similar process of change over time. Specifically, Darwin postulated that there are four properties of populations that together result in natural selection. These are:

1. Each generation more offspring is born than the environment can support - a fraction of offspring therefore dies before reaching reproductive age.

2. Individuals in a population vary in their characteristics.

3. Some of this variation is based on genetic differences.

4. Individuals with favorable characteristics have higher rates of survival and reproduction compared to individuals with less favorable characteristics.

If all four postulates are true (and this is generally the case) then advantageous traits will automatically tend to spread in the population, which thereby changes gradually through time. This is natural selection. Let us consider, for instance, a population of butterflies that are preyed upon by birds. Now imagine that at some point a butterfly is born with a mutation that makes the butterfly more difficult to detect. This butterfly will obviously have a smaller risk of being eaten, and will consequently have an increased chance of surviving to produce offspring. A fraction of the fortunate butterfly's offspring will inherit the advantageous mutation, and in the next generation there will therefore be *several* butterflies with an improved chance of surviving to produce offspring. After a number of generations it is possible that all butterflies will have the mutation, which is then said to be "fixed".

2.4 The Modern Synthesis

One problem with the theory described in "Origin of Species", was that its genetic basis—the nature of heritability—was entirely unknown. In later editions of the book, Darwin proposed a model of inheritance where "hereditary substances" from the two parents merge physically in the offspring, so that the hereditary substance in the offspring will be intermediate in form (much like blending red and white paint results in pink paint). Such "blending inheritance" is in fact incompatible with evolution by natural selection, since the constant blending will quickly result in a completely homogeneous population from which the original, advantageous trait cannot be recovered (in the same way it is impossible to extract red paint from pink paint). Moreover, due to the much higher frequency of the original trait, the resulting homogeneous mixture will be very close to the original trait, and very far from the advantageous one. (In the paint analogy, if one single red butterfly is born at some point, then it will have to mate with a white butterfly resulting in pink offspring. The offspring will most probably mate with white butterflies and their offspring will be a *lighter* shade of pink, *etc.* , *etc.* In the long run, the population will end up being a very, very light shade of pink, instead of all red).

Gregor Mendel (1822–1884)

However, as shown by the Austrian monk Gregor Mendel, inheritance is in fact particulate in nature: parental genes do not merge physically; instead they are retained in their original form within the offspring, making it possible for the pure, advantageous trait to be recovered and, eventually, to be fixed by natural selection. Although Mendel published his work in 1866 it was not widely noticed until around 1900, and not until the 1930's was Mendelian genetics fully integrated into evolutionary theory (the so-called "Modern Synthesis"). This led to the creation of the new science of population genetics which now forms the theoretical basis for all evolutionary biology.

2.5 Mendelian Genetics

An organism can be either haploid or diploid. **Haploid** organisms have one complete set of genetic material (and therefore one copy of each gene), while **diploid** organisms have two complete sets of genetic material located on two complete sets of chromosomes (and therefore two copies of each gene). A particular gene in a haploid or diploid organism is said to occupy a particular **locus** (plural: loci). If different versions of a gene are present at a particular locus (*e.g.,* in different individuals of a population) then these are referred to as **alleles** of that gene. A diploid organism may have different alleles present on the two individual copies of a chromosome. If a diploid organism has the same allele on both chromosomal copies, then it is said to be **homozygous** for that allele (it is a homozygote). If it has two different alleles present at a locus, then it is said to be **heterozygous** for that allele (and is then referred to as a heterozygote). The total complement of alleles present in an organism is its **genotype**. Depending on the molecular nature of the different alleles present at a locus in a diploid organism, one allele may not make an impact on the organisms appearance (its **phenotype**). It is then said to be a **recessive** allele. An allele that is fully expressed in the organism's phenotype is called **dominant**. In diploid organisms, one allele comes from the mother, one from the father. When diploid organisms reproduce sexually, it occurs via an intermediate, haploid sex cell called a **gamete** (the gamete is an egg cell if it is produced by a female, and a sperm cell if it is produced by a male). During gamete formation, genetic material from the two parents is mixed by the process of **recombination**. Recombination is one stage of the special type of cell division termed **meiosis** which ultimately results in formation of the haploid gamete. At any one locus, there will (by necessity) be only one allele present in the gamete. The diploid cell formed by fusion of two gametes is called a **zygote**. Sexually reproducing organisms have life cycles that alter between a haploid stage and a diploid stage. In some organisms most of the life cycle is diploid (*e.g.,* humans, where only the sex cells are haploid), while the situation is reversed for other organisms (including some algae where the diploid zygote quickly undergoes meiosis to form new haploid cells). There are also organisms (*e.g.,* ferns) where the life cycle alternates between a haploid, multicellular generation and a diploid, multicellular generation. Asexual reproduction is seen in both haploid organisms (*e.g.,* bacteria) and diploid organisms (*e.g.,* yeast and some plants).

2.6 Mutation

Note: parts of the following sections in this chapter are adapted from http://www.talkorigins.org/faqs/faq-intro-to-biology.html

As mentioned above, Darwin had no knowledge of the molecular basis for heredity. Consequently he did not understand the source of inherited variation, which forms the basis for all evolution by natural selection. Today, we know that hereditary information is stored in DNA molecules (Fig. 2.3). The structure of DNA (two complementary strands kept together by hydrogen bonded A-T and C-G basepairs) directly explains how this information is propagated from one generation to the next. Encoded within the string of nucleotides that make up the DNA of a cell is the information necessary for the production of catalytic and structural proteins and RNAs.

However, the cellular machinery that copies DNA sometimes makes mistakes (Fig. 2.4). These mistakes alter the sequence of a gene. This is called

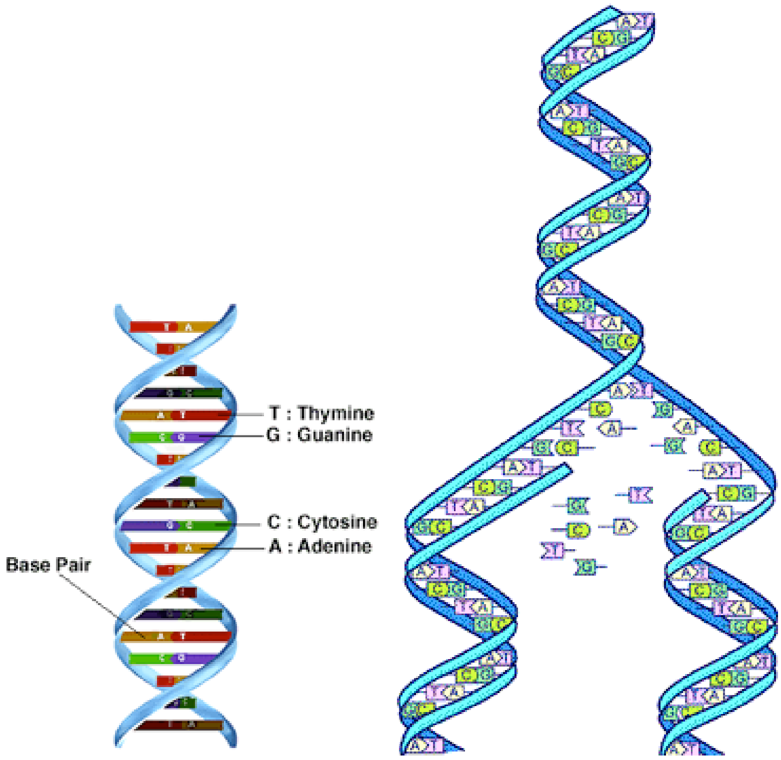


Figure 2.3: Hereditary information is stored in DNA molecules and replicated by copying each of the complementary strands.

a mutation. There are many kinds of mutations. A point mutation is a mutation in which one nucleotide is changed to another. Lengths of DNA can also be deleted or inserted in a gene; these are also mutations. Finally, genes or parts of genes can become inverted or duplicated. Typical rates of mutation are between 10^{-10} and 10^{-12} mutations per base pair of DNA per generation.

Most mutations are thought to be neutral with regards to fitness. The majority of these are lost soon after they appear, and only a small percentage reach fixation (*i.e.,* increase to a frequency at or near one).

Most mutations within coding sequences are probably deleterious. Mutations that result in amino acid substitutions can change the shape of a protein, potentially changing or eliminating its function. This can lead to inadequacies in biochemical pathways or interfere with the process of development. Deleterious mutants are selected against but remain at low frequency in the gene pool. In diploids, a deleterious recessive mutant may increase in frequency due to drift. Selection cannot see it when it is masked by a dominant allele. Many disease causing alleles remain at low frequency

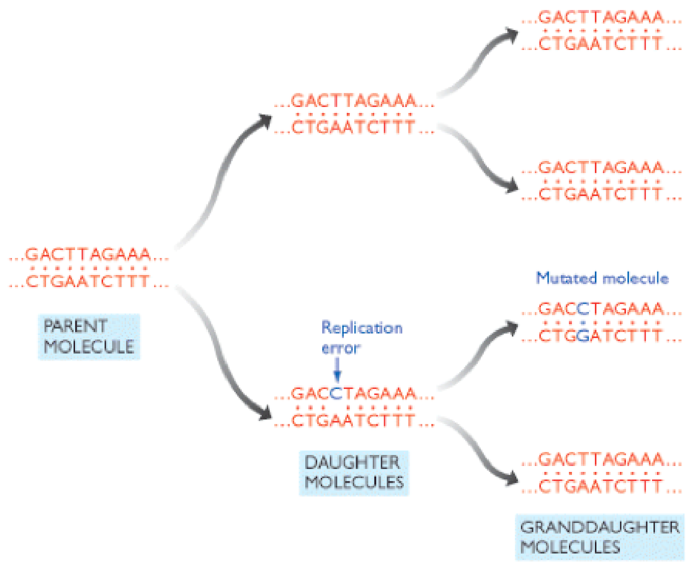


Figure 2.4: Errors during DNA replication is a source of genetic variation.

for this reason. People who are carriers do not suffer the negative effect of the allele. Unless they mate with another carrier, the allele may simply continue to be passed on. Deleterious alleles also remain in populations at a low frequency due to a balance between recurrent mutation and selection. This is called the mutation load.

Only a very small percentage of mutations are beneficial. The ratio of neutral to deleterious to beneficial mutations is unknown and probably varies with respect to details of the locus in question and environment. One example of a beneficial mutation comes from the mosquito Culex pipiens. In this organism, a gene that was involved with breaking down organophosphates - common insecticide ingredients -became duplicated. Progeny of the organism with this mutation quickly swept across the worldwide mosquito population. There are numerous examples of insects developing resistance to chemicals, especially DDT. And, most importantly, even though beneficial mutations occur much less frequently than detrimental ones, organisms with beneficial mutations thrive while organisms with "bad" ones die out.

2.7 Speciation

Biologists recognize two types of speciation: allopatric and sympatric speciation. The two differ in geographical distribution of the populations in question. Allopatric speciation is thought to be the most common form of speciation. It occurs when a population is split into two (or more) geographically isolated subdivisions that organisms cannot bridge. Eventually, the two populations' gene pools change independently until they could not interbreed even if they were brought back together. In other words, they have speciated.

Sympatric speciation occurs when two subpopulations become reproductively isolated without first becoming geographically isolated. Insects that live on a single host plant provide a model for sympatric speciation. If a group of insects switched host plants they would not breed with other members of their species still living on their former host plant. The two subpopulations could then diverge and speciate. Agricultural records show that a strain of the apple maggot fly *Rhagolettis pomenella* began infesting apples in the 1860's. Formerly it had only infested hawthorn fruit. Feder, Chilcote and Bush have shown that two races of *Rhagolettis pomenella* have become behaviorally isolated.

Biologists know little about the genetic mechanisms of speciation. Some think a series of small changes in each subdivision gradually lead to speciation. The founder effect could set the stage for relatively rapid speciation. Alan Templeton hypothesized that a few key genes could change and confer reproductive isolation. He called this a genetic transilience. Lynn Margulis thinks most speciation events are caused by changes in internal symbionts. Populations of organisms are very complicated. It is likely that there are many ways speciation can occur. Thus, all of the above ideas may be correct, each in different circumstances. Darwin's book was titled "The Origin of Species" despite the fact that he did not really address this question; over one hundred and fifty years later, how species originate is still largely a mystery.

2.8 A Brief History of Life

Biologists studying evolution do a variety of things: population geneticists study the process as it is occurring; systematists seek to determine relationships between species and paleontologists seek to uncover details of the unfolding of life in the past. Discerning these details is often difficult, but hypotheses can be made and tested as new evidence comes to light. This section should be viewed as the best hypothesis scientists have as to the history of the planet. The material here ranges from some issues that are fairly certain to some topics that are nothing more than informed speculation. For some points there are opposing hypotheses – I have tried to compile a consensus picture. In general, the more remote the time, the more likely the story is incomplete or in error.

The first replicating molecules were most likely RNA. In laboratory studies it

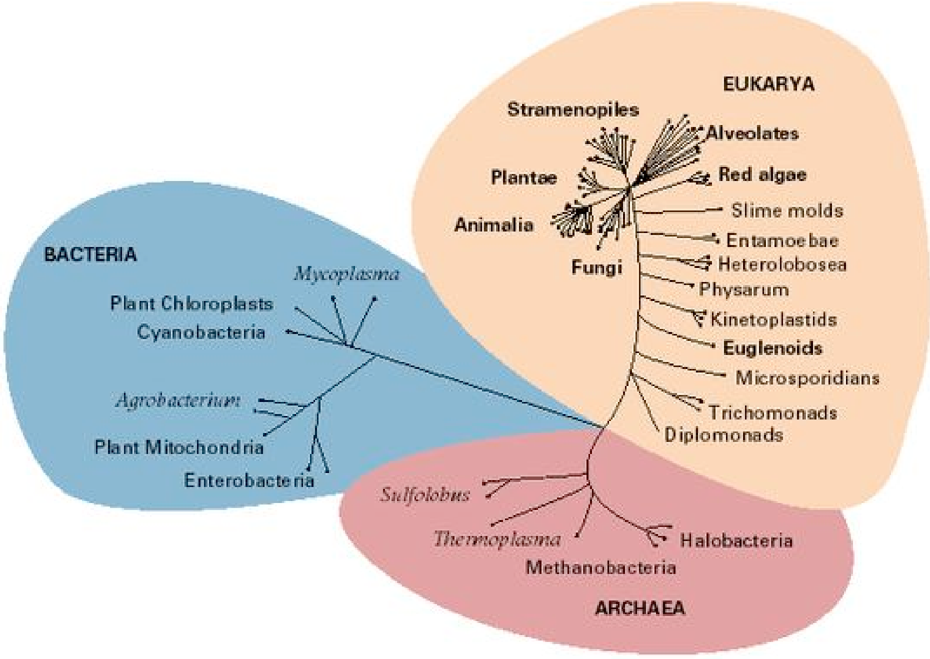


Figure 2.5: Three domains of life: prokaryotes ("ordinary" bacteria), archaea (thermophilic, methanogenic and halophilic bacteria), and eukaryotes (including both unicellular and multicellular organisms).

has been shown that some RNA sequences have catalytic capabilities. Most importantly, certain RNA sequences act as polymerases – enzymes that form strands of RNA from its monomers. This process of self replication is the crucial step in the formation of life. This is called the RNA world hypothesis.

The common ancestor of all life probably used RNA as its genetic material. This ancestor gave rise to three major lineages of life (Fig. 2.5). These are: the prokaryotes ("ordinary" bacteria), archaebacteria (thermophilic, methanogenic and halophilic bacteria) and eukaryotes. Eukaryotes include protists (single celled organisms like amoebas and diatoms and a few multicellular forms such as kelp), fungi (including mushrooms and yeast), plants and animals. Eukaryotes and archaebacteria are the two most closely related of the three. The process of translation (making protein from the instructions on a messenger RNA template) is similar in these lineages, but the organization of the genome and transcription (making messenger RNA from a DNA template) is very different in prokaryotes than in eukaryotes and archaebacteria. Scientists interpret this to mean that the common ancestor was RNA based; it gave rise to two lineages that independently formed a DNA genome and hence independently evolved mechanisms to transcribe DNA into RNA.

Figure 2.6: Modern stromatolites in Shark Bay, Western Australia.

The first cells must have been anaerobic because there was no oxygen in the atmosphere. In addition, they were probably thermophilic (”heat-loving”) and fermentative. Rocks as old as 3.5 billion years old have yielded prokaryotic fossils. Specifically, some rocks from Australia called the Warrawoona series give evidence of bacterial communities organized into structures called stromatolites. Fossils like these have subsequently been found all over the world. These mats of bacteria still form today in a few locales (for example, Shark Bay Australia; Fig. 2.6). Bacteria are the only life forms found in the rocks for a long, long time –eukaryotes (protists) appear about 1.5 billion years ago and fungi-like things appear about 900 million years ago (0.9 billion years ago).

Photosynthesis evolved around 3.4 billion years ago. Photosynthesis is a process that allows organisms to harness sunlight to manufacture sugar from simpler precursors. The first photosystem to evolve, PSI, uses light to convert carbon dioxide (CO_2) and hydrogen sulfide (H_2S) to glucose. This process releases sulfur as a waste product. About a billion years later, a second photosystem (PSII) evolved, probably from a duplication of the first photosystem. Organisms with PSII use both photosystems in conjunction to convert carbon dioxide (CO_2) and water (H_2O) into glucose. This process releases oxygen as a waste product. Anoxygenic (or H_2S) photosynthesis, using PSI, is seen in living purple and green bacteria. Oxygenic (or H_2O) photosynthesis, using PSI and PSII, takes place in cyanobacteria. Cyanobacteria are closely related to and hence probably evolved from purple bacterial ancestors. Green bacteria are an outgroup. Since oxygenic bacteria are a lineage within a cluster of anoxygenic lineages, scientists infer that PSI evolved first. This also corroborates with geological evidence.

Green plants and algae also use both photosystems. In these organisms, photosynthesis occurs in organelles (membrane bound structures within the cell) called chloroplasts. These organelles originated as free living bacteria related to the cyanobacteria that were engulfed by ur-eukaryotes and eventually entered into an endosymbiotic relationship. This endosymbiotic theory of eukaryotic organelles was championed by Lynn Margulis. Originally controversial, this theory is now accepted. One key line of evidence in support of this idea came when the DNA inside chloroplasts was sequenced – the gene sequences were more similar to free-living cyanobacteria sequences than to sequences from the plants the chloroplasts resided in.

After the advent of photosystem II, oxygen levels increased. Dissolved oxygen in the oceans increased as well as atmospheric oxygen. This is sometimes called the oxygen holocaust. Oxygen is a very good electron acceptor and can be very damaging to living organisms. Many bacteria are anaerobic and die almost immediately in the presence of oxygen. Other organisms, like animals, have special ways to avoid cellular damage due to this element (and in fact require it to live.) Initially, when oxygen began building up in the environment, it was neutralized by materials already present. Iron, which existed in high concentrations in the sea was oxidized and precipitated. Evidence of this can be seen in banded iron formations from this time, layers of iron deposited on the sea floor. As one geologist put it, "the world rusted." Eventually, it grew to high enough concentrations to be dangerous to living things. In response, many species went extinct, some continued (and still continue) to thrive in anaerobic microenvironments and several lineages independently evolved oxygen respiration.

The purple bacteria evolved oxygen respiration by reversing the flow of molecules through their carbon fixing pathways and modifying their electron transport chains. Purple bacteria also enabled the eukaryotic lineage to become aerobic. Eukaryotic cells have membrane bound organelles called mitochondria that take care of respiration for the cell. These are endosymbionts like chloroplasts. Mitochondria formed this symbiotic relationship very early in eukaryotic history, all but a few groups of eukaryotic cells have mitochondria. Later, a few lineages picked up chloroplasts. Chloroplasts have multiple origins. Red algae picked up ur-chloroplasts from the cyanobacterial lineage. Green algae, the group plants evolved from, picked up different urchloroplasts from a prochlorophyte, a lineage closely related

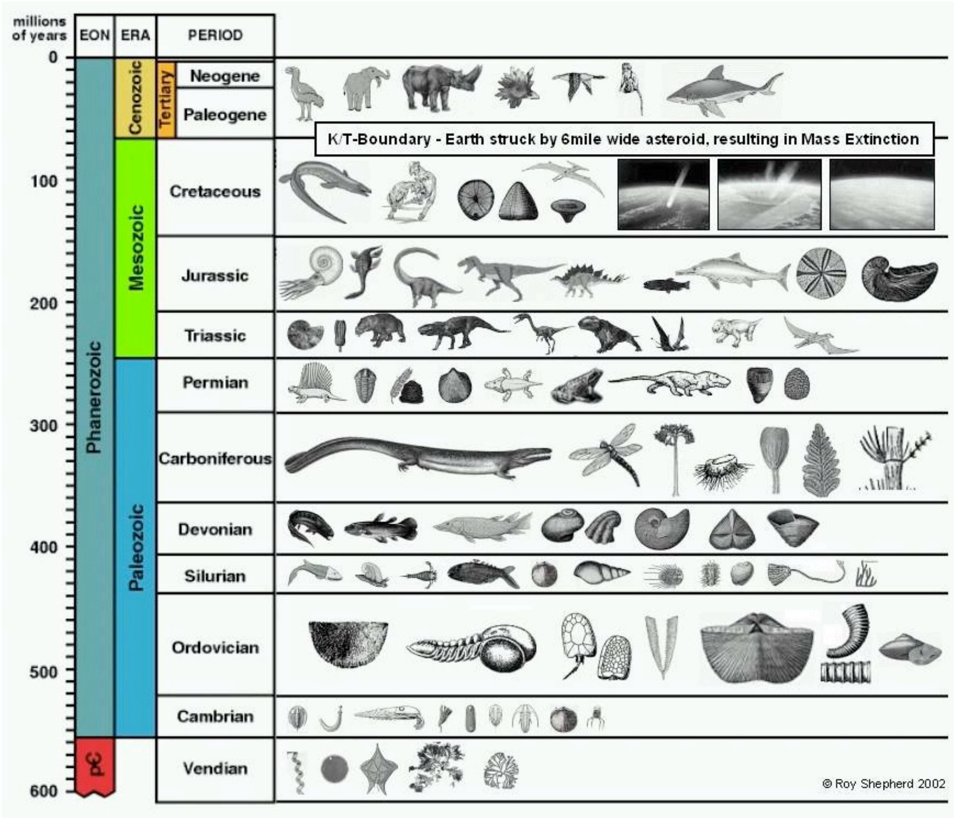


Figure 2.7: Overview of geological periods and examples of life forms existing at various time points.

to cyanobacteria.

Animals start appearing prior to the Cambrian, about 600 million years ago (see Fig. 2.7 for an overview of geological periods and examples of life-forms existing at various time-points). The first animals dating from just before the Cambrian were found in rocks near Adelaide, Australia. They are called the Ediacarian fauna and have subsequently been found in other locales as well. It is unclear if these forms have any surviving descendants. Some look a bit like jellyfish, sea anemones and the like; others resemble earthworms. The Cambrian 'explosion' may have been a result of higher oxygen concentrations enabling larger organisms with higher metabolisms to evolve. Or it might be due to the spreading of shallow seas at that time providing a variety of new niches. In any case, the radiation produced a wide variety of animals.

Plants evolved from ancient green algae over 400 million years ago. Both groups use chlorophyll a and b as photosynthetic pigments. In addition, plants and green algae are the only groups to store starch in their chloroplasts. Plants and fungi (in symbiosis) invaded the land about 400 million years ago. The first plants were moss-like and required moist environments to survive. Later, evolutionary developments such as a waxy cuticle allowed some plants to exploit more inland environments. Still mosses lack true vascular tissue to transport fluids and nutrients. This limits their size since these must diffuse through the plant. Vascular plants evolved from mosses. The first vascular land plant known is Cooksonia, a spiky, branching, leafless structure. At the same time, or shortly thereafter, arthropods followed plants onto the land. The first land animals known are myriapods – centipedes and millipedes.

Vertebrates moved onto the land by the Devonian period, about 380 million years ago. The recently discovered *Tiktaalik* illustrates the transition from sea to land (Fig. 2.8). *Tiktaalik* lived approximately 375 million years ago. Paleontologists suggest that it was an intermediate form between fish such as Panderichthys, which lived about 385 million years ago, and early tetrapods

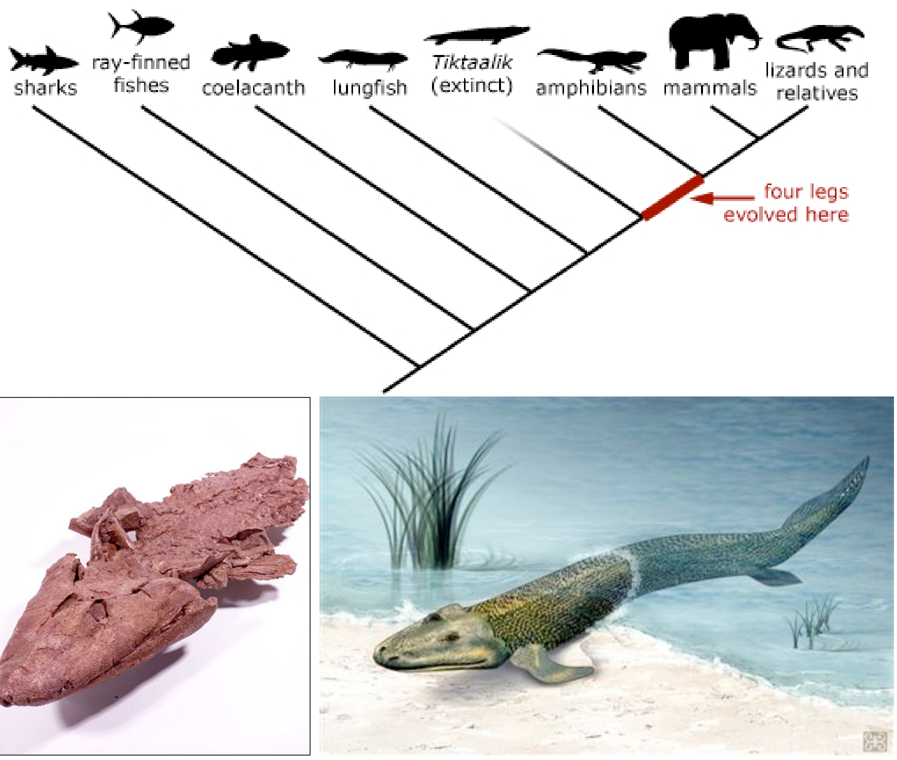
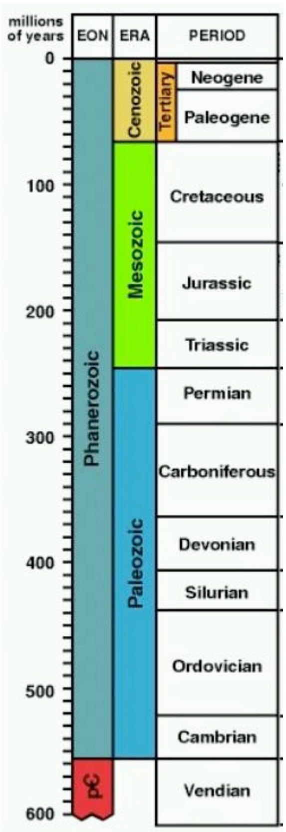


Figure 2.8: *Tiktaalik is a transitional form between fish and land-dwelling tetrapods living about 375 million years ago. Its fins show the beginnings of elbow and wrist-like features.*

such as Acanthostega and Ichthyostega, which lived about 365 million years ago. Tiktaalik generally had the characteristics of a lobe-finned fish, but with front fins featuring arm-like skeletal structures more akin to a crocodile, including a shoulder, elbow, and wrist. The rear fins and tail have not yet been found. It has rows of sharp teeth of a predator fish, and its neck was able to move independently of its body, which is not possible in other fish. The animal also had a flat skull resembling a crocodile's; eyes on top of its head, suggesting it spent a lot of time looking up; a neck and ribs similar to those of tetrapods, with the latter being used to support its body and aid in breathing via lungs; well developed jaws suitable for catching prey; and a small gill slit called a spiracle that, in more derived animals, became an ear. The incomplete specimens found thus far suggest animals that ranged from 4 to 9 feet (1.2 to 2.75 meters) in length.



Geological periods

The Permian extinction was the largest extinction in history. It happened about 250 million years ago. The last of the Cambrian Fauna went extinct. The Paleozoic fauna took a nose dive from about 300 families to about 50. It is estimated that 96% of all species (50% of all Families) met their end. Following this event, the Modern fauna, which had been slowly expanding since the Ordovician, took over.

The Modern fauna includes fish, bivalves, gastropods and crabs. These were barely affected by the Permian extinction. The Modern fauna subsequently increased to over 600 marine families at present. The Paleozoic fauna held steady at about 100 families. A second extinction event shortly following the Permian kept animal diversity low for awhile.

During the Carboniferous (the period just prior to the Permian) and in the Permian the landscape was dominated by ferns and their relatives. After the Permian extinction, gymnosperms (*e.g.,* pines) became more abundant. Gymnosperms had evolved seeds, from seedless fern ancestors, which helped their ability to disperse. Gymnosperms also evolved pollen, encased sperm which allowed for more outcrossing.

Angiosperms (flowering plants) evolved from gymnosperms about 245-202 million years ago. Two key adaptations allowed them to displace gymnosperms as the dominant fauna – fruits and flowers. Fruits allow for animal-based seed dispersal and deposition with plenty of fertilizer. Flowers evolved to facilitate animal, especially insect, based pollen dispersal. Petals are modified leaves. Angiosperms currently dominate the flora of the world – over three fourths of all living plants are angiosperms.

Dinosaurs evolved from archosaur reptiles, their closest living relatives are crocodiles. One modification that may have been a key to their success was the evolution of an upright stance. This allowed for continual locomotion. In addition, dinosaurs evolved to be warm-blooded. Warmbloodedness allows an increase in the vigor of movements in erect organisms. Birds evolved from sauriscian dinosaurs. Cladistically, birds are dinosaurs. The transitional fossil Archaeopteryx has a mixture of reptilian and avian features.

Insects evolved from primitive segmented arthropods. The mouth parts of insects are modified legs. Insects are closely related to annelids. Insects dominate the fauna of the world. Over half of all named species are insects. One third of this number are beetles.

Extinction of dinosaurs 65 mio years ago

The end of the Cretaceous, about 65 million years ago, is marked by a minor mass extinction. This extinction most likely was the result of a large meteor impact that eliminated over half of all species on the planet. This extinction marked the demise of all the lineages of dinosaurs save the birds. Up to this point mammals were confined to nocturnal, insectivorous niches. Once the dinosaurs were out of the picture, they diversified. Morgonucudon, a contemporary of dinosaurs, is an example of one of the first mammals. Mammals evolved from therapsid reptiles. The finback reptile Diametrodon is an example of a therapsid. One of the most successful lineages of mammals is, of course, humans. Humans are neotenous apes. Neoteny is a process which leads to an organism reaching reproductive capacity in its juvenile form. The primary line of evidence for this is the similarities between young apes and adult humans. Louis Bolk compiled a list of 25 features shared between adult humans and juvenile apes, including facial morphology, high relative brain weight, absence of brow ridges and cranial crests.

The earth has been in a state of flux for 4 billion years. Across this time, the abundance of different lineages varies wildly. New lineages evolve and radiate out across the face of the planet, pushing older lineages to extinction, or relictual existence in protected refugia or suitable microhabitats. Organisms modify their environments. This can be disastrous, as in the case of the oxygen holocaust. However, environmental modification can be the impetus for further evolutionary change. Overall, diversity has increased since the beginning of life. This increase is, however, interrupted numerous times by mass extinctions. Diversity appears to have hit an all-time high just prior to the appearance of humans. As the human population has increased, biological diversity has decreased at an ever-increasing pace. The correlation is probably causal.