Chapter 1

PIONEERS OF EVOLUTIONARY THOUGHT

Aristotle

Aristotle was born in 381 B.C., the son of the court physician of the king of Macedon, and at the age of seventeen he went to Athens to study. He joined Plato's Academy and worked there for twenty years until Plato died. Aristotle then left the Academy, saying that he disapproved of the emphasis on mathematics and theory and the decline of natural science. After serving as tutor for Alexander of Macedon, he founded a school of his own called the Lyceum. At the Lyceum, he built up a collection of manuscripts which resembled the library of a modern university.

Aristotle was a very great organizer of knowledge, and his writings almost form a one-man encyclopedia. His best work was in biology, where he studied and classified more than five hundred animal species, many of which he also dissected. In Aristotle's classification of living things, he shows an awareness of the interrelatedness of species. This interrelatedness was much later used by Darwin as evidence for the theory of evolution. One cannot really say that Aristotle developed a theory of evolution, but he was groping towards the idea. In his history of animals, he writes:

"Nature proceeds little by little from lifeless things to animal life, so that it is impossible to determine either the exact line of demarcation, or on which side of the line an intermediate form should lie. Thus, next after lifeless things in the upward scale comes the plant. Of plants, one will differ from another as to its apparent amount of vitality. In a word, the whole plant kingdom, whilst devoid of life as compared with the animal, is yet endowed with life as compared with other corporeal entities. Indeed, there is observed in plants a continuous scale of ascent towards the animal."

Aristotle's classification of living things, starting at the bottom of the scale and going upward, is as follows: Inanimate matter, lower plants and sponges, higher plants, jellyfish, zoophytes and ascidians, molluscs, insects, jointed shellfish, octopuses and squids, fish and reptiles, whales, land mammals and man. The acuteness of Aristotle's observation and analysis can be seen from the fact that he classified whales and dolphins as mammals (where they belong) rather than as fish (where they superficially seem to belong, and where many ancient writers placed them).

Among Aristotle's biological writings, there appears a statement that clearly foreshadows the principle of natural selection, later independently discovered by Darwin and Wallace and fully developed by Darwin. Aristotle wrote: "Wheresoever, therefore... all parts of one whole happened like as if they were made for something, these were preserved, having been appropriately constituted by an internal spontaneity; and wheresoever things were not thus constituted, they perished, and still perish".

One of Aristotle's important biological studies was his embryological investigation of the developing chick. Ever since his time, the chick has been the classical object for embryological studies. He also studied the four-chambered stomach of the ruminants and the detailed anatomy of the mammalian reproductive system. He used diagrams to illustrate complex anatomical relationships - an important innovation in teaching technique.

Averröes

During the Middle Ages, Aristotle's evolutionary ideas were revived and extended in the writings of the Islamic philosopher Averröes[1], who lived in Spain from 1126 to 1198. His writings had a great influence on western thought. Averröes shocked both his Moslem and his Christian readers by his thoughtful commentaries on the works of Aristotle, in which he maintained that the world was not created at a definite instant, but that it instead evolved over a long period of time, and is still evolving.

Like Aristotle, Averröes seems to have been groping towards the ideas of evolution which were later developed in geology by Lyell and in biology by Darwin and Wallace. Much of the scholastic philosophy written at the University of Paris during the 13th century was aimed at refuting the doctrines of Averröes; but nevertheless, his ideas survived and helped to shape the modern picture of the world.

The mystery of fossils

During the lifetime of Leonardo da Vinci (1452-1519) the existence of fossil shells in the rocks of high mountain ranges was recognized and discussed.

[1] Abul Walid Mahommed Ibn Achmed, Ibn Mahommed Ibn Rosched

"...the shells in Lombardy are at four levels", Leonardo wrote, "and thus it is everywhere, having been made at various times...The stratified stones of the mountains are all layers of clay, deposited one above the other by the various floods of the rivers." Leonardo had no patience with the explanation given by some of his contemporaries, that the shells had been carried to mountain tops by the deluge described in the Bible. "If the shells had been carried by the muddy waters of the deluge", he wrote, "they would have been mixed up, and separated from each other amidst the mud, and not in regular steps and layers." Nor did Leonardo agree with the opinion that the shells somehow grew within the rocks: "Such an opinion cannot exist in a brain of much reason", he wrote, "because here are the years of their growth, numbered on their shells, and there are large and small ones to be seen, which could not have grown without food, and could not have fed without motion...and here they could not move."

Leonardo believed that the fossil shells were once part of living organisms, that they were buried in strata under water, and much later lifted to the tops of mountains by geological upheavals. However his acute observations had little influence on the opinions of his contemporaries because they appear among the 4000 or so pages of notes which he wrote for himself but never published.

It was left to the Danish scientist Niels Stensen (1638-1686) (usually known by his Latinized name, Steno) to independently rediscover and popularize the correct interpretation of fossils and of rock strata. Steno, who had studied medicine at the University of Leiden, was working in Florence, where his anatomical studies attracted the attention of the Grand Duke of Tuscany, Ferdenand II. When an enormous shark was caught by local fishermen, the Duke ordered that its head be brought to Steno for dissection. The Danish anatomist was struck by shape of the shark's teeth, which reminded him of certain curiously shaped stones called *glossopetrae* that were sometimes found embedded in larger rocks. Steno concluded that the similarity of form was not just a coincidence, and that the *glossopetrae* were in fact the teeth of once-living sharks which had become embedded in the muddy sediments at the bottom of the sea and gradually changed to stone. Steno used the corpuscular theory of matter, a forerunner of atomic theory, to explain how the composition of the fossils could have changed while their form remained constant. Steno also formulated a law of strata, which states that in the deposition of layers of sediment, later converted to rock, the oldest layers are at the bottom.

In England, the brilliant and versatile experimental scientist Robert Hooke (1635-1703) added to Steno's correct interpretation of fossils by noticing that some fossil species are not represented by any living counterparts. He concluded that "there have been many other Species of Creatures in former Ages, of which we can find none at present; and that 'tis not unlikely also but that there may be divers new kinds now, which have not been from the beginning."

Similar observations were made by the French naturalist, Georges-Louis Leclerc, Comte de Buffon (1707-1788), who wrote: "We have monuments taken from the bosom of the Earth, especially from the bottom of coal and slate mines, that demonstrate to us that some of the fish and plants that these materials contain do not belong to species currently existing." Buffon's position as keeper of the Jardin du Roi, the French botanical gardins, allowed him time for writing, and while holding this post he produced a 44-volume encyclopedia of natural history. In this enormous, clearly written, and popular work, Buffon challenged the theological doctrines which maintained that all species were created independently, simultaneously and miraculously, 6000 years ago. As evidence that species change, Buffon pointed to vestigial organs, such as the lateral toes of the pig, which may have had a use for the ancestors of the pig. He thought that the donkey might be a degenerate relative of the horse. Buffon believed the earth to be much older than the 6000 years allowed by the Bible, but his estimate, 75,000 years, greatly underestimated the true age of the earth.

The great Scottish geologist James Hutton (1726-1797) had a far more realistic picture of the true age of the earth. Hutton observed that some rocks seemed to have been produced by the compression of sediments laid down under water, while other rocks appeared to have hardened after previous melting. Thus he classified rocks as being either igneous or else sedimentary. He believed the features of the earth to have been produced by the slow action of wind, rain, earthquakes and other forces which can be observed today, and that these forces never acted with greater speed than they do now. This implied that the earth must be immensely old, and Hutton thought its age to be almost infinite. He believed that the forces which turned sea beds into mountain ranges drew their energy from the heat of the earth's molten core. Together with Steno, Hutton is considered to be one of the fathers of modern geology. His uniformitarian principles, and his belief in the great age of the earth were later given wide circulation by Charles Darwin's friend and mentor, Sir Charles Lyell (1797-1875), and they paved the way for Darwin's application of uniformitarianism to biology. At the time of his death, Hutton was working on a theory of biological evolution through natural selection, but his manuscripts on this subject remained unknown until 1946.

Condorcet

Further contributions to the idea of evolution were made by the French mathematician and social philosopher Marie-Jean-Antoine-Nicolas Caritat, Marquis de Condorcet, who was born in 1743. In 1765, when he was barely 22 years old, Condorcet presented an *Essay on the Integral Calculus* to the Academy of Sciences in Paris. The year 1785 saw the publication of Condorcet's highly original mathematical work, *Essai sur l'application de l'analyse à la probabilité des décisions rendues à la pluralité des voix*[2], in which he pioneered the application of the theory of probability to the social sciences. A later, much enlarged, edition of this book extended the applications to games of chance.

Condorcet had also been occupied, since early childhood, with the idea of human perfectibility. He was convinced that the primary duty of every person is to contribute as much as possible to the development of mankind, and that by making such a contribution, one can also achieve the greatest possible personal happiness. When the French Revolution broke out in 1789, he saw it as an unprecedented opportunity to do his part in the cause of progress; and he entered the arena wholeheartedly, eventually becoming President of the Legislative Assembly, and one of the chief authors of the proclamation which declared France to be a republic. Unfortunately, Condercet became a bitter enemy of the powerful revolutionary politician, Robespierre, and he was forced to go into hiding.

Although Robespierre's agents had been unable to arrest him, Condorcet was sentenced to the guillotine *in absentia.* He knew that in all probability he had only a few weeks or months to live; and he began to write his last thoughts, racing against time. Condorcet returned to a project which he had begun in 1772, a history of the progress of human culture, stretching from the remote past to the distant future. Guessing that he would not have time to complete the full-scale work he had once planned, he began a sketch or outline: *Esquisse d'un tableau historique des progrès de l'esprit humain*[3].

In his *Esquisse*, Condorcet enthusiastically endorsed the idea of infinite human perfectibility which was current among the philosophers of the 18th century; and he anticipated many of the evolutionary ideas which Charles Darwin later put forward. He compared humans with animals, and found many common traits. According to Condorcet, animals are able to think, and even to think rationally, although their thoughts are extremely simple compared with those of humans. Condorcet believed that humans

[2] *Essay on the Application of Analysis to the Probability of Decisions Taken According to a Plurality of Votes*

[3] *Sketch of an Historical Picture of the Progress of the Human Spirit*

historically began their existence on the same level as animals and gradually developed to their present state. Since this evolution took place historically, he reasoned, it is probable, or even inevitable, that a similar evolution in the future will bring mankind to a level of physical, mental and moral development which will be as superior to our own present state as we are now superior to animals.

At the beginning of his manuscript, Condorcet stated his belief "that nature has set no bounds on the improvement of human facilities; that the perfectibility of man is really indefinite; and that its progress is henceforth independent of any power to arrest it, and has no limit except the duration of the globe upon which nature has placed us". He stated also that "the moral goodness of man is a necessary result of his organism; and it is, like all his other facilities, capable of indefinite improvement."

Like the other scientists and philosophers of his period, Condorcet accepted the Newtonian idea of an orderly cosmos ruled by natural laws to which there are no exceptions. He asserted that the same natural laws must govern human evolution, since humans are also part of nature. Again and again, Condorcet stressed the fundamental similarity between humans and animals; and he regarded all living things as belonging to the same great family. (It is perhaps this insight which made Condorcet so sensitive to the feelings of animals that he even avoided killing insects.) To explain the present differences between humans and animals, Condorcet maintained, we need only imagine gradual changes, continuing over an extremely long period of time. These long-continued small changes have very slowly improved human mental abilities and social organization, so that now, at the end of an immense interval of time, large differences have appeared between ourselves and lower forms of life.

Condorcet regarded the family as the original social unit; and in *Esquisse* he called attention to the unusually long period of dependency which characterizes the growth and education of human offspring. This prolonged childhood is unique among living beings. It is needed for the high level of mental development of the human species; but it requires a stable family structure to protect the young during their long upbringing. Thus, according to Condorcet, biological evolution brought into existence a moral precept, the sanctity of the family.

Similarly, Condorcet wrote, larger associations of humans would have been impossible without some degree of altruism and sensitivity to the suffering of others incorporated into human behavior, either as instincts or as moral precepts or both; and thus the evolution of organized society entailed the development of sensibility and morality. Unlike Rousseau, Condorcet did not regard humans in organized civilizations as degraded and corrupt compared to "natural" man; instead he saw civilized humans as more developed than their primitive ancestors.

Believing that ignorance and error are responsible for vice, Condorcet discussed what he believed to be the main mistakes of civilization. Among these he named hereditary transmission of power, inequality between men and women, religious bigotry, disease, war, slavery, economic inequality, and the division of humanity into mutually exclusive linguistic groups.

Regarding disease, Condorcet predicted that the progress of medical science would ultimately abolish it. Also, he maintained that since perfectibility (i.e. evolution) operates throughout the biological world, there is no reason why mankind's physical structure might not gradually improve, with the result that human life in the remote future could be greatly prolonged.

Condorcet believed that the intellectual and moral facilities of man are capable of continuous and steady improvement; and he thought that one of the most important results of this improvement would be the abolition of war. As humans become enlightened in the future (he believed) they will recognize war as an atrocious and unnecessary cause of suffering; and as popular governments replace hereditary ones, wars fought for dynastic reasons will disappear. Next to vanish will be wars fought because of conflicting commercial interests. Finally, the introduction of a universal language throughout the world and the construction of perpetual confederations between nations will eliminate, Condorcet predicted, wars based on ethnic rivalries.

With better laws, social and financial inequalities would tend to become leveled. To make the social conditions of the working class more equal to those of the wealthy, Condorcet advocated a system of insurance (either private or governmental) where the savings of workers would be used to provide pensions and to care for widows and orphans. Also, since social inequality is related to inequality of education, Condorcet advocated a system of universal public education supported by the state.

At the end of his *Esquisse*, Condorcet wrote that any person who has contributed to the best of his ability to the progress of mankind becomes immune to personal disaster and suffering. He knows that human progress is inevitable, and can take comfort and courage from his inner picture of the epic march of mankind, through history, towards a better future.

Eventually Condorcet's hiding-place was discovered. He fled in disguise, but was arrested after a few days; and he died soon afterwards in his prison cell. After Condorcet's death the currents of revolutionary politics shifted direction. Robespierre, the leader of the Terror, was himself soon arrested. The execution of Robespierre took place on July 25, 1794, only a few months after the death of Condorcet.

Condorcet's *Esquisse d'un tableau historique des progrès de l'esprit hu-*

main was published posthumously in 1795. In the post-Thermidor reconstruction, the Convention voted funds to have it printed in a large edition and distributed throughout France, thus adopting the *Esquisse* as its official manifesto. This small but prophetic book is the one for which Condorcet is now chiefly remembered. It was destined to establish the form in which the eighteenth-century idea of progress was incorporated into Western thought, and it provoked Robert Malthus to write *An Essay on the Principle of Population*. Condorcet's ideas are important because he considered the genetic evolution of plants and animals and human cultural evolution to be two parts of a single process.

Linnæus

Meanwhile, during the 17th and 18th centuries, naturalists had been gathering information on thousands of species of plants and animals. This huge, undigested heap of information was put into some order by the great Swedish naturalist, Carl von Linné (1707-1778), who is usually called by his Latin name, Carolus Linnæus.

Linnæus was the son of a Swedish pastor. Even as a young boy, he was fond of botany, and after medical studies at Lund, he became a lecturer in botany at the University of Uppsala, near Stockholm. In 1732, the 25-year-old Linnæus was asked by his university to visit Lapland to study the plants in that remote northern region of Sweden.

Linnæus travelled four thousand six hundred miles in Lapland, and he discovered more than a hundred new plant species. In 1735, he published his famous book, *Systema Naturae*, in which he introduced a method for the classification of all living things.

Linnæus not only arranged closely related species into genera, but he also grouped related genera into classes, and related classes into orders. (Later the French naturalist Cuvier (1769-1832) extended this system by grouping related orders into phyla.) Linnæus introduced the binomial nomenclature, still used today, in which each plant or animal is given a name whose second part denotes the species while the first part denotes the genus.

Although he started a line of study which led inevitably to the theory of evolution, Linnæus himself believed that species are immutable. He adhered to the then-conventional view that each species had been independently and miraculously created six thousand years ago, as described in the Book of Genesis.

Linnæus did not attempt to explain why the different species within a genus resemble each other, nor why certain genera are related and can be grouped into classes, etc. It was not until a century later that these resemblances were understood as true family likenesses, so that the resemblance between a cat and a lion came to be understood in terms of their descent from a common ancestor[4].

Erasmus Darwin

Among the ardent admirers of Linnæus was the brilliant physician-poet, Erasmus Darwin (1731-1802), who was considered by Coleridge to have "...a greater range of knowledge than any other man in Europe". He was also the best English physician of his time, and George III wished to have him as his personal doctor. However, Darwin preferred to live in the north of England rather than in London, and he refused the position.

In 1789, Erasmus Darwin published a book called *The Botanic Garden* or *The Loves of the Plants.* It was a book of botany written in verse, and in the preface Darwin stated that his purpose was "...to inlist imagination under the banner of science.." and to call the reader's attention to "the immortal works of the celebrated Swedish naturalist, Linnæus". This book was immensely popular at the time when it was written, but it was later satirized by Pitt's Foreign Minister, Canning, whose book *The Loves of the Triangles* ridiculed Darwin's poetic style.

In 1796 Erasmus Darwin published another book, entitled *Zoonomia,* in which he proposed a theory of evolution similar to that which his grandson, Charles Darwin, was later to make famous. "...When we think over the great changes introduced into various animals", Darwin wrote, "as in horses, which we have exercised for different purposes of strength and swiftness, carrying burthens or in running races; or in dogs, which have been cultivated for strength and courage, as the bull-dog; or for acuteness of his sense of smell, as in the hound and spaniel; or for the swiftness of his feet, as the greyhound; or for his swimming in the water, or for drawing snow-sledges, as the rough-haired dogs of the north... and add to these the great change of shape and color which we daily see produced in smaller animals from our domestication of them, as rabbits or pigeons;... when we revolve in our minds the great similarity of structure which obtains in all the warm-blooded animals, as well as quadrupeds, birds and amphibious animals, as in mankind, from the mouse and the bat to the elephant and whale; we are led to conclude that they have alike been produced from a

[4]Linnæus was to Darwin what Kepler was to Newton. Kepler accurately described the motions of the solar system, but it remained for Newton to explain the underlying dynamical mechanism. Similarly, Linnæus set forth a descriptive "family tree" of living things, but Darwin discovered the dynamic mechanism that underlies the observations.

similar living filament."

"Would it be too bold", Erasmus Darwin asked, "to imagine that in the great length of time since the earth began to exist, perhaps millions of ages before the commencement of the history of mankind - would it be to bold to imagine that all warm-blooded animals have arisen from one living filament?"

Lamarck

In France, Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829), contributed importantly to the development of evolutionary ideas. After a period in the French army, from which he was forced to retire because of illness, Lamarck became botanist to the king, and later Professor of Invertebrate Zoology at the Museum of Natural History in Paris.

Lamarck deserves to be called the father of invertebrate zoology. Linnæus had exhausted his energy on the vertebrates, and he had left the invertebrates in disorder. Their classification is largely due to Lamarck: He differentiated the eight-legged arachnids, such as spiders and scorpions, from six-legged insects; he established the category of crustaceans for crabs, lobsters etc.; and he introduced the category of echinoderms for starfish, sea-urchins etc. Between 1785 and 1822, Lamarck published seven huge volumes of a treatise entitled *Natural History of Invertebrates.* However, it is for his book *Zoological Philosophy*, published in 1809, that the Chevalier de Lamarck is chiefly remembered today.

In his *Zoological Philosophy*, Lamarck stated his belief that the species within a genus owe their similarity to descent from a common ancestor. He was the first prominent biologist since the age of Aristotle to believe that species are not immutable but that they have changed during the long history of the earth.

Although Lamarck deserves much credit as a pioneer of evolutionary thought, he was seriously wrong about the mechanism of change. For example, Lamarck believed that the long neck of the giraffe evolved because each giraffe stretched its neck slightly in an effort to reach the leaves on high trees. He believed that these slightly-stretched necks could be inherited, and thus, in this way, over many generations, the necks of giraffes had grown longer and longer. Although Lamarck was right in his general picture of evolution, he was mistaken in the detailed mechanism which he proposed, since later experiments proved conclusively that, in general, acquired characteristics cannot be inherited. (One must say "in general", because in the case of symbiosis and genetic fusion, acquired characteristics are inherited. Plasmids containing genetic material are also frequently exchanged between bacteria. Furthermore, in human cultural evolution, innovations can be passed on to future generations. We will discuss these Lamarckian mechanisms of evolution in later chapters.)

The debates between Cuvier and Geoffroy St. Hilaire

In 1830, a year after the death of Lamarck, a famous series of debates took place between Georges Léopold Dagobert, Baron Cuvier (1769-1832) and Étienne Geoffroy St. Hilaire (1772-1844). The two men, both professors at the Musée National d'Histoire Naturelle in Paris, were close friends and scientific collaborators. However, they differed in their opinions, especially on the question of whether the form of an animal's parts led to their function, or whether the reverse was true. Cuvier almost singlehandedly founded the discipline of vertebrate paleontology, and he firmly established the fact that extinctions have taken place. However, he did not believe in evolution. In 1828, Cuvier wrote: "If there are resemblances between the organs of fishes and those of other vertebrate classes, it is only insofar as there are resemblances between their functions." In other words, function produces form. Cuvier denied that similarity of form implied descent from a common ancestor.

St. Hilaire, on the other hand, considered all vertebrates to be modifications of a single archetype. He maintained that similar vestigial organs and similarities in embryonic development implied descent from a common ancestor. He was especially interested in homologies, that is, cases where similar structures in two different organisms are used for two different purposes. In 1829, St. Hilaire wrote: "Animals have no habits but those that result from the structure of their organs: if the latter varies, there vary in the same manner all their springs of action, all their facilities, and all their actions."

The opposing viewpoints of the two men led to a famous series of eight public debates, which took place from February to April, 1830. Although Cuvier was thought by most observers to have won the debates, St. Hilaire's belief in evolution continued, as did the friendship between the two naturalists. In 1832 St. Hilaire partially anticipated Darwin's theory of evolution through natural selection: "The external world is all-powerful in alteration of the form of organized bodies...", he wrote, "These [modifications] are inherited, and they influence all the rest of the organization of the animal, because if these modifications lead to injurious effects, the animals which exhibit them perish and are replaced by others of a somewhat different form, a form changed so as to be adapted to the new environment."