BEGINNING of LIFE

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Introduction

Between 3700 and 2500 million years ago, the Earth was born. Nothing was as it is today, neither the continents, nor the oceans, nor the atmosphere. In those times, the atmosphere was crossed by electric storms, and ultraviolet rays of the Sun. These phenomena transformed the substances that were present, by means of chemical reactions, into macromolecules that were able to reproduce and feed themselves. Life was born!

Between 3200 and 2900 million years ago, thanks to the appearance of blue algae that could carry out chlorophyll photosynthesis, oxygen spread into the atmosphere. Thanks to the oxygen in the air and the nitrogen, life could also be transferred to the surfaces above the water. According to some scientists, life originated in puddles of water on the surface, others instead believe it originated in the ocean abysses, where there are sources of very hot water rich in minerals. To date, in these inhospitable environments we find bacteria that are able to live without light and receive energy from chemical oxidation of the sulphur compounds.

The beginning of life

Philosophers from ancient Greece believed that life was contained in matter itself and when conditions were favourable it would appear spontaneously. Aristotle synthesized in one of his theories all the ideas on spontaneous generation by the philosophers that came before him. According to the great philosopher, living beings are born from similar organisms, but sometimes they can also be generated from inert matter. All things, in fact, have a “passive element” which is their matter and an “active element” which is their shape, meaning a sort of inner force which gives the matter its shape. For example, clay is a non-living matter that has an active element which enables it to shape inert matter into a living being, such as for example a worm or a frog. The spontaneous generation theory was supported by famous scientists such as Newton, Descartes and Bacon and in 1500 there were people who still believed that geese were born from certain trees that lived in contact with the ocean and that lambs were generated inside melons. The first experiments to prove the spontaneous generation theory were done in the XVII century and a doctor called Jean Baptiste Van Helmont declared he had performed a unique experiment: he placed a dirty shirt together with some wheat and according to him, mice were born 21 days later. According to the Doctor the sweat in the shirt was the active element which gave life to the inert matter.

First experiments

Following the first incorrect experiments such as Van Helmont’s one, many others were performed. In 1668 Doctor Francesco Redi led a series of experiments that were supposed to prove that spontaneous generation does not exist. Redi placed in containers some samples of veal and fish, some he sealed while others he left in the open air. As time went by, he noticed that in the open containers on the decomposed meat there were worms (that were in fact larvae!), flies and other insects, while there were no signs of life in the sealed containers. In that same period, the Dutch naturalist Anton Van Leeuwenhoek (1632 –1723) built a rudimental microscope which enabled him to watch microorganisms. This made it possible to see that all substances contained a large number of living organisms, and this obviously brought back the spontaneous generation idea which had apparently been abandoned following Redi's experiments. Following numerous examinations with Leeuwenhoek's instrument new arguments arose among those who sustained the abiogenesis theory (life is born from lifeless substances) and the biogenesis one (life is generated only from living beings). In 1745 the English naturalist John Needham invented new experiments to prove the abiogenesis theory. He filled some test tubes with chicken broth and herb infusions and then he closed them with some gauze. The test tubes had been sterilized by the heat, nevertheless after a few days hundreds of living beings could be seen inside them. This result reinforced the spontaneous generation theory. A few years later the abbot Lazzaro Spallanzani, who was not convinced by Needham's experiment, tried to repeat it heating the nutritious liquid for much longer and at much higher temperatures, actually making it boil for a few minutes. He sealed the test tubes and the result was that even several days later there was no sign of any living organisms in them. As a result, the naturalist Needham, criticized Spallanzani saying that the nutritious liquid had been heated too much, and this had killed the active elements and that sealing the test tubes had not allowed the presence of air which is indispensable for life. Discussions went on for a long time until half way through the nineteenth century, when a French biologist Louis Pasteur, ran a new experiment that settled the matter. Pasteur created some glass containers with a long-curved neck (called "swan neck balloons"). Inside these the nutritious liquid was boiled for over an hour, letting the vapour out through the container's curved neck. After boiling, the broth inside was left to cool slowly, while the contaminated air carrying microorganisms entered from the outside as a result of the post heating depression. Thus, the microscopic organisms that came in contact with the boiling vapour of the liquid inside, would die and even after some months there was no trace of life to be found, instead on the outer part of the container's neck, one could see dust and microorganisms that were coming in from the outside. This experiment put a definite end to the abiogenesis theory, those that claimed that the long boiling of the nutritious liquid killed the active element. Pasteur instead, proved that once the curved neck of the container was broken, air in contact with the substance would bring germs and microorganisms inside, shortly after. Furthermore, the unsealed container allowed air to enter, even if through a tortuous neck, disproving the objections of those who supported that the active element needed air to generate life.

Life on Earth

There are two different theories on the origin of life on Earth: the autotrophy theory and the heterotrophy one. The first theory assumes that the first living being was autotrophic, meaning that it is able to produce organic substances from inorganic ones like green plants do, through a complex reaction called "chlorophyll photosynthesis". In the second case instead, the first living organism would have been heterotrophic, meaning that it was not able to produce its own food, but had to feed on other living beings. In fact, animals (heterotrophic) need to eat plants (autotrophic) to survive, while the latter have no such need. In the 1920s the English biologist John Burdon Sanderson Haldane (1892 –1964), considering that at the time the environment on Earth was very different from what it is today, began to draw up his own conclusions. Initially on the primitive Earth there was no life as there is today. According to Haldane if organic matter formed nowadays, it would be immediately eliminated by some living organism, while at the time, in the total absence of any microorganisms that could decompose it, would have had plenty of time to develop and become more complex. In 1924 the soviet researcher Aleksandr Ivanovic Oparin came forth with theories which were similar to Haldane's one, but with the difference that according to the first, the primitive atmosphere had to be rich in hydrogen, while according to the English scientist, it was rich in carbon dioxide. To have experimental proof of this new theory we shall start from this last supposition. Oparin and Haldane approached the argument from a scientific point of view omitting any religious interference and this obviously wasn't accepted by the faithful that instead were trying to prove that life couldn't have sprung forth from the random encounters between atoms but was an act of God. Actually, proteins are extremely complex molecules, that cannot have formed from random encounters between hydrogen, carbon, oxygen and nitrogen atoms, but it has been scientifically proved that the possible combinations of simpler molecules are ruled by physical and chemical laws therefore they are limited and not random.

Primordial atmosphere

The sun and its planets formed about 5 billion years ago following the explosion of a supernova, which is a big star, that before bursting had generated heavy elements starting from Hydrogen and Helium. At the beginning Earth was an enormous incandescent ball composed primarily of Hydrogen and Helium, but also by heavy elements such as carbon, nitrogen, oxygen, iron and silicon which had been flung into space by the explosion. After that, the planet cooled down and part of the lighter gasses, such as hydrogen and helium, bonded with heavier elements and part got lost in space. Actually, Helium was practically totally lost because it is light and not very reactive with other compounds, while a part of hydrogen (the lightest element of all) reacted with other elements forming hydrogenated compounds such as methane (CH_4), ammonia (NH_3), hydrogen sulphide (H_2S) and water (H_2O). Thanks to gravity the heavier elements began to form a central nucleus, composed mainly of iron and nickel, surrounded by a mantle, formed by heavy elements and an outer crust, made of the lightest elements such as aluminium, potassium and sodium. While the crust was forming, many volatile gases coming from the center of the Earth were released through the cracks and created what we consider to be the primordial atmosphere. Indirect proof of the primordial atmosphere can be obtained from the mixture of gasses which are still being released nowadays by volcanoes and solfataras, whose composition is very similar to that of the primordial atmosphere. Another proof of the primordial atmosphere composition theory is given by the atmosphere analysis of the farthest planets of the solar system thanks to a rover, and they have been found to be rich in hydrogen compounds. The latest proof is obtained by analyzing meteorites which contain all of the assumed substances although in a very low concentration. In any case scientists are sure that the primordial atmosphere contained no free oxygen (O_2)and therefore ozone could not exist either (formed by three oxygen atoms O_3, instead of two) and so the sun's ultraviolet rays that generally are blocked by a thick ozone layer, could reach the planet's surface in much larger quantities compared to today and help with their energy in the formation of primitive chemical compounds.

Miller's experiment

In 1952 the American professor Harold Clayton Urey, Nobel prize for chemistry in 1934, asked a young researcher, Stanley Lloyd Miller, to perform an experiment. Inside a glass bottle, Miller put some extremely hot water and in another one he put a Hydrogen mix (H_2). ammonia (NH_3) and methane (CH_4), which are all those gasses that combined with water vapour (H_2O) were thought to have created the primordial atmosphere. Hot water, which according to scientists was in the primitive ocean, created vapour that passed through a tube and went to the container that held the gas mix. Inside this container they generated 60.000-volt electric discharges so as to reproduce the probably very frequent and powerful storm phenomena which occurred at the time when the planet was forming. The experiment was carried out for a whole week and, in the end, they were amazed to see that in the water container there was a red-orange liquid which had many compounds, particularly some amino acids, that are the precursors of proteins that are the main components of every living being. Miller's experiment proved that from simple compounds, that were thought to be in the primordial atmosphere, there could be the formation of complex molecules, those that are found in organic compounds of all living organisms. So, the assumption was that the biologic precursors of living beings could have formed with a simple chemical synthesis process in a primitive atmosphere with frequent storm phenomena, heat and ultraviolet radiation. After that, rains would have carried these simple organic compounds to the sea, where they could subsequently change and grow. Anyway, creating amino acids in a laboratory doesn't mean that one is creating a living organism, but obviously this was a step forward in the abiotic (that is chemical) formation of living beings. From then on scientists performed many variations of Miller's experiment. It is possible to modify the gas mixture, change the temperature, use a different energy form from electric discharges, but the final result will always be the same: organic substance.

The primordial soup

Similar experiments to those done by Miller have definitely proved that in high temperature conditions, with frequent storms and intense ultraviolet rays, which are similar to the kind of conditions present on Venus nowadays, simple inorganic molecules can transform into more complex substances which we call organic because they are part of living organisms. These organic substances spread in the sea and reacted between themselves and with inorganic salts. Even small water basins such as lakes and lagoons offered the right conditions for these reactions to take place leading to the creation of certain compounds and increasing their concentration. Presumably the accumulation of organic substances was remarkable because neither decomposing microorganisms nor oxygen that could modify them existed. This is how a thick substance that scientists call "primordial soup", or "prebiotic soup", was created. Today this kind of substance would ferment and produce poisonous gasses with an acrid smell. In the sea some molecules will have found shelter from the ultraviolet rays that could destroy them, while others will have found great conditions to gather and bind to become more complex structures, forming the so called "polymers". Therefore, the sea is where the chemical evolution of organic substances will have continued.

Proteins' ancestors

In 1957 Sidney Walter Fox, an American biochemist, invented an experiment that proved how proteins could be formed outside of living beings starting from amino acids. Fox simply warmed an amino acid mix on a metal plaque. Right after it cooled off it was possible to notice some complex molecules, very similar to proteins, which he called proteinoids so as not to get them mixed up. At that point it was believed that these new molecules had formed from the union of amino acids freed of the water through its evaporation. The same reaction could have happened on the burning hot rocks of the Earth's crust as it had just solidified. The tides might have brought the primordial soup enriched with organic substances on land where water would have evaporated allowing the amino acid molecules to bind together. These protein precursors would then be carried once again to these a by the rains and the tidal ebb and flow.

The coacervates

Actually, we are still a long way away from what could be defined as a living organism also because nowadays it is surrounded by a wrap called "cellular membrane", that separates it from the outer world. Starting from these suppositions, Oparin assumed that in the hot primitive seas organic molecules would gather in small drops, similar to the actual cells. These small drops wrapped up in water molecules are called "coacervates" (from *cum acervo* = gather together) and were already known before Oparin's research. It has been proved that by placing certain proteins which bind well with it in the water, with certain temperature and acidity conditions, numerous small drops will form holding within them most of the larger molecules bound together. This can be explained by the existence of opposite sign electric charges on the proteins, which are then attracted to one another and gather polar molecules of water on the outer surface to form a membrane around the aggregation transforming it into a small drop. In 1958 the biochemist Sidney Walter Fox , who discovered protein precursors (proteinoids), made some proteinoids melt in hot salty water. When the solution cooled down, he noticed that there were thousands of small corpuscles similar to bacteria, that he called "microspheres". Through the microscope he saw that the small organic substance corpuscles had a double protection membrane. This membrane is not like a cellular membrane, but in certain conditions it acts as one. In fact, when placing them in solutions at higher or lower concentrations compared to their inner liquid, they shrink or swell exactly like living cells will do in the same situation. Furthermore, the microspheres are able to keep some molecules inside and let others out. These features make the microspheres look very much like living cells.

The living cell

In 1665, while observing a sliver of cork, Robert Hook discovered the cell, that extremely complex building block in multicellular beings. In fact, each one contains an incredible number of structures which can be observed through an electron microscope and each one of them performs specific biological and biochemical activities that make the cell into a perfectly organized living "factory". One can see the cell's evolution by watching unicellular organisms through the microscope. Within these cells one can see complex structures and organs which are similar to other multicellular organisms. As early as in 1940, following the invention of the electronic microscope, we knew of the existence of a much simpler form of life: the virus. In spite of its tiny size (only a few hundred millionths of a millimeter) and its simplicity compared to other unicellular organisms, it still has a nucleic acid. This nucleic acid known as DNA (deoxyribonucleic acid) is the basic building block of life and is responsible for the transmission of a being's hereditary features. Many viruses contain this nucleic acid that is the same DNA that transmits hereditary features in extremely complex beings such as man. Viruses obviously do not represent life as it was created on Earth because they are parasites that need other plant or animal cells to live on. Nevertheless, they show a connecting bridge between chemical and living substances. In 1967 two American scientists, Arthur Kronberg and Mehran Goulian, were able to synthesize, that is to produce artificially in a lab the DNA and joined it with protein molecules taken from a virus. As a result, they created a new virus that could reproduce itself. Thus they had reached the moment when life begins.

Energy for life

All living beings need an energy source to activate chemical reactions. For example, to light a match requires some kind of energy source to trigger the reaction. In this case one simply has to rub the top on a rough surface to produce heat and make it light. This is a case of "activation energy". Almost all the experiments we spoke about in the other chapters, used electric discharges, ultraviolet light and heat as energy sources. However, these energy sources can be harmful to living molecules, because too much heat can disintegrate the molecules and the coacervate in them, causing irreparable damage. The primordial earth didn't have a sufficiently thick and dense atmosphere, so ultraviolet radiations could have destroyed everything on the planet's surface. This blocked the evolution of organisms in the areas struck by this energy. Both electric discharges and ultraviolet rays were generally active in the atmosphere, while life began almost certainly in the water or in protected humid places. Therefore, other forms of energy must have helped the beginning of life on Earth. As time passed, the diluted hot soup that was found in the depressions of the Planet's surface, started to cool down and so the reactions become slower. At this point it is believed that new substances must have appeared which were able to help chemical reactions. These substances actually exist in every living organism: enzymes. Enzymes activate chemical reactions in living beings even at temperatures so low to be unable to supply the necessary energy to trigger them. Enzymes generally are formed by two parts: a protein part and a non-protein part. The protein part includes the so called "active site", meaning an area that adheres to the molecules on which it acts. The other non-protein part is often a vitamin and helps the protein part in its function. Enzymes can function also outside the living cell and this has been useful in multiple lab experiments. Today living beings tend to use sugars as a source of energy. Sugars or carbohydrates are molecules formed by carbon, oxygen and hydrogen and are synthesized by green plants. Did these substances exist in the primordial ocean? Melvin Calvin was able to answer this question with a new experiment. He struck different chemical compounds from those used in Miller's experiments, but which could have existed nonetheless in the primitive atmosphere, with high energy radiation. Thus, Calvin was able to obtain new molecules like simple sugars such as glucose. Thanks to specific enzymes, glucose and other similar sugars can create more complex structures such as starch and cellulose. Primordial oceans might have contained glucose molecules that could be usable as an energy source, but a lot of activation energy is needed to undo the ties among atoms of glucose and produce other energy. So presumably there was a similar mechanism to the one that happens in living beings nowadays, which means that they must bind some atoms to the molecule that must be divided so that they will attract electrons that will form a bond to weaken the molecular structure and break it down. In the case of glucose, the phosphorous groups (a group of phosphor, oxygen and hydrogen atoms) bind to a sugar molecule and transform it into glucose – phosphate, a weaker molecule than the initial one which consequently requires less activation energy to break down. ATP (acid adenosyntriphosphate) is a chemical compound that supplies not only energy to add phosphoric groups to glucose, but also the necessary phosphoric group to weaken the molecule.

Fermentation and respiration

ATP or adenosyntrophosphate is a complex molecule formed by a nitro compound called adenine, by one sugar with five carbon atoms called ribose and three phosphoric groups. The phosphoric groups were present in the Earth's crust as phosphates, that is, salts found in the rocks that the hot water of the primordial earth could have melted and carried to the sea. Adenine and ribose instead formed spontaneously and we have experimental proof of this. In 1960 the American biochemist Juan Oro made hydrocyanic acid (one of the products of Miller's experiment) react with ammonia thus obtaining adenine. In a further experiment, the biochemist added formaldehyde, a compound used as a disinfectant also known as formalin, obtaining ribose. As we said before, ATP has three phosphoric groups of which, when two are detached, will release a huge amount of energy. For this reason, the terminal binds of phosphoric groups are called "high energy" binds. When one of the phosphoric groups detaches from the ATP, what remains is called ADP (adenosyndiphosphate) because it has only two phosphoric groups. Thanks to a particular enzyme a phosphoric group can pass from an ATP molecule to a glucose one creating glucose –phosphate and ADP. ADP must transform into ATP again to become once again an active molecule. The transformation of ADP into ATP actually happens through chemical reactions that release energy. If these reactions happen without oxygen they are called fermentation, with oxygen instead they are called respiration. In the primitive atmosphere, however, there was no oxygen and so we can assume that in primitive heterotrophy something similar to fermentation took place. Today fermentation happens in many unicellular organisms but also in many complex organisms, including man, which allow cells to survive, even for short time, in the absence of oxygen. The best known fermentation reaction, from a chemical point of view, is the one that transforms grape juice into wine. A sweet liquid such as grape juice thanks to the presence of glucose turns into a watery solution of ethyl alcohol: wine. Most of the energy produced in this transformation is stored in the phosphoric binds of the ATP. The transformation of glucose into ethyl alcohol releases carbon dioxide, of which there was very little in the atmosphere in those times, but then it will become vital for the subsequent evolution of metabolism. The anaerobe primitive organisms needed glucose and other simple organic substances for vital processes that were found easily in the water at the time, storing the energy produced in ATP.

Protein or DNA?

Today, proteins are formed following instructions given by DNA (deoxyribonucleic acid) which in turn is synthesized by specific enzymes that are proteins. So, which came first, protein or DNA? Nucleic acids (DNA and RNA) are made up by nucleotides which are molecules formed by one sugar with 5 carbon atoms, one phosphoric acid molecule and a nitro base. Sugars with 5 atoms of carbon are ribose, which is found in the RNA (ribonucleic acid) and the deoxyribose in the DNA. Nitro bases are compounds with basic proprieties (which means that they can receive protons) that have nitro atoms and are: adenine, cytosine, guanine, thiamine, and uracil. We find the first four bases in the DNA, whereas in the RNA there are the first three and the … DNA contains the genetic information of all living organisms. Proteins are large molecules made up by 20 small molecules called amino acids. All living organisms have the same 20 amino acids, but they are arranged in different ways and this determines the different function for each protein. Proteins perform all of an organisms' vital functions, but the unique disposition of the amino acids within them is determined by a specific sequence of the nitro bases in the DNA. The RNA carries the message contained in the DNA to the cell area where protein is synthesized and will have to perform the synthesis as well. So, in a living being nucleic acids contain the information that is passed to the proteins that are in charge of many functions, including rebuilding these nucleic acids. It seems rather unlikely that two molecules which are so important for life appeared at the same time, but on the other hand it seems absurd to have one without the other. Some biologists among which Francis Crick and Leslie Orgel, each one of them on his own, assumed that there was a compound which could both duplicate without the help of proteins as well as catalyze each phase of the protein synthesis. This compound is supposed to be the RNA, because it is a simpler molecule compared to DNA and it is easier to synthesize. Subsequently, many studies confirmed this supposition, including the discovery of enzymes made of RNA so they understood that not all chemical reactions are performed by proteins. They even succeeded to modify some RNA molecules with enzyme functions to make them able to bind nucleotides of RNA itself. It still is not possible to prove for sure that the cells' ancestor had an RNA which could synthesize proteins, as well as duplicate and modify itself; but it is even more important to be able to understand how this RNA was born. We have already seen how adenine synthesis, one of the four nitrogen bases of DNA, was obtained in a lab experiment. Subsequently, other reactions among compounds that existed in this ancient atmosphere created also the other three nitrogen bases of nucleic acids.

The origin of photosynthesis

The first cells fed on organic substances in the primordial soup as its concentration gradually diminished. It is likely that the scarcity of energy resources imposed a selection. Some cells acquired the ability to feed on others, while other cells developed the ability to synthesize new organic substances by using energy from oxidation. Even today there still are prokaryotes (cells that don't have an actual nucleus but a nuclear "equivalent") that draw energy in this way to live, they are the so called chemosynthetic bacteria. Other cells instead could exploit energy from light to transform water and obtain the hydrogen necessary for photosynthes is (a reaction that can transform simple inorganic substances into organic ones such as carbohydrates thanks to the energy given by light). Living organisms that are able to perform photosynthesis however released simple oxygen which, thanks to its high affinity with organic substances, must have killed most primitive cell forms. Only those cells that could handle the increasing oxygen concentration survived. Subsequently some prokaryotes learned to use free oxygen as an oxidant for energy production. This is how respiration appeared bringing with it the great advantage of being a more efficient energy stocking method than fermentation and guaranteeing survival in the oxygen rich atmosphere.

The evolution of life

The first living organisms we have proof of thanks to fossils, are three and a half billion years old. They are the so called "stromatolytes"; structures made of several layers piled one on top of the other like a stack of pancakes. Today one can find organisms similar to the fossilized stromatolytes in Australia's hot seas. These present day stromatolytes are made up by the growth of bacteria communities and blue algae on which grains of sand deposit. Both bacteria and blue algae are prokaryote organisms, meaning that they do not have a differentiated nucleus, and therefore they are more primitive. But blue algae are able to perform photosynthesis and so we can believe that the first forms of life on Earth date even further back than 3 and a half billion years ago. We don't have eukaryote cell fossils over a billion years old, so we can assume that life's evolution in the first two or three billion years was very slow and affected only unicellular organisms. Instead, researchers believe that the step from unicellular to multicellular organisms happened very quickly, because the first fossils of complex organisms were already plentiful six hundred million years ago. Precisely six hundred million years ago the Precambrian Era finished and the Palaeozoic era began, of which we have sure fossil proof, when life existed only in the sea. Subsequently algae made their first attempts to colonize the land. After the appearance of the first plants on dry lands came the first herbivores, of which some subsequently evolved into carnivores.

Darwin’s theory

Pasteur’s simple and remarkable experiment put a definite end to all controversy among abiogenesis and biogenesis believers, but new questions about life’s origin arose. If to create a living being there had to be another living being, who created the first one? Furthermore if an organism creates only identical beings, how can it be that on Earth one can find such a large variety of living beings? Fortunately, the fossils that were found and Darwin’s theory on evolution are able to give some answers to these new questions. In fact, according to the English naturalist, in fact, fossils prove that ancient living organisms were different from present day ones and according to the evolution theory individuals within a same species that have minor differences from one another (such as in the case of man, where there are people with light blue eyes, others with brown ones etc..). When the surrounding environment changes, individuals that have better characteristics to adjust to new conditions, are those that will survive and generate new living beings with similar features to theirs, while others less adapted will be extinguished before being able to reproduce. Consequently, the better adapted individuals, through the natural selection of the best characteristics, will create individuals with even better ones. Darwin believed that all species alive nowadays descended from a single common ancestor and thanks to the natural selection they were able to create new organisms that adapted to the requirements of an ever changing environment.

The development of evolution theories

Towards the end the 19th century Weismann (1834 –1914) debunked Lamarck’s belief according to which features acquired during the course of a generation were transferable to descendents and identified in the mix of different heritages, as happens with sexual reproduction, which is the main cause of biological variability. Thus a relationship between evolution and genetics was established. The first genetic contributions to evolutionism came from two researchers, Hardy and Weinberg who in 1908, each one of them on his own, did a statistic study on gene distribution among a population and on the necessary conditions to avoid variations between one generation and the next one. The opposite conditions, in fact, can constitute a number of evolution factors such as: Gene mutations Advantage of individuals with a specific genetic makeup compared to others Numeric limitation of the population Gene migration between neighbouring populations Around 1920 some geneticists among whom Fisher, Wright and Haldane, did a statistic study of the evolution issue, including Hardy’s and Weinberg’s theories in a broader spectrum of causes that can modify genetic balances in a certain population and influence its evolution. Thus natural selection became an evolution factor and certain basic elements of Darwin’s theory were upheld. Mathematical models calculated by population genetics have been proved both in laboratory experiments as well as in different natural habitats thus providing final evidence.

A revolutionary bestseller. Charles Darwin introduced his famous theory in 1859 in a book whose title was “The origin of the species”. In this book Darwin expanded and modified Lamarck’s evolution theory by introducing the natural selection concept. This new theory fueled strong debates and harsh criticism, but the book was a real bestseller which was sold out within one day!

The first fossils

The oldest sedimentary rocks that we know of date back to 3 and a half billion years ago and they probably contain traces of life. These rocks were found in Canada, in South Africa and in Australia and have been given a precise age thanks to the radioisotope method. The chemical analysis of these rocks has revealed the presence of certain compounds that could be considered as "chemical fossils" because apparently they come exclusively from the metabolism of living beings. As a matter of fact, we cannot be 100% certain about them being so ancient because the rocks may have been contaminated subsequently by organic material which was produced much more recently.

Fossils in history. Man's fascination with fossils dates way back to the old ages. For instance, some shellfish fossils apparently were used as prehistoric jewels. Plinius believed that they had been created by lightning while Empedocles described some hippopotamus fossils that were found in Sicily as giant bones. Descriptions of these findings were gathered in the so called "gigantologies".

Fossils

We may say that every day, palaeontology researches, active worldwide, present some new discovery: it may be a new species, or totally unknown organisms, that are not represented in the modern flora and fauna, at times they are so "strange" that it is difficult to understand their anatomy and way of living, at times they show small "flashes" of day to day life, trapped forever in the geological layers. A general picture of the evolution of life on Earth is now quite clear, at least the general lines, however every new discovery forms a small piece of the puzzle of a picture that is becoming increasingly complete and greatly detailed. At times a small detail, preserved by chance in the sediments, that surfaces equally by chance, and is recognized, brings a fundamental contribution, and at times also generates a small "revolution" in the way of thinking and interpreting the long history of life on our Planet. This is the case, for example, of a recent discovery in Utah, that shows how a ferocious predator, Falcarius, a dinosaur covered with feathers, similar to a Velociraptor, evolved subsequently into an herbivorous dinosaur, approximately 125 million years ago, in a sort of "counter-evolution".

What is a fossil?

When an organism dies, the parts that normally are not affected by decomposition are the hard, mineralized parts: shells and exoskeletons, bones and teeth, scales and plates. When the soft tissues have dissolved, the mineralized parts may be transported by water or by gravity and accumulated in fossil deposits where they become part of the sediments that include them and may be preserved for millions of years. In these cases, complete skeletons are rarely found, and fossil remains are generally mixed together, often with organisms of different species. Furthermore, the mode of transportation, as in the case of river currents, may lead to a further selection of the remains, for example, only the larger sized fragments may be accumulated or, on the contrary, only the smaller fragments are transported. In exceptional cases, as, for example, in the case of a very rapid burial under a blanket of very fine sediments, with a poor availability of oxygen, the soft organic parts may be preserved, leaving an impression in the sediments which, at times, is incredibly clear cut and full of very fine details such as feathers, scales, bark, traces of skin. The Jurassic fossils, wonderfully preserved in their finest details, of the German areas of Holzmaden and Solnhofen, the extremely salty ancient lagoons which were real death "traps" for the organisms that were carried by the waves, are very famous. In other cases, the tissues may be dissolved in the water circulating in the sediments and may be replaced, molecule after molecule, with other minerals, as for example, calcites, surely the most diffused mineral, and also by silica, as in the case of silicified tree trunks and wood, that often form real "petrified forests" (as the fossil palms of the Sahara and the coniferous forest in Arizona), quartz or pyrites, and in this case real natural "jewels" are formed, as for example, the well-known piriticized ammonite fossils with their characteristic "metallic" appearance. At times this process also preserves the most minute details of the organism. The more interesting fossils are the ones that besides remaining whole, are found in their "living position", i.e. in the position they were living in, perhaps surprised by death as they carried out their activities: hunting, sleeping, in battle, giving birth. These fossils not only provide indications of the physiognomy, but also important proof of the environment they lived in, their lifestyle and their interaction with other living creatures. This usually occurs if the organism dies due to catastrophic events that provoke an immediate burial : as for example a volcanic eruption that covers an area with ashes, a landslide that immediately buries all that it finds in its way, a flood or an accidental fall into natural "traps", such as lakes, natural tar deposits (as the skeleton of the Sabre Tooth Tiger at Rancho La Brea near Los Angeles), wells or crevasses, or in the case of more recent organisms, ice or permafrost, as in the case of the Siberian mammoths. As far as smaller organisms are concerned, as for example insects, even the spilling of resin on the trunk of a coniferous tree may be the cause of a dramatic event, leading to a rapid death and instant fossilization: this is the case of the small arthropods that have been magnificently preserved in amber, a natural fossil resin. The state of conservation of these small fossils provided the initial idea of Crichton's famous book, in which the blood taken from the stomach of a mosquito fossilized in amber provides the possibility of reconstructing the DNA of the future guests of the Jurassic Park. Other fossils are not real organisms, but only the traces of their activities: tracks of animal paws or of the bodies of animals that crept on the ground, dens, excretion. In many cases it has been possible to find the origins or the "culprit", but in the case of some of the more ancient fossils, they are the only traces of organisms that are still unknown at the present date.

The beginning of life

The following era, the Mesozoic Era, is characterized by the extraordinary evolution of reptiles, the undisputed masters of this Era. Reptiles evolved from amphibians, with the "invention" of the egg, that made them independent from water also for reproduction. Some reptiles returned to the water and became good swimmers. Most reptiles were herbivorous, however many carnivorous species evolved. Some, like the feathered dinosaur of the Falcarius genus, which has been recently the subject of much attention, returned to an herbivorous style of life. During the Mesozoic Era also some particular reptiles developed, perhaps they were hot-blooded, their size was small, they were ungainly and they swayed as they walked. From these, towards the end of the Jurassic Period, mammals evolved. Among the reptiles, those which stimulate our fantasy most are the dinosaurs, whose name means “terrible reptile”, even though only some of them were really terrible. In fact, they occupied all the ecological niches with species of all sizes and were mostly herbivorous. More precisely, up to the end of the Jurassic Period they were mostly small, and their gigantic size that fascinates us so, developed in the Cretaceous Period, not long before the mass extinction cancelled most of the species. The first flying reptiles appeared at the end of the Triassic Period, approximately 70 million years before real birds, and, however they were not their ancestors. Birds appeared approximately 140-150 million years ago, at the end of the Jurassic Period; they evolved from a class of reptiles known as Ornithischian dinosaurs (“bird-hipped”, to which the Stegosaurus and Triceratops belong). The extremely famous Archaeopteryx, found in a cave in southern Germany, is one of the first representatives to be classified as a bird due to the extraordinary preservation, in a very fine grain limestone, of the traces of the extremely thin structures of the feathers. Researchers are still discussing the appearance of the attitude to fly and the role of feathers: recent discoveries, in fact, in China, in Utah and in Alaska, show the existence of many dinosaurs covered with feathers which were quite unsuited to fly, like the Beipiaosaurus, the Falcarius or the Troodon. The feathers seem to have appeared much before the possibility of flying in the sky. Insects, that were less attractive than the reptiles, were killed by the dozen in the Paleozoic extinction. These diversified remarkably during the Mesozoic Era. The role of insects became very important at the end of the Mesozoic Era (in the Cretaceous Period, 100 million years ago), with the appearance of flowering plants (angiosperms) that further enriched the scenario of life, making the terrestrial environment increasingly similar to what is known to us. In the Cretaceous-Tertiary boundary, 65 million years ago, another great mass extinction took place, which drastically reduced the number of living species, as had already occurred at the end of the Paleozoic Era. These are the two best known extinctions, and the most drastic, but other episodes of this kind were repeated several times during the course of the history of the Earth. With regard to the possible causes of this extinction, many theories have been proposed, some are rather fanciful (like the one that states that the great quantity of excretion produced by the large herbivorous dinosaurs caused an increase in the concentration of methane in the atmosphere that poisoned most of the living creatures); among the more reliable theories, there is the hypothesis of a meteorite that fell in the Gulf of Mexico (the Chicxulub meteorite in Yucatan) whose dusts produced by the impact, caused the opacification of the atmosphere, with a consequent drop in the temperatures and decrease of photosynthesis, thus drastically decreasing the food available for the herbivorous animals and the death of most of the living creatures. The crater of the impact is no longer visible because it has been buried by tertiary sediments, but proof of the asteroid’s fall lies in the presence of anomalous quantities of iridium in the geological levels of this age worldwide.

The following Era, the Cenozoic Era, was the era of mammals. After the disappearance of the most powerful antagonists the reptiles, mammals experienced an enormous diversification of species during the Cenozoic Era. In fact, during the Mesozoic Era, due to the competition with the stronger reptiles, mammals remained small and not very striking, but during the 10-million-year period after the mass extinction, approximately 130 kinds of mammals appeared, more than the existing amount up to then!

The history of life

The birth of life on the Earth required a very long “incubation” period. In a period between 4.5 to 3.8 billion years ago, the bases were set for the formation of the “ingredients” that led to the birth of the first cells. This remote world can now be found in one of the most inhospitable areas of the Earth: in the sources of warm water and in the volcanic fumaroles in the oceanic ridges. However, there are no “records” of the very first phases of life in the geological layers. The most ancient fossils, dating back 3.5 billion years, were found in sedimentary rocks in North-Western Australia. These are unicellular organisms, similar to bacteria, extremely thin filaments whose shape is very similar to the present-day organisms known as cyanobacteria or blue-green algae (these are prokaryote organisms whose cells do not have a nucleus nor other internal organules). The study of the sediments in which these were found, enables us to establish that they lived in a marine environment with shallow, warm waters, perhaps a lagoon. The entire Archean Eon, the first and most ancient geological period, was dominated by bacteria: for a billion years, no other type of fossils has been found. The following Eon, the Proterozoic Eon, stretched over a period of about 2 billion years. The study of fossils and rocks of this Eon shows the appearance of organisms, the stromatolites, colonies of cyanobacteria, capable of carrying out photosynthesis, that modified the composition of the Earth’s atmosphere, enriching it with oxygen and preparing the subsequent step in the evolution of life. Approximately 1.4 billion years ago, a remarkable step was made in life, with the appearance of eukaryote cells, which were characterized by a nucleus and internal organules, similar to the cells that form all the superior living organisms, including man – however, we must wait for 300 million years more to see multiple-cell organisms appear on the Earth. Life continued to evolve very slowly, characterized by simple organisms, with soft bodies, without shells, teeth, skeletons or carapaces – structures that appeared starting from the next Eon, the Phanerozoic Eon. The great revolution took place at the beginning of the Paleozoic Era, that opens with the Cambrian period, 540 million years ago: it was here that what the paleontologists call the “Cambrian explosion” took place. Almost suddenly the evolution of life accelerated enormously with the appearance of over 100 phyla (a phylum is the larger systemic subdivision of the animal kingdom): to properly understand the real explosion of new forms of life, just think that today there are about 30. Most of the present living organisms descend from the organisms of the Cambrian Period. However, many organisms became extinct without leaving any present descendents. Many were strange, bizarre animals from our point of view, that do not have an equivalent in the present animal kingdom, and for this reason it is difficult to understand their way of moving, the environment and the living conditions, and in some cases even to identify the different parts of the body. The Burgess site, in the Rocky Mountains, in British Columbia, is famous for having disclosed the most vast and bizarre samples of the strange creatures of the Cambrian Period, so strange that some experts have hypothesized that these may the results of a period of evolutive "experiments", in which only those that were most "successful" had descendents. The most characteristic and well-known fossils of the Cambrian Period, of creatures that are extinct today, are the Trilobites (the present organisms that are most similar to these strange creatures are the horseshoe crabs). During the Paleozoic Era, which lasted approximately 300 million years, fish (approximately 440 million years ago), insects (approximately 380 million years ago), amphibians (400 million years ago) and reptiles (little over 350 million years ago) appeared, and towards the end also the precursors of mammals appeared. Towards the end of this era, during the Carboniferous Period, luxuriant forests covered vast areas of our planet and gave origin to the principal carbon deposits that are used today. The end of this Era, which was so full of life, however, was marked by the greatest mass extinction of all times, in which 80-90% of all the species disappeared, the causes of which are still unknown.

How are they reconstructed?

Paleontologists carry out a patient investigating task, in which even the smallest element may be fundamental for the reconstruction of the types and habits of the life of a creature of the past, at times it can be a very small bone fragment. Generally, even in paleontology, as in geology, the principle of actualism is used, in which it is hypothesized that similar organs (a paw, a skull, a backbone) in organisms of the present day and of the past, had the same purpose and worked in the same way. For this reason, the reconstruction of fossil organisms is carried out trying to compare them with present day organisms that are the most similar to the specimen that is being examined. At present the use of computers and new biomechanical and bio-engineering technologies enable reconstructions that were unheard of up to only a few decades ago. Using bone-casts, for example, it is possible to reconstruct the insertions of tendons and muscles, it is possible to determine the development and the arrangement of the mass of muscles, in other words, it is possible to cover the skeletons with muscles and flesh, creating reconstructions of the animals in "flesh and bone". If, as in some lucky cases, preserved traces of delicate skin or cartilage tissues are found, it is possible to add other details to the "model" such as crests and bone, membrane or cartilage protuberances, the appearance of the skin, either smooth or wrinkled or with scales, the presence of hairs and feathers. In some cases, due to the discovery of traces of the cerebral cortex in the skull it has been possible to reconstruct the size of the brain, and in some exceptional cases, to reconstruct the internal organs. In order to reconstruct and recognize a species, however, it is not necessary to find a complete individual, the characteristics of the species are patiently reconstructed using the parts of various individuals that have been preserved better, as in a complicated puzzle. Naturally when complete individuals are found, which are perfectly preserved, the information provided by these is of particular importance because it is possible to verify the model. However it may occur that, especially for very ancient organisms, belonging to extinct phyla, as for example the bizarre animals of the Burgess fauna, it is not possible to compare these specimens with analogous organisms of the present: in this case the principle of adaptive convergence will be used, based on the assumption that different organisms that live in the same environment eventually have a similar morphology, thus it will become important to understand what environment the discovered fossil lived in.

Paleoecology

Having reconstructed the physiognomy of living beings in the past, it is also important to reconstruct their environment and lifestyle. The sediments in which fossil remains are found often provide important indications with regard to the geography of the environment in which the organisms lived, in particular for those organisms that are found in their "living position", as they died and became fossilized, and therefore in their natural environment. Also, the association with other fossil species can help us to understand in what type of environment they lived. Think, for example, of the typical associations of organisms living on a coral reef. The study of the anatomy can provide further important indications: for example, it was hypothesized that the large dinosaurs lived in water in order to support the large weight of their body and that their long neck was used to keep their head effortlessly out of the water. Other researchers, instead, hypothesized that these animals were the equivalent of giraffes today and that their long neck was necessary to reach the leaves on the higher branches of the trees that were isolated and rather bare, in an environment that was similar to the African Savannah today. Finding remains of food in the stomach of some fossils or traces of predation in others, such as signs of bites on the bones, but also the type and wearing of their teeth, help to understand the animal's diet. The study of any wounds, fractures, traces of bone disease such as bone tuberculosis, arthrosis, infections and other degenerative diseases of the skeletal system, help to understand for example, what animals our fossil had to confront, if it was subjected to frequent aggressions, if it faced mortal duels with its opponents or only "skirmishes" that left scars, which healed in time, how long they could live…For example, many Jurassic sauropods show signs of bone degeneration, probably due to the weight of the large mass that their skeleton had to support.

The dinosaurs' adapting capacity

In Alaska and in South Australia (which at the time was joined with Antarctica) fossils of Cretaceous dinosaurs that lived in territories situated beyond the Antarctic Circle were found. At the time, the climate was not as severe as it is at present, but due to the long Polar nights, the temperatures must have been quite low in the season of low insolation, probably only a few degrees. Some researchers, when faced with these exceptional findings of animals that were traditionally believed to be cold blooded in an environment with low temperatures, hypothesized that they ventured in long migrations during the colder periods, or that they went into lethargy, somewhat like tortoises and amphibians in our times. However, a careful morphological study showed that the dinosaurs in Alaska, plumed predators (but unable to fly) which were 2-3 m long, called Troodons, and the dinosaurs in Antarctica, hypsilophodontid dinosaurs of the Leaellynasaura genus, had unusually large eyes. A particularly well-preserved specimen of Leaellynasaura in which a natural cast of the brain is visible, shows that the eye lobes were also very developed. This could seem to be an adaptation to the long months of semi-darkness in the regions beyond the polar circles, which would therefore exclude the hypothesis of migration. The capacity of nocturnal sight and the consequent possibility of hunting in the darkness too, lead to the belief that these animals were active also during the months in which there was a poor amount of light, which would therefore exclude even the hypothesis of lethargy. However, activity during the colder months necessarily implies another characteristic: homeothermy, i.e. the capacity to regulate body temperature; in other words, dinosaurs, or at least some of them, must have been warm blooded organisms. This had already been hypothesized in order to explain the ability to move and the possibility of dispersing heat in animals with a gigantic mass, however these discoveries are probably the final proof. It is also curious, that at the opposite poles of the Earth animals evolved with physical characteristics that were so similar, a sign of the adaptation to the environment they lived in. Curiously, it seems that in the apparently more hostile environment, dinosaurs survived longer after the extinction at the end of the Cretaceous Period – perhaps because they had a better capacity to adapt, as they were used to living in a severe and difficult environment.

Stories of daily living

The study of fossils, organisms that died millions of years ago, sometimes offers incredible surprises with the discovery of organisms struck by death during their daily activities. These findings are extremely precious for the reconstruction of the way of life, they offer us the possibility to observe, in a surprisingly vivid manner, some scenes of daily living, at times cruel, at times gentle and moving. In a cave in Mount Generoso, near the frontier between Italy and Switzerland, near Chiasso, a cave was discovered in which a group of cave-bears had hibernated: it is possible to see the “nests” these large animals had dug in order to be more comfortable and also traces of predation on their “room-mates” that had died during the winter, or perhaps due to a too deep sleep, small skeletons of cubs that perhaps had died at the time of their birth, which took place, as for modern-day bears, during the winter sleep. Nests and eggs of reptiles have sometimes been found near to each other, to testify a kind of nursery, at times near the skeletons of cubs. The presence, that is still not completely confirmed, of adult individuals near the nests, shows that also large reptiles dedicated parental care to their offspring. In Holzmaden, in Germany, a perfectly preserved skeleton of a female **ichthyosaurus** (*Stenopterygius*) carrying embryos was found, and she was surrounded by other cubs who had already been born: an unlucky prehistoric mother who died giving birth to her cubs. In the Gobi Desert a specimen of *Baluchiterium* was discovered, a mammal that was over 5 m tall of the Oligocene Epoch: from its position, standing on its legs, it is supposed that it must have fallen into a thick muddy deposit from which it tried to free itself in vain. At Rancho La Brea, near Los Angeles in California, during the Pliocene Epoch there were tar lakes in which numerous animals got trapped, probably as they fled from some predator. From the black mass today, perfectly preserved skeletons of sabre-toothed tigers (Smilodon, the gruff Diego in the computer-animated film “Ice Age”) and gigantic quaternary elephants from North America, *Archidiskodon imperator*, have emerged. In Bereskova, in Siberia, a perfectly preserved mammoth was found trapped in the frozen ground, between its teeth there were traces of his last meal – 25,000 years ago the animal had fallen into a crevasse in the ice and remained trapped within, due to the severe fractures caused by its fall. On the shell of a Placenticeras ammonite, of the Cretaceous Period, traces of the teeth of a large sea predator, the Mosasaurus, were found. Evidently ammonites were one of their favourite foods, in fact, in the stomach of these enormous sea reptiles numerous remains of these cephalopods have been found. The Eocene deposit of Mount Bolca, near Verona, is famous for the splendid fish specimens. These instead, tell the story of a terrible catastrophe, an eruption that heated the water of an internal lagoon near a coral barrier, causing the sudden death of thousands of organisms. One of the latest discoveries of these scenes of life of the past was brought to us, a few months ago, from China. In sediments dating back 130 million years, the skeleton of a mammal was found, the *Rapenomamus robustus*, the size approximately of a big cat, about sixty centimetres long, weighing approximately 7 kg, in whose stomach, the skeleton of about 13 cm of a *Psittacosaurus* dinosaur cub was found. The Psittacosaurus dinosaur was an herbivorous dinosaur, about two metres long when fully grown, with a robust beak, similar to that of a parrot. The well-fed and full up predator was surprised by a volcanic eruption that covered it with ashes together with its small victim. Besides being a proof of life, these fossils show an ecological picture that is very different from the former theories that were hypothesized. It had always been believed in fact that the mammals in the entire Mesozoic Era had been timid and shy, always escaping the terrible predator reptiles (some have hypothesized that our innate fear of snakes derives from this ancestral memory…). However, this finding proves that predators were to be found also among mammals. The discovery, near an even larger relative, the *Rapenomamus giganteus*, that weighed about twice its weight and presumably had similar predatory habits, indicates that competition with mammals was not always to the disadvantage of the latter. Paleontology, therefore, even though it is a study of the organisms of the past, enables us to reconstruct scenarios of natural environments with their inhabitants, their struggle for life and their habits in a clear and at times surprising manner. Each one of these scenarios then fit into the large complex puzzle of the history of life on the Earth, enabling us, with every new discovery, to understand our planet better.

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