Fossils

Fossils and palaeontology

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 a 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 Solnhoven, 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 life-style 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 a 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

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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 life-style. 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 a 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.