CAVES

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CAVES

Introduction

Interesting landscapes are not only found on the Earth's surface, but also in the depths of the Earth. We are speaking of underground cavities, caves, that are very important for various aspects. All the changes that take place around the cave, such as tectonic movements, climatic changes, changes in the topography, cause changes inside the karst systems, that tend to find a new balance with the new situation. Therefore, caves are not characterized by stable features, that do not change in time and space; it must always be borne in mind that they were formed in topographic and climatic situations that were greatly different from the current situation. The study of the sediments that are carried inside the caves, with their characteristics, their composition, their contents in fossils, enables us to reconstruct the variations in the environment and in the climate on the Earth's surface. Karst aquifers account for a very important source of water in a large number of regions of the Earth: in fact karst areas are, by nature, without water on the surface and all the water circulation takes place underground. However these resources are very delicate to use and to protect. In fact karst aquifers, due to some of their characteristics, are particularly vulnerable to pollution and excessive exploitation.

Caves knowledge

Most rocks have pores and cavities within them. Generally, however, these are not large enough for a person to explore. Caves are cavities or hollow spaces inside a rocky mass that are large enough for a person to explore. There are many types of caves formed through different processes: some are small, and it is difficult for man to penetrate into; others, on the contrary, stretch underground for tens or hundreds of kilometres, reaching depths of over 2,000 m. Formation processes control lenght, development and shape of a cave, and also the difficulties that will arise when exploring them. Most of the longest and deepest caves do not consist in an isolated cavity, but they form a system, which at times may be very complex, made of rooms, sinkholes, shafts, meanders, canyons, interconnecting galleries, which are arranged to form a system or karst complex.

Large quantities of underground water move through karst systems, caves may therefore be classified in different sub-areas, i.e. occupied by air and completely dry or scoured by streams, they may be flooded at times, or permanently invaded by fresh and salt water.

Processes to form a void

There are many mechanisms leading to the formation of cavities and voids underground. Some caves are classified as "primary" because they are generated at the same time as the rocks containing them, others instead form subsequently, due to rock weathering that modify their original characteristics.

Primary caves

- formed by biologic processes (in coral reefs);
- formed by lava flows;
- formed by cooling processes.

Secondary caves

- eolian caves;
- sea caves;
- tectonic caves;
- karst caves.

First a void and then the rock

Caves formed by biologic processes. Among the primary caves, the most widespread are caves forming when corals and coralline algae grow forming encrusted coral reefs: the growth of these organisms is neither uniform nor homogeneous and voids of various shapes and sizes are created, which are often large enough for a man to visit. All those who have done scuba-diving near a coral reef must have observed these caves. Most are practically anfractuosities or recesses and, at times, small irregularly shaped channels or galleries are formed, through which it is possible to cross the reef from one side to the other. The entrances of the galleries may be at different levels (e.g. the Dahab Blue Hole in the Red Sea belongs to this category – as we will see later, the term "blue hole" is used in an improper manner in this case), furthermore these cavities are rarely larger than a few tens of metres. The presence of large size cavities in fossil reefs, in sub-aerial continental environments is very rare. During the transformation of the reef into rocks, in fact, the primary cavities are generally filled with sediments that fossilize them completely.
Volcanic caves. Primary caves can form during the cooling process of a lava flow. Volcanic caves are created when a lava flow, generally basaltic lava that is very fluid, cools on the surface forming a solid "crust" underneath which liquid lava continues flowing. At the end of the eruption lava stops flowing outwards, the last emissions flow underneath the solidified crust and come out at the base of the lava flow, leaving channels that are real tunnels with a circular or elliptical shaped cross section.
Lava tubes can reach remarkable lengths, as in the case of the Kazumura Cave in Hawaii, that is over 60 km long, with depth of over 1100 m. These are prevalently horizontal caves, with a very modest slope, however, when they stretch over long distances, they can reach remarkable depths.
Rocks are generally very dark in colour, with a vitreous appearance due to the rapid cooling, near the walls characteristic steps form due to a supra-excavation that lava flows carries out on the floor of the caves, and also features similar to stalactites and stalagmites are formed due to the dripping of lava as it cools. In fact, on the ceiling the heat released by the cooling flow causes a

new melting process of the rock, which drips downwards solidifying in stalactites-like features (whose origin however is completely different) while the drops falling on the floor form curious slender and contorted “stalagmites” (similar to the towers built by children on the beach, with droplets of sand and water).
These caves, due to the particular mechanism by which they are formed, are always very close to the surface: their ceiling often crumbles and fall, and therefore lava tubes are scattered with external pits, in the form of small shafts, which often have a circular section, known as sky-lights. This type of caves always forms in continental environments, and therefore in sub-aerial conditions. If a lava flow comes into contact with sea water, the violent cooling that follows gives rise to explosions that shatter the rock and the formation of lava tubes stops. For different reasons, however, the sea can subsequently flood part of these caves when these form near the coast as, for example, in the Canaries, on Lanzarote island, in the complex Atlantida system, which has a flooded part that is over 1600 m long. Here, the pressure created by water occupying the galleries helps preserving the tunnels. These are on the contrary very fragile on the surface due to the short thickness of the ceiling and are subjected to rapid degradation due to the caving in of the vault.
Caves formed by cooling. Much smaller size primary caves in volcanic rocks can also form in particular effusive rocks, i.e. basalts, when a rapid cooling creates a “column” like structure, with the formation of large columns several metres high, characterized by a hexagonal cross-section. Collapses along the cooling fissures may give origin to suggestive cavities, specially near the coast where collapses are facilitated by the wave action: a very well-known example is the famous Fingal’s cave on the Island of Staffa in Scotland.

First the rock and then a void

Unlike primary caves formed at the same time as the rock in which they are formed, the origins of secondary caves imply different processes acting on rocks that already exist. At times these processes take place many millions or tens of millions of years after the formation of the rock.
Eolian cave. These caves do not have a great lenght, no more than a few metres, and are formed by the abrasive action of the wind and due to particular weathering processes in arid and desert zones, or near the coasts on tender rocks that are particularly flaky, such as poorly cemented sandstone or rocks such as granite, particularly subjected to weathering processes due to hydrolysis (which weathers feldspathic minerals forming clay and transforming the rock into a sand made of quartz crystals). Cavities in this category include, for example, the famous “tafoni” in Sardinia. Due to their origin and due to the nature of the rocks containing them, these caves generally have short lives and are not very interesting for both cavers and speleologists.
Tectonic caves. A large number of secondary caves have a tectonic origin, due to collapses and breaking down along joints, fractures or faults that weaken a rock. Faults and fractures form due to the effect of tectonic deformations affecting rocks deeply buried inside the Earth’s crust: when rocks are uncovered by erosion, the presence of large hollow spaces or high walls determines the opening

of breaking surfaces, with the consequent collapse of blocks that can be of a remarkable size. This process can lead to the formation of large caves that are however rarely very deep and long. These caves are characterized by typical geometric squared walls formed along the surface of the fractures or fault that determined the break-down, and large heaps of crumbled material and fallen blocks on the floor. These caves often are large, high and narrow rooms. These caves do not form in underwater environments where the water pressure decreases the possibility of break-down and detachment of blocks, but these types of cavities are commonly found near large mountain walls, often at the base of cliffs along the coast line, where the action of waves can contribute to break-down processes and water can easily erode and take away the material from the floor. These caves may form in any type of rock and generally they are not of any particular speleological interest.
Sea caves. All sea caves are secondary caves. It must be pointed out that caves of marine origin are relatively few and generally they are not very long or deep, their length being not much more than a few tens of metres, and their depth being quite modest, not much more than a few metres. Caves occupied by sea water, but whose development is more complex and whole depth is greater, are, as will be seen hereunder, of another origin, even though the sea that invades them can contribute to modify them in various ways. Sea caves, in the strict sense, are created by the mechanical action of waves that shatter the rock with their striking force, by the erosion carried out by the debris they carry, and mainly by the chemical corrosive action that sea water, specially when mixed with meteoric waters, can carry out on rock, together with the biological action of sea organisms. Generally, these cavities are only a few metres or tens of metres in size, even though at times they may have large portals at their opening. They tend to have a sub-horizontal stretching and form a few metres above or below the water surface. The origin of notches or "solchi di battente" is similar to that of sea caves and can often be a continuation of the same. These are a typical coastal formation and are often clearly visible, like a marked indentation at the base of walls and cliffs, at sea level. The presence of sea caves at levels that differ from the present sea level can be a precious instrument to reconstruct the evolution of sea level oscillations. Sea caves of this type can form in different types of rock, however their size grows to an interesting one only in rocks that are particularly sensitive to the corrosive action of sea water, such as carbonatic rocks (which are described in greater detail in the next chapter). Also sea caves can actually be classified in the large category of karst caves.

How caves form

Most of the longest and deepest caves in the world are formed by chemical corrosion processes in rocks particularly water-soluble thanks to their mineral composition. These corrosion processes are known as karst processes.
Water and rock. All minerals are more or less soluble in water, but some are much more soluble than others, and require a very short time span to dissolve (in a geological sense, naturally), while others require much longer periods of time, and are therefore considered practically insoluble. Rocks made of the most soluble minerals are the ones in which karst features develop more

easily, even though the karst process is a complex one in which rock composition is only one of the many factors involved in the development of the phenomenon.

When studying the solubility of the main minerals forming the most diffused rocks of the Earth's surface, it can be observed how the solubility of the different minerals varies greatly. For this reason, rocks such as rock salt (made of sodium chloride NaCl, or halite), one of the most water-soluble minerals, are practically absent in humid climates as they dissolve rapidly. In quartzite rocks, made of quartz (SiO_2), one of the minerals most resistant to weathering, karst features may develop only in particular climatic conditions and in areas in which waters had a very long time, i.e. millions of years, to dissolve the rocks (e.g. the Amazon Tepuy quartzite cave systems).

Not only water. In nature, however, things are not that simple. In fact, natural waters are never pure waters, but they are water solutions containing various ions dissolved within them that can increase the aggressiveness and corrosive action on some types of rocks, thus complicating the simple dissolution reaction. The process is well known to those who have to clean the bathroom at home. In order to remove the calcareous incrustations that ruin all the bathroom fittings (geologically speaking, these are calcium carbonate crystals, $CaCO_3$, calcite; rocks that prevalently contain calcite are called limestones), we use aqueous solutions enriched with acids that increase their corrosive streght, such as hydrochloric acid (also known to housewives as muriatic acid), or acetic acid, that are present in many house-cleaning products. These substances make the removal of incrustations easier in two ways: on one hand they increase the solubility of calcite, on the other they greatly accelerate the speed of reaction (that is very rapid and violent, in fact bubbles form because of gases freed when these products are used). Even pure water could obtain the same results, but the time taken would be decidedly beyond the scale of human observation…. and by far too long for the housewives' patience! In fact natural water behaves in the same way as the detergents, but since the acid solution is much more diluted and with much weaker acids, chemical reactions are much slower, at least on a human-observation scale. Nature, unlike housewives, has no hurry, and the results are even more spectacular!

Carbon dioxide: allied with karst

Among the substances that can increase the corrosive power of natural water, carbon dioxide (CO_2) has the most important role. It is already present in meteoric waters, as it is one of the gases of the atmosphere, however its percentages are very low (0.03 atm). Its concentration increases greatly in waters that cross through thick layers of soil covered with dense vegetation. Enrichment with CO_2 and other organic acids produced by vegetation and biological activity of water coming into contact with rock can lead to a remarkable increase in the solubility of minerals like calcite (calcium carbonate, $CaCO_3$) and dolomite (calcium carbonate and magnesium, $CaMg(CO_3)_2$, which increases from 10-12 mg/l to 200-400 mg/l. Other minerals, such as quartz or rock salt are on the contrary insensitive to the presence of CO_2 in the water they come into contact with, and their solubility therefore remains unchanged.

The dissolution reaction of calcium carbonate responsible for the formation of most caves is: $CaCO_3 + CO_2 + H_2O = Ca_2^+ + 2HCO_3^-$
In the case of dolomite, the reaction is very similar:
$CaMg(CO_3)_2 + 2CO_2 + 2H_2O = Ca_2^+ + Mg_2^+ + 4HCO_3^-$

Rocks that are most suited

Calcite and dolomite (calcium carbonate and calcium carbonate and magnesium, respectively) are minerals that are very abundant on the Earth’s surface and are the main constituents of particular sedimentary rocks, known as carbonatic rocks, such as limestone and dolomite rocks. These rocks are not the most prone to karstification (gypsum and rock salt are much more soluble), however they are the most common rocks in which karstification processes take place, the most widespread and the ones able to support the existence of large volume rooms and galleries without collapsing, unlike other “weaker” rocks. For this reason the longest and deepest caves on the planet are to be found in this type of rocks. (In dolomite rocks, that are actually as soluble as calcite, the dissolving reaction is much slower and as a residue of the reaction, the rock tends to produce a sand that fills the fissures where water circulates, and this finally slows karstification down. Therefore karstification in dolomite rocks is a much less important process than in limestone rocks).

Underground water

Water commonly found underground creating caves is mainly of meteoric origin, however other kinds of water may be mixed to it in various ways. The following can be found: “Connate” water, i.e. ancient water that was trapped in a sedimentary rock during its formation, and generally very rich in salts, and therefore potentially very aggressive; deep so-called “juvenile” water, produced by magma activity, often very hot and aggressive; or meteoric water that reaches the deeper layers where it is heated and enriched with salts and acids and then comes out at the surface again through faults, generally with the characteristics of hydrothermal water. These are almost always very aggressive waters and generally their temperature is high. When these deep waters come into contact with the rock, they give rise to very rapid and intense dissolution processes, known as hyperkarst processes creating particular caves, called hypogenic caves (i.e. generated from the deep) as for example the Grotta Giusti cave near Pistoia.

Hot waters, cold waters

The possibilty of water to corrode the rocks it comes into contact with depends on the chemical composition of both water and minerals building rocks. However other factors intervene to make reactions complex. In particular, temperature is a fundamental factor that acts in two ways that are apparently in contrast one with the other. In fact, the quantity of CO_2 that can dissolve in water depends on temperature – (at the same pressure) the lower the temperature, the greater the amount of CO_2 that can dissolve (also pressure is important, but as it can be affected by relatively small variations at normal environmental conditions, it is neglected for the sake of simplicity). How temperature influences the quantity of CO_2 dissolved in water can easily be seen when a bottle of carbonated mineral water is opened: the action may happen quite peacefully if the bottle has just been taken from the refrigerator, however it can have explosive results if the operation is carried out on the same bottle that has been left inside a car parked in the sun. In fact hot water cannot contain the same amount of CO_2 as cold water, and the excess amount is freed in the form of bubbles as soon as it is given the chance (i.e. when we remove the cap, decreasing pressure). This theoretically tends to favour karst processes in mountain areas at high altitudes, where water temperatures are low and therefore can contain a greater quantity of CO_2. However two other contrary factors must be considered: first the speed of reaction is higher when temperature is higher, and second at high temperatures vegetation, and as a consequence the production of CO_2 in the soil are much greater, thus, in practice, making warm waters much more aggressive than cold ones (furthermore the content of CO_2 in the atmosphere decreases with altitude, therefore mountain waters, although they are colder, have a lower content of CO_2). Once again boring domestic chores offer an occasion for an experiment: if we heat the products used for cleaning, the reaction, and therefore the action of removing the calcareous incrustations, is even more rapid (this operation is not really advisable because detergents also contain other substances that can release toxic and irritating vapours when heated – therefore it's best to carry out this experiment with a glass of hot vinegar, as our wise grandmothers used to do!). It is of fundamental importance, when studying karstification processes, to know the diagram that shows the solubility of calcite at different temperatures and with different quantities of dissolved CO_2.

As a consequence of this, therefore, areas that are most favourable for karstification are those in which, besides an abundance of carbonatic rocks there is abundance of water with a large amount of CO_2 and at a high temperature. These conditions are present in the intertropical zone. Most cavities in Italy, in fact, are the relicts of caves that formed when climate was humid tropical even at our latitudes.

Complicated reactions. Another factor able increase the dissolution of calcite and dolomite in water solutions is the presence of particular ions, such as chlorine and magnesium, sulphurs or sulphates. For this reason, sea water and even more, sea water mixed with fresh water form a very aggressive mixture. Aggressive mixtures also originate when waters with different chemical properties mix. Corrosion due to water mixing, or Boegli's effect, named after the speleologist who discovered this phenomenon, is responsible for the formation of underground galleries and conduits. In fact aggressiveness would otherwise tend to wear out as water corrodes rocks thus increasing its calcium carbonate content, but can be "renewed" by these waters. A proof of this effect is witnessed by those privileged cave-divers when they penetrate karst conduits that have been widened by sea water and observe the gradual widening of the conduits near the area in which sea water and fresh water mix. Or when, in the presence of fresh water, a sudden widening can be observed, forming particular forms of corrosion, such as dissolution pockets, cupolas, and bell holes, in galleries joining and anastomosing into each other, where waters with a different chemical content flow and mix. In order to activate this mechanism, large quantities of water are not necessary. Forms of water mixing corrosion can be seen on the walls or on the ceilings of galleries, close to very small conduits, at times simple fractures (cupolas and bell holes formed by corrosion due to mixing waters are recognizable from similar forms, created by mechanical erosion, as they become narrower in the deeper parts and they always form near conduits or fractures, even of very small diameters).

Aggressive waters, saturated waters

Water that comes into contact with rocks initially is undersaturated, i.e. it can dissolve the minerals of the rock and progressively be enriched with the ions freed in the dissolving reaction, till it reaches a point of saturation, i.e. the water solution contains the maximum quantity possible of a particular ion in certain temperature conditions, atmospheric pressure or content of other acids. When this condition of saturation is reached, water no longer has a chemical effect on rock, and therefore it can only affect rock with mechanical erosion processes (as in the case of surface free flowing water). If variations in temperature, in CO_2 content or in concentration of the solution (e.g. in the case of evaporation) occur, saturated water becomes oversaturated, i.e. it contains an excessive quantity of dissolved calcium carbonate that should therefore be deposited in the form of calcite crystals, forming speleothemes, among which stalactites and stalagmites are the better known forms; however speleothemes may exhibit a vast range of forms and colours, at times bizarre and curious (when drops of water that carelessly drip on the sink evaporate, these form the detested calcareous deposits, which are a form of concretion).

A bit of geology

The fundamental ingredients to produce karst processes are abundant water rich in CO_2 and organic acids, and a favourable type of rock, but in order to have long and deep cave systems, these conditions are not sufficient.

Pores and fissures. Carbonatic rocks, which are most favourable for karst process, are generally very compact rocks. The granules forming them are very densely packed, the mechanisms by which they were formed led to a primary porosity (i.e. a percentage of voids) and permeability (i.e. a percentage of interconnecting voids that allow the passage of water) of these rocks that are very low. They are practically almost impermeable (the primary porosity of a limestone generally varies from 1 to 20%; only reef limestones have a higher primary porosity). In these conditions, karst processes can act only on the surface of the rocks, creating surface karst forms, such as karren (furrows and small depressions created by the dissolution of the rock): water has no possibility of filtering underground which is an indispensable condition for the formation of caves deep underground.

In order to be affected by karst processes deep underground, a rock must be characterized by discontinuities, through which water can filter and begin to percolate underground.

Discontinuities that are very useful for this purpose are bedding planes, which often characterize limestones (dolomites instead are often massive and do not have any stratifications). Bedding planes form during sediment deposition, however most discontinuities in carbonatic rocks are secondary, of a tectonic origin. In fact carbonatic rocks are very fragile and get fractured easily if they are subjected to mechanical stress. Bedding planes are initially horizontal, but subsequent tectonic deformations can incline and fold them in various ways.

Chemical deposits

All caves are filled with more or less large amounts of chemical deposits, minerals and physical deposits, sediments of various types which are mostly transported by water into caves. These, as a whole, are known as speleothemes, and are a very precious database regarding the geological, environmental and especially climatic evolution of the past.
Chemical sediments form when water saturated with calcium carbonate is subjected to variations in temperature or CO_2 content, or gets concentrated due to evaporation, thus becoming oversaturated. Therefore excess carbonate deposits in the form of concretions, known as speleothemes, which can have various shapes and morphology depending on where they form, the way the minerals precipitate, etc. Most speleothemes are made of calcite, which is surely the most widespread cave-mineral. Almost all speleothemes form in a sub-aerial environment. However, in particular conditions, in small closed basins with over-saturated water, even underwater speleothemes can form. Most speleothemes that can be observed in flooded caves formed in the sub-aerial zone, and were subsequently brought to the phreatic zone thanks to a flooding of the conduits with fresh or salt water, or as a consequence of a subsequent rise in the base-level.
Speleothemes form more rapidly and more abundantly in warm climates. Growth generally takes place in concentric bands, and their chemical composition (particularly with regard to the oxygen isotopes) is controlled by that of both water and atmosphere in which they formed. Therefore they provide important data regarding the climate of the past.

Physical deposits

Physical deposits include a large variety of materials that accumulate in caves thanks to gravity (deposits, blocks abd boulders due to break- down) or transported by water. Sediments may be autochthonous, produced in the cave (as in the case of blocks and boulders due to breaking down, or the clay formed by the insoluble minerals in the calcareous rock), or allochthonous, transported into the caves by different agents, generally by water. The material transported by water can be distinguished because its rounded characteristics, the more rounded the grains, the longer is the time they have been being transported and the softer the type of rock. Water capacity to transport material or competence, depends on its energy, in particular its speed and its density and, naturally, the density and weight of the material to be transported. Since most rocks have a density around 2.7 g/cm^3, which is therefore the same for all types of rock, this can be considered a constant parameter. Instead of the weight, the mean diameter of the granules or pebbles of material to be transported can be used, i.e. what is called the granulometry. The higher the speed of water, the greater the size of the particles the current is able to transport. The size of the particles vary from millimetric to metric, as for example in large floods where water is dense with sediments. In a cave, the transport of large-sized materials is rare, because even if water were to have a competence able to move large blocks, transportation would soon be stopped by the size of the conduits. The most commonly transported materials are generally sand and pebbles. When the speed of the current decreases, also the competence decreases and water abandons the coarser material, thus carrying out a granulometric classification of the material, i.e. a separation depending on the size of the particles. If coarse material is found in a flooded conduit this means that the current may have high speeds. Since the water is constantly moving, and with very variable speeds, it is not rare to observe a continuous reorganization and changing in the shapes and granulometry of the deposits on the bottom of a gallery. A visit to a well known gallery immediately after a flooding event can hide some surprises that are not always welcome, as for example the occlusion of the narrow and smaller passages, which must be opened again with difficult digging operations, or the presence, mainly near sinkholes, of material carried by the flow into the cave, such as large tree trunks or vegetable rubbish. These changes in the deposits can also cause barrages in the outflow of the vadose zone, thus giving origin to the formation of lakes or siphons. The presence of fine-grained silts and clays on the ceiling and on the walls of a sub-aerial cavity, specially where the material seems humid and fresh, not dusty or dry, can indicate that the gallery may undergo a total flooding, and therefore great care must be paid while exploring during particularly rainy periods. Physical deposits, specially those coming from outside, can provide precious information with regard to the evolution in the region. In fact these may contain remains of rock formations that are now completely worn out by erosion, or testify the passage of glaciers, or document the alternation of hot and cold periods. A detailed study of the chemical and physical deposits in a cave is fundamentally important for the reconstruction of the most recent geological and climatic history.

Karst landscape

A large number of factors influence the formation of cave systems : chemical factors and climate control the dissolving capacity of water; geological factors control the type of rock, the geological structure and the characteristics of fracturing and jointing, which in their turn control underground water circulation and the development and trend of the cave zone; topographic factors such as altitudes gradient and the presence of deep valleys control the prevalently vertical or horizontal development of karst systems. Caves therefore show different characteristics depending on the conditions and the environment in which they were formed.

Tropical caves. In tropical environments, all caves have similar characteristics. They are often arranged in vast underground systems, generally with a prevalently horizontal development, often drained by veritable underground rivers, and cave passages are very large and rich with speleothemes. Thanks to high temperatures, dissolution reaction is fast: since water filtering underground is very aggressive due to the presence of CO_2 and organic acids deriving from the dense plant overgrowth, it rapidly dissolves large quantities of limestone near the surface, soon becoming saturated or oversaturated, thus forming large quantities of speleothemes, which are a peculiar features of tropical karst.
High mountain caves. On the extreme opposite hand, caves in high mountain areas have a prevalently vertical trend due to the energetic potential created because of the large differences in altitudes and a geological structure that is generally complex, with big shafts, which are often very deep (at times over 600 m). Due to the slower dissolution speed as a result of low temperatures, circulating water may remain aggressive even at deeper levels, thus creating deep and vertical systems. Because of low temperatures, speleothemes are on the contrary very rare. On the surface, vertical shafts and sinkholes are often peculiar features. Their formation is often due to the conjoined action of karst processes and corrosion processes controlled by the presence of ice and snow.

Surface karst landscape

Karst landscapes have two peculiar characteristics which make them immediately identifiable even where rocks are covered by soil and vegetation: particular forms of dissolution on the surface and the practically total absence of watercourses on the surface, as all the water or most of it, rapidly is swallowed into the depths. This characteristic makes the work of speleologists particularly important, because karst zones are generally characterized by water supply problems: the identification of underground water reserves, their localization and the study of the possibility of exploiting them are a very important contribution to the wellbeing of local populations, specially in the arid zones of developing countries. Among the most particular karst forms, besides the afore mentioned karren or lapiez, which are forms on a small scale, dolines are surely the most well known and striking. These can be of different origins, but for cavers the most interesting ones are surely those formed by collapse, which often allow access to cave systems. Dolines formed by collapse, often are shafts and their cross-section is often sub-circular. At times they are very deep (like the famous sòtanos in Mexico, of which the Sotano de las Golondrinas, 370 m deep, is the most well-known representative) . At times forms of this type allow direct access to flooded systems: as in the case of the cenotes (those in Yucatan are the most famous, but there are many in most coast areas in tropical zones). More complex and larger forms are polja (singular: polje), large flat bottom depressions characterised by caves, the ponores, that act alternatively as sinkholes during dry season or as springs during rainy season, when the water flowing within the karst system exceeds the drainage capacity of the system. Water rises up the sinkoles from which it flows out, often forming temporary lakes (for example the polja in the karst area of Postojna, in Slovenia). Tropical zones are characterized by particular karst landscapes, such as cone karst and tower karst (famous tower karst can be found in Southern China or Thailand). The formation of underground drainage systems often brings about the swallowing of surface water through sinkholes, leaving valleys “dry”. Thus dry valleys are formed with water courses in which water no longer flows; in blind valleys, water courses disappear underground, often sinking into large entrances. Pocket valleys are on the contrary valleys suddently closed upstream, where waters comes out a spring, often at the base of a wall, or beginning at big karst springs (for example the famous Fontaine de Vaucluse, in France).

Underground landscape

Observing a vertical cross section of a karst system it is possible to point out different zones, depending on the presence of water and on how water moves within.

The catchment zone. The catchment zone is the one closest to the surface where surface water and meteoric water sink and seep deep underground. Catchment may take place through a large number of fractures, thus being diffuse, or through concentrated sinking input points, such as dolines, where surface water can collect and concentrate: in this way the corrosive action of water concentrates on a small number of fractures that are then widened preferentially, thus leading rapidly to the creation of underground karst galleries. At times the entrance of surface water into the deeper layers is characterized by spectacular forms. When water courses flowing on impermeable rocks that cannot be karstified come into contact with karstifiable rocks, such as limestones and dolomite, they are literally swallowed underground, at times with small losses, that gradually dry up the flow of the river, till it disappears, leaving a dry valley, at times with spectacular sinkholes that capture the flow of the water totally. This is the so called allogenic recharge. A particularly impressive example is the sinking of the Reka river in Slovenia. Through the San Canziano caves the river is swallowed and disappears, to reappear 40 km downstream, from a resurgence near Trieste, with the new name of Timavo.

The transfer or vadose zone. Below the catchment zone, the vadose zone of vertical transfer develops, where water mainly flows downwards and caves have a prevalently vertical trend. Due to the progressive union and concentration of underground water flows, from the vertical transfer zone water gradually passes to the horizontal transfer zone where veritable underground water courses exist, Just like surface water courses, they entrench and erode canyons, gorges, meanders, characterized by a series of erosion forms similar to potholes and cauldrons at the base of shafts. Here water generally has a strong energy and a high speed, so that erosion phenomena prevail over corrosion.

This entire zone belongs to the so called vadose zone, a term that indicates the presence of voids filled with both air and water, where water flow is free. In the vertical transfer zone, it is quite rare to find completely flooded galleries or conduits, while in the horizontal transfer zone underground lakes may form, where obstacles to the outflow may cause the formation of small basins, which may often be temporary. At times the water level can rise above the ceiling of the gallery, in which case the lake is turned to a siphon, i.e. a part of a gallery completely flooded, where the ceiling sinks below the water surface. Normally in the zone of horizontal flow, after passing a siphon it is possible to continue explorations of the sub-aerial zone. Siphons of this type generally are not very deep. One of the main causes of the formation of lakes or siphons is the presence of depressions whose bottom is impermeable due to clay deposits. Furthermore, the water level in lakes and siphons may vary remarkably, depending on external input (rainfalls). In very rainy periods, galleries that are normally dry can be completely flooded and vice versa. In some karst systems, water level is known to rise over 100 m, in particularly rainy periods, thus obviously flooding all the galleries below this level.

The phreatic zone. Below the vadose zone of horizontal flow, is the phreatic zone, i.e. in this zone, all cave passages, conduits, galleries, rooms, shafts,fractures, voids of any shape and size are completely flooded. This zone draws the attention of cave-divers. The top of the phreatic zone, also called the water table, is found at sea level, in karst close to coastline, while far from the sea it is at the same level as the main valley floors, close to the so-called base-level, i.e. the level below which all voids are completely full of water.

Base level

The peculiarity of the base level is that it is not a fixed unchanging level, but it varies in (geological) time. It generally tends to lower progressively, as valleys deepen getting more and more entrenched. When a valley cuts the phreatic zone of a karst system the cave conduits that were previuosly filled with water get empty, letting water drain out. Thus karst springs are formed. These are normally found close to the base level, on valley floors – at times directly feeding water courses, at times creating pocket valleys. A subsequent deepening of valleys leads to the formation of springs at a lower level and to the fossilization of the oldest springs, which remain perched over the valley floor, and above the new base level. During exceptional flooding events, when springs at the base level are unable to take away the large discharge of water flowing through them, the karst water table inside caves may rise, invading the upper galleries, which are normally inactive, thus temporarily flowing out of the ancient springs: these are known as overflow springs. Also in this case, a good knowledge of the behaviour of the karst systems and the geological structure are very important in order to be able to foresee possible hydro-geological problems. The new activation of ancient galleries and springs, in fact, is often sudden and difficult to foresee, if one does not know the structure and the behaviour of the karst systems.

Caves have a shape

Cave morphology is often complex and difficult to describe, however there are few elementary shapes: galleries, shafts, meandering channels,or canyons, rooms.

The trend of galleries is prevalently horizontal or slightly inclined, and generally galleries are large (if the size is small they are often called “passages”, but this definition is purely speleological and not geologic. From the point of view of the origin, there is no difference between a “passage” and a gallery). The diameters of the galleries can be impressive. The largest gallery in the world is in Deer Cave in Sarawak – its average diameter is over 80 m.
Underground meanders, or canyons, are horizontal tracts characterized by a very high and narrow channeling. Meanders is an improper term because these are real underground canyons that are perfectly similar to the entrenched canyons on the surface, eroded by flowing water. Often these are the most difficult passages to explore, because they are frequently very narrow at the base and have water courses flowing on the bottom that can even be quite violent, therefore they must be explored at a mid-height, progressing delicately and painstakingly.
Shafts have a vertical trend: they can be perfectly cylindrical tubes, with smooth vertical walls (as in the case of the shafts formed in the phreatic zone, or at high mountain altitudes, due to the presence of snow or ice, or they may develop in ledges, or steps with erosion potholes on the bottom, as in the case of the vertical shafts originated from water courses on the surface, which recede due to the erosion of a water fall. Shafts can be of incredible heights, an example is the Vritiglavica (Slovenia) shaft that is over 643 m deep and has an absolute vertical drop of 500 m.
Rooms form due to collapses where shafts and galleries meet. The size of an underground room may at times be immense. The largest chamber in the world is the Sarawak Chamber, in the Lubang Nasib Bagus cave, in the Gunung Mulu karst area in Sarawak. It is 700 x 430 m in size, with a height of 120 m. It is still a mystery how a similar void underground can exist without breaking down.

Different zones, different forms

Cave morphologies are controlled by the zones in which they have been formed : in the vadose zone mechanical erosion features prevail (such as canyons, gorges, meanders and vertical shafts) and collapses, such as rooms; while in the phreatic zone corrosion features prevail. Finding typical phreatic zone features in a vadose zone (or more rarely vice versa) is a precious clue in order to reconstruct the evolution and the geological history of a cave. Most underground caves form in the phreatic zone, in particular at its top (near to what is called the water table, or, less correct, the piezometric surface), where galleries are permanently flooded, but where there is a certain mixing of water and a merging with meteoric water, which periodically renews the corrosive capacity. Therefore caves are not formed starting from the surface but from inside, because flowing water must be concentrated in order to give rise to galleries and conduits of a certain size. The shapes of galleries and conduits in the phreatic zone are peculiar. Water occupying uniformly the entire section of a gallery leads to corrosion over the entire surface, thus giving origin to conduits with a circular cross section (both vertical and horizontal). If the rock contain portions that are easier to corrode or to erode, such as bedding planes or layers where the rock is particularly frail, fracures, etc, cross sections will elongate along these layers and elliptical or more complex galleries will form. Galleries of this type are known as phreatic galleries, and form in the first phases of the birth and evolution of a cave. If the water flow is very slow, on the bottom of the conduits fine sediments that “protect” the rock may accumulate. In this case dissolution only takes place on the ceiling, and galleries, known as paragenetic galleries, are formed, usually characterized by a flat roof. Together with large-scale phreatic morphology, small-scale corrosion forms may be present, and when these are found they are precious evidence in the reconstruction of the history of a cave. For example it is possible to see ceiling half tubes or anastomoses (remains of the most ancient conduits of a karst system, which can be seen winding on the ceilings of larger galleries), dissolution pockets and boneyards where water mixes (at the confluence of conduits, where the chemical composition of water is transformed by mixing), or scallops. The latter are small asymmetric scoops, with an elongated tip indicating the direction of flow, formed by the presence of eddies in non laminar water flow. At times these may be seen also in inactive caves and can be examined by speleologists. They are extremely precious clues regarding water flow in the past. In fact is it possible to recognize the direction of flow and in addition the scallops size can help evaluating the speed of flow in flooded conditions. In fact scallops sizes are inversely proportional to the speed of flow. Small, tightly packed forms indicate a rapid flow, large well separated forms indicate slow flows.

Studying caves

There are many different reasons that drive some men and women towards speleology: for some it is the sporting or technical aspect, for others it is the urge for adventure and ‘strong’ emotions or the curiosity to know ‘what lies beyond’, or even scientific research. Often it is a mixture of all these put together or yet some other reason. In any case, the aim of a speleologist is rarely just visiting an underground environment, be it sub-aerial or flooded, (we call him/her a caver), but it is the exploration of new conduits and galleries and the conjunction of the caves, to be able to reconstruct one large karst system, that is vaster and deeper, to be able to understand how these caves formed and evolved and to discover the potential of the system and how much vaster and deeper it may become (we call him/her a caver). Man, however, is not suited to the cave environment, so in order to explore it he must be aware of certain specific techniques and equip himself adequately. Since we are unable to move about in the dark, at least two sources of light are necessary, the main one usually being an acetylene lamp. It is essential to protect oneself from cold and mud by wearing clothing made of pile and appropriate jump-suits. At times the use of a wet suit is required to cover parts that are very wet without risking hypothermia. Generally, boots or mountain climbing boots are the required footwear, while rubber gloves must be worn to protect one’s hands from rock and rope abrasion. To cope with the vertical parts, static ropes with a 10 or 9 mm diameter are used, along with a climbing harness (similar, with some modifications, to those used for climbing) and suitable equipment for climbing up and descending ropes.

Many dangers are present when exploring a cave, but actually all can be foreseen and overcome with a correct technical preparation and the right equipment: you cannot stand in as a caver! Contrary to what is usually thought, no caver has ever died trapped in a narrow passage or under a collapsed cave roof (which, on the contrary, might happen in a mine, where the hollow is man-made, and is therefore unstable): the main risks are falling stones (always caused by the passing of explorers) and water. Since flood propagation in a karst system can be very rapid at times, it is possible that, in conjunction with an external rain event, galleries that are normally dry might get flooded, even completely: this is one of the most frequent causes of entrapment inside caves of imprudent cavers (often with a limited knowledge of the underground system),which requires the intervention of a rescue team of cave divers and adds another, at times, gruesome anecdote to the literature on this subject even though, fortunately, the majority have a happy ending. An example is the incident in the French cave of Vittarelle, where some cavers were trapped for days on board a small inflatable boat, in a chamber that was rapidly turning into a lake: the rise of the waters stopped when the boat was just a few metres from the roof…). In caves, however, water leaves unmistakable and evident traces, so that those who normally visit this type of caves know its behaviour and can foresee it easily: it is unnecessary to underline that before venturing into complex cave systems, especially if they are close to the springs, it is essential to collect information from the local caving groups.

Tracers and dyes

At times, the fact that a cave and a spring belong to the same system can be perceived immediately, especially in the case of the so-called hydrogeological tunnels, where the course of the underground waters can be followed physically by cavers from the sinkholes to the spring. Other times, on the contrary, the relationship between caves and karst springs is not obvious; it may happen that the closest springs, that rationally seem to be the most likely to be connected to a karst system, do not in fact belong to it. One must not forget that, while on the surface topographic morphology makes the identification of the divide between different hydrographic basins quite easy, underground, the dependence of karst systems on the geological structure can create dividers that are difficult to identify externally unless the geology of the area is well-known. The easiest and safest method to establish the connection between caves and springs is water tracing. The technique is very simple: a tracer, mostly a dye, is put in the water, in any part of the system, either at the entrance or at a deep internal point, and then its presence is verified at the spring. Finding the tracers at the spring is an unmistakable proof of the connection between the input point and the check point. Moreover: the analysis of the time the tracer takes to reach and the dilution it has undergone when correlated to the discharge at the spring and to a chemical analysis of the water, enable the extrapolation of important information regarding the karst aquifer, its water reserves, the water flow rate and also the depth of the saturated zone and the presence of big underground drainage conduits. The most commonly used tracers are dyes such as Fluorescein (that gives a green colouring) or optical bleachers such as Tinopal (the substance that makes our washing 'whiter than white'). These substances not only have very low toxicity, even on the most delicate organisms, but have the advantage of being identified with simple methods even at low concentrations invisible to the naked eye, which makes it possible to use only modest quantities. In the past, different substances were used, among which some really curious ones that are now part of the literature on this subject, such as the legendary eels used to 'trace' the waters of the Timavo river, rather than straw, sawdust, spores, radioactive elements and kitchen salt. At times the colouring has been totally involuntary as in the case of the overturning of a road tanker full of Pernod in the South of France that brought about the discovery of the connection between a small stream on the side of the road and an important karst system close by, to the joy of the cavers present in the cave when the 'tracer' flowed past… However simple in theory, tracing operations need, as a matter of fact, a series of precautions so as to avoid pollution and incorrect results and they must be carried out by specialists…to avoid accidents that can be tragicomical at times. Some examples are the big green patch that mysteriously appeared in front of Nesso, on Lake Como, in the Eighties or the tens of km2 of fluorescent rice fields in the Philippines caused by an Italian expedition, whose members were subsequently forced to drink the water to prove to the infuriated inhabitants, lead by some old beheaders, that the substance was not toxic…the side effects connected to a glass of water from a rice field are certainly greater than the toxic effect of the fluorescein used…

The age of caves

Chemical deposits in caves offer extraordinary research possibilities to those who are engaged in reconstructing the geological history of the past. These can, in fact, be easily dated with a method based on the decadence of certain isotopes of the radioactive 'family' of $_{238}$U. The latter, in fact, decays into a series of elements: ^{234}Th, ^{234}Pa, ^{234}U, ^{230}Th, up to ^{206}Pb, which is stable.
Cave speleothemes contain uranium, which substitutes calcium in the crystalline network of calcite, but they do not contain thorium. From the moment the speleotheme is formed, ^{238}U starts decaying, changing into ^{230}Th. The measure of the concentration of ^{230}Th in the calcite is therefore a measure of the time elapsed from its formation. Hence, by measuring the ratio ^{230}Th/^{234}U and ^{234}U/^{238}U (^{234}U is another descendent of ^{238}U) it is possible to obtain the age of a calcite speleotheme.
The U/Th method of dating is very efficient, but only allows the dating of very young calcite, not older than 350,000 years. Using the ^{234}U/^{238}U ratio it is possible to extend this limit to 1.5 million years. Recently it has been discovered that most speleothemes are much older than 1.5 million years and hence other methods are being studied currently, such as the U/Pb method (that works well on very old deposits) or paleomagnetic methods.
As far as the study of sediments that contain pebbles brought from the outside is concerned, experiments are being carried out with the so-called cosmogenic isotope method. Cosmic ray radiation (which gives the method its name) produces ^{10}Be, ^{26}Al and other isotopes in addition

to the better known ^{14}C in the network of certain minerals (for example, quartz) when they are exposed on the surface.
When sediments are buried beyond the effect of the cosmic rays (for example, in caves deeper than 30 m), the cosmogenic isotopes begin to decay and it is possible to determine, in a way similar to the U/Th method, the moment of burial, i.e. the age of the deposit, for dates varying between 100,000 to 5 million years.

Caves remember the past

When the base level sinks, due to the continuous erosion of the valleys, the syngenetic passages are suspended above the base level, and slowly empty, while new passages begin to widen deeper down. Karst systems always tend to be in equilibrium with the base level, but if variations in the base level are rapid, or rather, more rapid than the caves' ability to adapt, a certain imbalance may occur, with the presence of overflow springs or suspended springs, and flooded sections even above the base level. The end result, however, with the passage of (geological) time, is an emptying of the syngenetic passages, which thus become part of the vadose zone, where the water flow is free flowing, with higher velocities and where erosive processes therefore prevail, with forms similar to those of surface watercourses. When the water level in a syngenetic passage drops, the water begins to flow only on the floor, which becomes deeper, while the walls and ceiling remain intact: thus 'keyhole' passages are formed, which still retain traces of the original circular section, providing valuable clues to the origin of the tunnel. If erosion continues, however, the passage deepens, becoming a high, narrow meander, often with a winding course, and traces of the original forms are completely erased. Added to this are subsidence phenomena that affect the vaults and walls of shafts and passages and are generally responsible for the formation of the larger underground cavities, caverns: such subsidences always occur along fractures and thus give a typical square cross-section to the cavities, with smooth, straight walls and ceilings, and varying slopes depending on the course of the fractures that originate the subsidence. Most subsidence occurs when water leaves the syngenetic passages. Because they were formed long ago, for the most part caves are relatively stable structures, much more so than is generally believed: the danger of collapse is in fact mostly linked to the carelessness of those who walk, perhaps on the edge of a shaft, on piles of collapsing boulders, rendered unstable by the movement of inattentive visitors. Underground cavities can sometimes be enormous: it is difficult to imagine the effect of such large spaces when the only source of illumination is an acetylene lamp or an underwater torch.

Cave evolution

Caves are formed progressively in relatively long geological periods and evolve continuously: their history depends on many factors, among which the amount of water (depending mainly on climate), the way in which the latter enters the system, the variations of the base level and of the surface topography. Modifications in the topography can change the hydraulic supply of a cave causing, for example, the transfer of phreatic conduits to vadose zones, or bring about variations in position and functioning of springs, and much more: every modification in the cave surroundings, such as tectonic movements, climatic variations or topographical changes result in modifications within the karst system which tend towards a new equilibrium in the new situation. Hence, caves are not stable and unchanging in time and space and one must always keep in mind that they were formed in topographi and climatic conditions very different from the present ones (for example, caves in the Lombard Prealps started forming a little less than 30 million years ago when the valley presently occupied by Lake Como did not exist and there was a tropical climate with a dense rain forest covering the entire area). Any variation is promptly registered within a cave both as karst features that originated in conditions different from the present ones and as deposits of minerals and sediments that vary depending on the amount of water or on the climate (for example, in many caves in Northern Italy it is possible to find sediments related to the advance of the great glaciers that, during the last 2 million years, have repeatedly scoured the valleys from the Alps). Since on the surface erosion often results in the disappearance of all traces of the geological history of a region, caves, being on the contrary a very conservative environment, are often an important archive of precious geological data. Cavers, who are the only visitors in this environment, are often asked to unearth these data. Hence it is important that cavers should have some geological knowledge to be able to recognise the main karst features and collaborate effectively with speleologists who are engaged in researches in this field.

Landscape evolution

Generally, the evolution of karst systems is similar to that of the mountain massif in which they are found. The general tendency is a gradual deepening of the cave systems as a consequence of the deepening of the base level of the valleys. But this is not always the case: the base level can also rise, bringing about the flooding of galleries that previously were fossilized. This has taken place, for example, in all the caves of coastal areas where, in the course of the last 2 million years, continental glaciations determined fluctuations in the sea level. The formation of big continental glaciers, in fact, causes the entrapment of enormous quantities of water on lands above sea level: this implies that during each ice age the expansion of glaciers provoked the lowering of the average sea level, and hence the lowering of the base level by about 100-120 m. This led to the formation of continental caves at altitudes presently below sea level. During warm interglacial periods, on the contrary, waters freed by the ice melt caused the sea level to rise and brought about the flooding of the ‘terrestrial’ caves that had been formed previously. As a result of the last Ice Age, during the last 10,000 years the average level of the Mediterranean has risen by about 100-120 m, while 125,000 years ago, not long before the last Ice Age, it was 8 m higher than today (as can be deduced from ancient nips and remains of sea caves).
Naturally, it is not always that simple: variations in the sea level can also be a consequence of other causes among which, for example, tectonic activity that can raise or sink lands, and isostasy

raising areas formerly covered by the weight of thick ice sheets, as is happening in Scandinavia. These variations can amplify or thwart the eustatic variations of the sea level, producing different effects from one place to another.
In general, however, the result is that the majority of the sea caves does not actually have a marine origin but is the result of the flooding of continental caves with sea water. Confirmation of this is given by the study of the morphologies that are typical of continental karst caves but not of marine ones. The finding of speleothemes, in particular, is the proof of this fact and is a very precious element in the reconstruction of the history of the caves and of climatic evolution. Speleothemes can in fact be dated and the study of their morphology and of the minerals they are made of at times allows surprisingly detailed reconstructions. By studying the stalagmites formed at a depth of 20-30 m in sea caves, in Southern Italy, it has been possible to observe, for example, consecutive deposits of minerals of a continental environment and those of marine organisms, at times even with the holes of stone-boring mussels, with a cyclical alternation showing the advance and retreat of the continental glaciers. Cave-divers are a precious allies for geologists!
Fluctuations in the sea level, particularly the rise of the last 10,000 years, have created vast systems of flooded caves: the most beautiful examples are the cenotes in Yukatan, entrances to ancient systems of sub-aerial caves that have been flooded by the rise in the water table to a depth of just a few metres or the blue holes of the Bahamas or Belize, where a very old karst plain, pitted with karst systems, has been completely flooded by the rising sea level.

Caves and climate in the past

A study of sediments transported within caves, their characteristics, their composition and their content in fossils allows the reconstruction of the variations of the environment on the surface and of the climate: in particular, remains of soil formed in tropical climates can be interesting, as well as sediments related to cold climates, such as material deriving from glacial or periglacial deposits. Speleothemes, on the other hand, are formed prevalently in warm climates and are therefore very important climate markers. In a way similar to that of ice cores, the isotopic analysis of the ratio $^{16}O/^{18}O$ enables us to determine air temperature when the calcite of which spleothemes are made of was deposited. The overlapping laminated structure and the possibility of dating calcite allow a reconstruction of the temperatures in the past that can be very detailed at times. The curve of past climatic fluctuations plotted with data from the analysis of cave speleothemes fits very well with paleo-climatic data obtained from other sources, such as the isotopic analysis of foraminifers (marine organisms with a calcareous shell) or pollen analysis.

An example close by

Even caves close to the big prealpine lakes (Maggiore, Como and Garda) have experienced a similar evolution: Lake Como, for example, is set in a deep canyon whose formation dates back more than 5 million years and hence is not of glacial origin (like its fellow-lakes, Lake Maggiore, Lake Iseo and Lake Garda). At present, Lake Como is over 400 m deep, which means that its bed is 200 m below sea level, but the bottom of the canyon, filled with sediments, is 700 m deeper. Considering that it is surrounded by highly karstifiable rocks, it is most probable that complex, highly developed karst systems are present in the depths, in equilibrium with the old base level at the bottom of the canyon. Successively, a little over 2 million years ago, the sea flooded the border of the Lombard Prealps, as ancient valleys filled by clays containing fossils of marine organisms testify. Hence, even deep caves at the bottom of the canyon were flooded, filled with sediments and colonized by marine organisms. The sea then withdrew, emptying the caves once again, and the canyon filled up with alluvial sediments, first of marine and then of glacial and fluvio-glacial origin, when the big Adda Glacier advanced repeatedly down the valley now occupied by the lake. Along the steep submerged walls of the lake, big flooded galleries must therefore exist. The proof of this is given by the springs of the most important karst systems of Pian del Tivano and of the Grigna Settentrionale. The springs that are visible on the surface are only overflow springs, whose discharge is very poor with respect to the great amounts of water that enter the system in the catchmente zone. The main springs must therefore be below lake level, but they have not been found yet. All this simply means that the origin of caves is usually very ancient and that their evolution is often complex and closely controlled by geographical events in the area. Speleologists and cave-divers have on hand the keys to open the important archives of geological data contained in the darkness of the caves. And these data can, in turn, give important suggestions for new explorations!

Caves and water

Water that is normally present in porous rocks, such as sand or gravel, fills all the voids in a continuous manner. However, in karst rocks, the water forms courses of water which at times become large underground rivers that flow in enormous galleries whose diameter is many meters wide and are many kilometres long. The water of the underground streams flows in the same way as those on the surface, and similarly they are subjected to floods caused by rainfalls on the surface (in caves, floods arrive with a certain delay in time, due to slow seeping in the catchement zone). Water is able to entrench and erode rock by means of mechanical abrasion processes, to transport sediments of various granulometries, and to create alluvial deposits inside caves.

Immense reserves

The phreatic zone in a karst system can grow in size and depth depending on the geological structure. At times the phreatic zone may be quite thin or absent as in karst systems that are perched above the base level, at times the phreatic zone may be hundreds of metres deep and thus provide an immense and precious water reserve.

The more superficial area of the phreatic zone, known as the epiphreatic zone, varies during seasons, and can rise various tens of metres during rainy periods. This is a very important zone

for the formation of caves because, as a result of Boegli's effect, due to mixing of waters with different chemical compositions (meteoric water and groundwater), most of the largest galleries are formed in these zones.
Below the epiphreatic zone, the water in the deep phreatic zone moves very slowly and may remain inside the karst aquifer for tens or hundreds of years before it returns outside in a spring. For this reason karst water is very vulnerable to pollution (a polluting agent may remain for decades inside a phreatic zone) and excessive exploiting (the emptying of a phreatic zone may require decades in order to reach the original water level again). Therefore karst aquifers are precious reserves that must be protected and exploited very cautiously.

Springs

Ground water coming out on the surface is called a spring, if the origin of the water is unknown, or if it comes from an unconfined catchment area. It is called a resurgence if it is on the contrary the re-emergence of a watercourse that sank upstream, as the already mentioned case of the Timavo river. Springs can be classified in various ways, depending on the flow rate, the constancy of the discharge, or the geological characteristics that determine its formation. Many springs are characterized by a perennial flow, even though there can be remarkable differences in the discharge, depending on precipitation. Other springs, as the already mentioned overflow springs, may be characterized by a temporary outflow. From the name of the famous Fontaine de Vaucluse spring (France), springs characterized by a vertical development and a great depth (in many cases over 300 m) are called vauclusian springs. Thanks to the particular shape of the outlet galleries, some may have an intermittent outflow. A regularly intermittent outflow may also be observed in springs near the sea, where the influence of tides may be felt. The direction of the current is generally from inside the cave outward, and generally remains constant, but in some cases the flow may be inverted. Some springs in fact can alternatively act as springs or sinkoles. This depends on precipitations with a seasonal variation, as in the case of the ponor described before, or near the coast, due to the tide effect, as in the katavothre (for example those in the island of Cephalonia), or the submarine springs also known as estavelles. In some particular types of submarine springs, the vrulja, the flow rate of the fresh water feeding springs through karst conduits is such that it contrasts the pressure of the sea water, and in some points it exceeds it, thus giving rise to bubbling waters, a phenomenon that is well known along the Greek and Dalmatian coastlines, and once upon a time was exploited by sailors to collect a supply of drinking water. The speed of flow in these springs can be impressive, so much so that in the past they have often given rise to legends about sea monsters.

How underground waters move

Karst springs greatly depend on surface rainfall for different reasons. Considering that the speed of waters in the vadose zone is as high as that of surface streams, the increase in the hydraulic head when great quantities of water enter a cave can exert a high pressure on waters in the

phreatic zone that are literally pushed out with a piston flow, a term that clearly explains the mechanism involved. The flood wave that follows the arrival of infiltration waters will reach after a period of time equal to the time it takes to physically transport these infiltrated waters, while the piston flow makes the flood wave spread like an energy wave (called a pressure pulse) rather than a kinematic one. The speed at which a flood wave spreads is therefore much higher than the speed of water, and is taken to be equal to the speed of sound: hence, in some cases, the propagation of a flood wave is practically instantaneous. This implies that a rainfall on the surface can produce an almost immediate flood at the spring, which takes place a few hours or a few minutes after the rainfall. The outcoming of this type of floods is fast and has no premonitory signs, such as a progressive rise in water level or increase in the speed of flow. Some caves situated close to the water table are known to fill up in a few minutes after relatively small showers (eg. The Peyrejal cave in South France): to explore these caves it is compulsory to look at reliable weather forecasts and to have a thorough knowledge of the system.
The arrival of a flood wave as a result of direct propagation is on the contrary often pre-announced by signals such as a gradual rise of water level or an increase of the flow rate, often accompanied by a heavy beating sound against the walls, whistles or rumbling caused by the ejection of air from the conduits that are getting flooded (a famous example is the Masera cave on Lake Como, when the spring gets saturated it is announced by a loud rumble that is clearly audible in the nearby town, so its inhabitants rush out to enjoy the show).
It is interesting to compare the discharge during a flood (with a graph known as a hydrograph) in a circulation through pores aquifer (typical of porous rock) and in a karst aquifer: the presence of big karst conduits makes the flood wave arrive faster and more concentrated in time so that its peak is much higher, for equal precipitations.
A flood wave is usually accompanied by an increase in the content in ions in solution in the water and transportation of additional materials. The relationship between the discharge and the variations in the content in ions in solution (calculated by measuring the electric conductivity) during a flood in a karst aquifer indicate that an increase in electrical conductivity is related to the piston effect on waters that have remained in the phreatic zone for a long time (and are therefore rich in carbonates), while a decrease in ions in solution is related to the direct arrival of infiltrated surface waters: hence, the analysis of these waters allows us to highlight the arrival of a dynamic flood wave rather than a ‘physical’ one. A chemical analysis of water and the study of the discharge of a spring are rather complex, but are essential to understand the flood mechanisms in a karst system.

Karst aquifers

Karst aquifers provide a very important water resource in many parts of the Earth: karst terrains, in fact, are, by nature, lacking in surface waters, and all water circulation occurs underground. However, these resources are very difficult to utilize and to protect. Karst aquifers, in fact, due to some of their characteristics, are particularly vulnerable to pollutants and excessive exploitation. An excessive and uncontrolled utilization of the reserves of deep phreatic zones can be a hazard for these kinds of aquifers: deep waters, in fact, move very slowly and need years or decades to be substituted, so an excessive exploitation could endanger the utilization of the entire aquifer forever. But it is mainly with regard to the propagation of polluting substances that karst aquifers seem particularly vulnerable. In sand or gravel, where the speed of water is very slow, the result of the prolonged contact of water and rock is that the former gets depurated of possible pollutants because of a mechanical filter effect, the natural deterioration of some substances with time and because of the action of bacterial colonies living on the surface of the granules. These processes allow the aquifer to eliminate many pollutants, especially the organic ones, through a mechanism of auto-purification that helps to protect the aquifer from pollution. In the uppermost zone of the karst aquifer, water flows fast, similar to surface water flow regimes and the effect of auto-purification is practically nil: whatever enters a karst aquifer generally exits unchanged at the spring, often a very short time later. On the contrary, in deep phreatic zones, where circulation is very slow, pollutants can collect and get stored and more and more concentrated. Subsequently, the particular mechanism of flood propagation, the piston flow, can provoke the instantaneous release, at high concentrations, of the possible polluting substance which might have accumulated slowly over the course of time. Often these episodes of instantaneous pollution seem inexplicable because no current source of pollution can be identified: small quantities of pollutants that are well tolerated in other kinds of aquifers, become potentially very dangerous in karst aquifers. Unfortunately karst areas have another property that makes them even more vulnerable: the presence of a great amount of depressions, sinkholes, shafts and dolines in the catchment zone. These seem ideal for use as convenient dumping grounds, where useless things can be concealed, at times even highly dangerous material. Too often one forgets, or pretends not to know that by doing this the entire karst system gets polluted. Since the location of the springs is not always known in karst aquifers, the contamination produced in the catchment zone can pollute springs several kilometres away, at times even in adjacent valleys: at times the self-interest of those who live at higher altitudes can cause severe problems to unknowing inhabitants living in the valley below. Unfortunately, knowledge of karst aquifers is still so limited that a few years ago there was a proposal to use caves for the storage of toxic and radioactive waste!

Cave inhabitants

Cave environment, dark and mysterious, has always stimulated man’s fantasy, provoking a mixture of curiosity and fear. Man has envisioned cave inhabitants as being arcane and fantastic, often related to the netherworld and worship of the dead: in western cultures they were seen as evil and devilish, but for many others such as the oriental ones, they were (and in many cases still are) positive supernatural beings that gave protection and brought good luck. Further studies and knowledge on this particular environment made us understand that caves are not home to devils or dragons, but to a microfauna of tiny and shy beings, difficult to observe but interesting for studies on evolution and management of the environment.

Special biologists. Biospeleology is a zoology branch that studies animals, big and small, that live in caves, their life cycle and how they have adapted to life in environments with particular characteristics. Man's interest in cave inhabitants dates back to a very long time ago: in a cave on the Pyrenees (France) a bison bone was found on which 15.000 years ago an ancestor of ours had drawn an insect that is easy to find in our caves nowadays: a grasshopper which belongs to the Troglophilus species (trogo means cave and philo means friend). Anyway the first scientific descriptions of cave animals date around 1500, and only in 1700 researchers started to be interested systematically in this kind of environment. Biospeleology was born in 1907 thanks to the work done by a Rumanian naturalist called Racovitza, that started off modern day-type studies. Initially biospeleology focused on animals that lived in caves, but as they progressed in their studies, researchers have realized that for smaller animals (such as insects, spiders and other Arthropods) small cracks or tiny shaded valleys have the same environmental characteristics as caves. This way the term biospeleology has broadened to include the study of all types of organisms that live in environments similar to caves.

Temporary and permanent guests

Biospeleologists divide cave inhabitants into 3 big categories: troglossens, troglophiles, and troglobes. These are difficult sounding names that classify animals that live by chance in a cave (troglossens) or by necessity (troglophiles), or animals that live out their entire lifecycle in a cave (troglobes). The latter have adapted so well to cave life that that they could not survive on the outside.

Unwilling visitors. Troglossens are animals that end up living in a cave by chance, possibly because they fell inside a well or in a crack or were dragged into a cave by an overflowing creek or water infiltration. They are animals that generally live on the surface and that have never adapted to actual cave life. They are doomed to a quick death in this strange environment, and if in some cases they survive it is because they receive food from external sources, and usually they settle near the entrance where there is some daylight. In any case they are unable to reproduce themselves and merely try to survive as they can. Caves often contain fossils remains of troglossen animals, that entered by chance, and man happens to be among those (such as, for instance, the famous Altamura man, in Puglia) …

Comfortable shelters. Troglophiles are "cave friends", animals that live generally in the daylight, but occasionally will seek shelter in caves where they look for protection from the cold, storms and excessive heat, or to hide from predators. It is the case of bats, foxes, opossums, raccoons, porcupines, small rodents, snakes and many kinds of other animals that look for shelter and a safe place to bear their young as well as storage space fo their food reserves (as many rodents do) or to hide their prey from other predators (as, for instance, hyenas and leopards do). Bats and bears live out the winter in caves and give birth to their young who will then get to know the

outside world only in spring because caves offer a warm shelter to spend the wintertime. Near the entrance speleologists often find traces left by cave guests: excretions, food leftovers, prints, nests and burrows. Occasionally speleologists become involuntary sources of food and shelter to cave guests: during an exploration it isn't unlikely that one might find a whole dormouse family peacefully wrapped up around the ropes of a rucksack left at the botton of a 90-meter deep well! Cave animals are not always large and visible: many insects and other arthropods (such as spiders and centipedes) or amphibians (such as frogs and salamanders) find shelter in caves and in cracks dring the colder months: during the winter time near the entrance of a cave it is easy to see butterflies, spiders, and other small "refugees" that take advantage of the warmth within. Troglophiles are animals that live on the surface, that need daylight to move about and eat food that cannot be found in caves. These guests are "opportunists" that use them as dens, for resting or as shelter for their young, but that cannot live permanently in a cave: in fact they must go out to search for food or a partner. Some of them, however, have the ability to move well in the dark such as bears and rodents. Others, in spite of needing their eyesight to move about, have developed specific systems to move in the dark, such as bats or other types of birds that make their nests in caves: the salangane (a kind of dove that comes from South-East Asia that make nests that are considered to be very refined delicatessen food in Oriental cuisines) or the guacharo (a very strange South American bird). These animals have an "echolocation" radar-like system: they are able to emit high frequency sounds that, bouncing on obstacles or preys are then perceived by a sophisticated hearing system which allows them to put together a surprisingly precise map of their surroundings even in total darkness.
Permanent residents. Troglobes are animals that spend their entire life cycle in a cave, where they are born, live, reproduce and eat. Spanning over thousands and millions of years, they have evolved so as to adapt to life in this particular environment. They have no need to go on the outside and in many cases will live their entire lifecycle without ever leaving the cave. Not all animal phyla are represented in this category: mammals and birds are missing. Instead we find many belonging to the Arthropods (spiders, scorpions, and pseudo scorpions, centipedes and millipedes, crustaceans, such as shrimps, and especially insects), fish and amphibians.

A particular environment

Cave environment has certain physical and morphological characteristics that make it very particular and different from any other environment on earth. These characteristics don't allow for all animals to survive, but only those that have developed particular evolutionary modifications. The hypogeous ambient can be divided into different under-ambients:

- surface ambient;
- endogeous ambient (soil);
- superficial subsurface (rock cracks and holes);
- deep subsurface.

The deeper the more animals have changed to adapt to it. Of all the aspects that characterize the subsurface the most important is the dark, which increases as one moves further from the entrance. This means that animals had to undergo major evolutionary changes in order to be able to move, to defend themselves or run away from predators, to hunt for food and to look for a partner and reproduce in permanent total darkness. Another significant consequence of the absence of light is the gradual disappearance of vegetable organisms that live thanks to the chlorophyll photosynthesis. The superior plants are the first to disappear, while other plants were able to adapt to living in low light conditions. Plants that likely to live deep in caves are ferns (cryptogams) and the last vegetables that disappear are mosses and green- blue algae, that can live in conditions that our eyes perceive as almost total darkness. Therefore without vegetable organisms a very important food source is missing, which is typical of an oligotrophic environment, which means very short on food. In this way the food chain is upset and animals that live there must adapt to this.

Temperature is a very important parameter too because it controls all living beings' metabolisms. Caves have a very particular characteristic: the temperature inside is very stable and remains constant throughout the year at the average outside temperature for the year. This means that most cave animals cannot manage thermal differences and even very minor temperature variations can kill them. Another important parameter is humidity, which is usually very high in caves and around cracks and fractures. Most cave animals need very high humidity levels, close to saturation: some are sthenhydros and need constant humidity. This is the reason why, if we want to go and look for animals in caves we must remember that dry areas are practically uninhabited.

Evolution

Cave environment is hard and selective and a very few organisms have adapted by undergoing specific morphologic and metabolic modifications. Changes aren't immediate, but come as the result of an evolution that can take up to millions of years, starting from species that lived outside and that for many reasons ended up trapped and isolated in underground cavities. Species that have been used to living longer in underground conditions are the ones that show more specific modifications.

In the absence of light, eyes are a useless instrument: species that have lived in caves the longest can be recognized by the fact that they are eyeless, while a species that is in the process of adapting to this type of environment still has eyes but they are very small or underdeveloped. Others have eyes at the time of birth but then they disappear as the animal reaches adulthood. To move in the dark, to feel the presence of predators or other animals of their same kind, they develop other senses: cave organisms generally have long legs, long antennas, hairs and bristles that function as tactile organs as well as a highly developed olfactory sense.

In total darkness, even the ability to fly is useless: cave animals that descend from species that were originally able to fly (such as insects) have all lost this capacity, with the subsequent atrophy and loss of their wings.
In the dark colours disappear too: cave fauna shows a depigmentation phenomenon, animals are scarcely coloured and have mostly light colours such as beige and yellow tones (the colour of chitin), as is the case of many insects, or are completely pale or transparent, such as shrimp or certain fish. It is interesting to notice that species that have adapted only recently, when exposed to the light they tend to regain their colour, while species that have totally adapted to cave life no longer have this capacity and often are killed by the intensity of solar radiation.
The lack of light has an influence also on chitin production (the substance that makes up insects' and crustaceous' exoskeleton), so in general these have a lighter and finer exoskeleton which makes them more vulnerable to predators and dehydration. Some beetles have evolved by developing a particular elytra welding, that creates a cavity inside the abdomen that can contain a small quantity of "reserve" liquids: this is why many cave insects have a large spherical abdomen.

Miniature tigers

Because of the lack of vegetables, in the hypogeous environment the food pyramid is structured differently: the alimentary base is represented by autotrophic bacteria, which are organisms that are able to produce organic substance not from light but directly from mineral substances, such as nitrobacteria (that use nitrogen), sulphur bacteria (that use sulphur) and many others. There is a bacteriophage fauna too, that lives in mud and feeds on bacteria. Bacteriophages are in turn hunted and eaten by the limivous fauna (earthworms, crustaceans, insect larvae), that eats by sifting mud and becomes in turn prey to chilopodas (centipedes), arachnids (spiders), and insects that in caves are at the apex of the food pyramid.
The "large carnivores" are represented by chilopodas and coleopterans, that, in spite of being small, have the same ecological role of lions and tigers in surface environments. Coleopterans are, of all cave animals, the ones with the most sophisticated techniques: they are efficient and terrible predators, provided with a very fine sense of smell, with a great ability to spot their prey and go great distances for food. The mouth and trophus apparatus, which is very sophisticated, leaves no escape to the prey, and makes them into the real "tigers" of the insect world.
Other very efficient hunters are chilopodas and crustaceans, such as shrimp. Fish are troglobe organisms which can be larger (a few tens of centimetres), which is a sign of their position at the apex of the food pyramid in the submerged underground world.

Lifestyles

The cave environment offers very little in the way of food. The trick in underground life is energy saving, so the best adapted organisms are those that need less energy to reproduce and live. For this reason, most of the cave inhabitants have very slow metabolisms: slow growth, small

dimensions, a long life cycle, they are slow and don't move very much, sexual maturation occurs very slowly and very often they maintain the typical characteristics from their youth, they reproduce very little, they are satisfied with minimum quantities of food and normally they use very little oxygen.
Since there is no night and day, their life rhythms aren't based on the usual 24-hour cycle such as other organisms that live under the sun. Because of the scarce food sources, that depend on autotrophic bacteria and the rare supplies coming from the outside, the hypogeous environment can give hospitality only to a very reduced number of species each made up by few individuals: so caves aren't very crowded and have a few predators, which means it is a safe and protected place.

Bats: small devils that need protection

The typical cave animal is the bat. In many caves in tropical areas, bats form colonies made up by thousands or millions of individuals. The show offered by these animals is one of the most fascinating in nature: at dusk they move about the sky, "drawing" a black snake in search of insects. This animal has very particular characteristics: it is the only mammal able to fly, with real wings and muscles unlike other "flying" mammals, such as some squirrel species that simply have skin membranes. But their most particular characteristic is the echolocation system: no other animal has such a precise and sophisticated "radar" system, that allows it fly far from the cave entrance and to hunt even very small prey such as insects. When going through small and narrow paths speleologists are used to feeling a light air current and the butterfly like flapping of wings of a bat that flies through the very narrow spaces between their heads and the cave walls without ever even grazing either one!
Their sophisticated hearing system has given them enormous ears (as opposed to the eyes, which are small and underdeveloped even though bats are not completely blind) and the nose is often very strange looking, since it has been modified to emit certain ultrasounds necessary for orientation purposes. This makes them not particularly nice looking which together with the membranous wings and their dark colour, gives them that "devil like" look. In fact man has put out many stupid and unfair theories about bats being evil and dangerous that in the past (and often at present too) has led to to real persecutions towards them. Many people nowadays are still convinced that these animals will get tangled in one's hair, which is almost impossible, given the highly sophisticated system by which these "little devils" fly and it is more likely that all the noise that we make is going to make them escape faster and a lot more scared than we are! There is another silly belief that bats suck blood: there is only one kind called "vampire", that belongs to the Desmodus genus, that lives in South America, that generally bites his preys without hurting because his saliva contains anticoagulants as well as a kind of anaesthetic. Contrary to what most people believe, it is a tiny animal just a few centimetres long, that can such a very small amount of blood (unable to kill a person!) and generally attacks quadrupeds, that don't have hands that can fight it off. The vampire bat has a social behaviour that makes it

easier to forgive its feeding habits: since they aren't able to resist without food for more than a few hours, they help their babies and wounded or sick ones that can't seek food for themselves, by regurgitating food into their mouths.
Leaving behind legends and popular traditions, bats are in fact very useful animals: in fact they are great insect hunters, which they eat by tons every night. If they are adequately protected, they are very efficient "natural insecticides", that don't cost at all, don't pollute and make our summer nights more interesting with their oscillating flight. Their guano is also a very fine and rich fertilizer. Unfortunately, they are becoming rare animals in industrialized countries because of the large amount of pesticides used, which, by killing their usual preys, end up poisoning our little friend too.

Dragon tales

The animal man's fantasy located in caves, as a guardian of huge treasures or kidnapped princesses, is the dragon. But are they only legends? Very often are exaggerations of reality and legends on dragons aren't an exception. Dragons are generally provided of wings, just like bats (and devils too in the end): maybe these small cave inhabitants scared them so much, that in some way, they seemed to be bigger than what they actually are.
Many palaeontology findings (such as the dinosaur ones) have contributed surely on making up legends on dragons and on the fact that often many big bones have been found in caves (such as for example, the cavern bears, the big Ursus spelaeus) and this made people think that these places were homes of these fantastic animals. For instance, in the southern part of Italy, the findings of elephant fossils, which skull has a big hole for the nasal cavity where the proboscis starts, gave life to Cyclops legends, gigantic beings that have one big eye in the middle of their forehead. But legends on dragons had an extraordinary confirmation in 1689. A naturalist called Valvassor, one of the first cave scientists, found in a fount near by a cave of the Carso a small curious animal: long and pinkish, that has 4 paws, a long tail and two strange red whorls on the sides of the muzzle without eyes, this animal seemed like a small dragon in miniature…surely a cub of some kind of gigantic and monstrous being, taken out of the waters! In 1768 the mystery was revealed: it wasn't a dragon's cub, but an adult specimen of Proteus anguinus, one of the most strange cave inhabitants.

Proteus

It's an amphibious, a distant salamander relative, that represents one of the most surprising adaptations of life in caves. It lives in caves in the Oriental Mediterranean area, in Dalmazia, Slovenia and in the Carso triestino and goriziano part. It is 20-30 centimetres long, pinkish colour and extended form, with a long tail and 4 small paws (that have 3 anterior fingers and 2 posterior), that aren't though able to sustain it, so the proteus can't walk but can swim. When it is born it has developed eyes, but these, during the growth, regress completely. Their particularity are the red whorls of the gills on the sides of the muzzle, that remain in the adult stage too. The proteus doesn't complete his metamorphosis and remains at the larva status, which is young, all life long: it is practically an eternal baby… Many underground biospeleology labs that rear them so they can study them better, but it is difficult for them to reproduce in captivity. In 1832, Alberto Parolini who is a naturalist introduced a few specimen in the Oliero caves, near by Vicenza, where the specie was absent. There weren't any news on the introduced proteus and they thought these species didn't survive, but in 1965 a few speleolosubs in the Cogol fount of Veci had an extraordinary meeting with different specimen that, evidently, adapted and reproduced, and now it frequent for the speleologists that immerse into the Olieri fount to see these funny small animals. This demonstrates the big adaptability these animals have and they hope it is possible to reinsert it in zones originally presented, but where they disappeared later on, often because of the water pollution.

A vulnerable environment. A cave environment, for it's nature and for the modalities superficial waters enters and moves, is a delicate ambient and very vulnerable to pollution. Their inhabitants, so sensible to small variations around them, are then in big danger.

Only a serious and a focusing environment political can maintain intact this particular ambient and fauna, that for a million years they adapt slowly to very tough life conditions in the world underground. Do we want to help out the mysterious, strange, curious and useful inhabitants of the caves too?

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