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EXPLORATION AND DOCUMENTATION OF UNDERWATER ARTIFICIAL STRUCTURES

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Abstract
The exploration and study of hypogeal structures used to supply water or used as quarries, defence systems, mines, tombs, store rooms or escape routes often requires the support of specialized cave divers. In such cases the aim of the immersion is to obtain information which would otherwise not be accessible; it is for this reason that during a first fact-finding "dive" it is essential to bring to the surface data and images, even when the quality of the photos and videos is not very good because of the murkiness of the water. In most cases submerged hypogeal structures have lost their main function and abandonment is the cause of their being flooded. This results in the risk of structural and environmental decay. Therefore, a dive can present not only technical difficulties but also high biological risks. This is one of the main reasons why, even though the water may be shallow, there are specific requirements that need to be complied with, in order to safely undertake an underwater exploration in an artificial cavity. These requirements include the need for great attention, specific experience in immersions in closed spaces and often the use of complicated equipment for the protection of the diver, which, however, may not be compatible with the logistical and environmental conditions of the space. Therefore, the diver must not be misled by the shallowness of the water and by the apparent banality of a dive in a small space. From a technical point of view these explorations are far less demanding than an excursion in a natural cave, but they can hide a series of dangers which are not usually encountered by those who are used to carrying out immersions exclusively in natural caves. This contribution intends to analyse the most frequent problems encountered during speleological underwater explorations in artificial cavities based on experience, as well as information on technical instruments /equipment and the procedures and precautions to be adopted.
Keywords: submerged artificial cavities, cave diving, risks, pollution.

Riassunto
Strutture ipogee di approvvigionamento idrico, cave, sistemi di difesa, miniere, sepolture, magazzini e vie di fuga possono richiedere il supporto di subacquei specializzati per la loro esplorazione e studio. In queste aree lo scopo delle immersioni è finalizzato al reperimento di informazioni diversamente non accessibili ed è per questo che dopo una prima immersione conoscitiva è fondamentale portare fuori dall'acqua dati e immagini, anche se la frequente cattiva visibilità impedisce molto spesso la realizzazione di foto e filmati accettabili. Nella maggior parte dei casi le strutture ipogee sommerse hanno perso la loro funzione primaria e la condizione di allagamento è dovuta ad abbandono con conseguente rischio di degrado strutturale e ambientale. Una immersione, quindi, oltre a difficoltà di carattere tecnico può presentare elevati rischi biologici. Questo è uno dei principali motivi per i quali, nonostante le scarse profondità, la progressione subacquea in cavità artificiali richiede grande attenzione, esperienza specifica di immersioni in ambienti chiusi e talvolta complesse attrezzature per la protezione dello speleo-subacqueo, il cui impiego non sempre è compatibile con le condizioni logistiche ed ambientali del luogo. Lo speleo-sub non deve quindi lasciarsi condizionare dalla bassa profondità e dalla apparente banalità di immersioni in ambienti di dimensioni contenute. Queste esplorazioni, sotto il punto di vista tecnico, sono di gran lunga meno impegnative di una "punta" in grotta, ma potrebbero nascondere una serie di insidie non usuali per chi è abituato ad immergersi esclusivamente in cavità naturali. Questo contributo è finalizzato ad analizzare le problematiche più frequenti nelle esplorazioni speleo-subacquee in cavità artificiali e a fornire elementi esperienziali ed informazioni su strumenti tecnici, procedure e precauzioni da adottare.
Parole chiave: *cavità artificiali sommerse, speleosubacquea, rischi, inquinamento.*

Introduction

When thinking of a cave diver, one imagines him/her at the bottom of a cave, dirty with mud, surrounded by cavers who, after transporting the equipment, help him/her to set up the outfit on the edge of a cavity sump. At that point, the cavity prevents the team from continuing the exploration, that, on the other hand, can only go ahead thanks to a diver whose attitude and mind-set is very close to that of a caver (Fig. 1).
In spite of this close connection with cavers, in the earlier days of cave diving, there was some hesitancy towards cave divers who were seen to be somewhat reckless and whose equipment had to be carried, and who would rarely bring up anything useful, beside their excitement.
Time and above all facts, instead, have made cave diving an integral part of the exploration and documentation of natural cavities. People have started to become aware

Fig. 1: inside the Su Gologone karst cave in Sardinia: 135 metres is the maximum depth achieved (photo Attilio Eusebio).
Fig. 1: nella sorgente carsica di Su Gologone in Sardegna: massima profondità raggiunta 135 metri (foto Attilio Eusebio).

of what cave divers across the world had been saying for decades. In specifically technical terms, and as concerns risk, there are no major differences between going into a submerged cave and slipping into the hold of a sunken ship. You cannot go back up vertically, you have to exit from where you went in. You have to be well trained and endowed with specialized equipment, and there is the risk of having zero visibility. These and other characteristics made clear that the people best suited to exploring sunken ships were cave divers (Fig. 2). Then came the era of technical diving: great depths and unusual environments. Consequently, shipwrecks and caves became the most important environments for diving, and the first international training courses on technical diving drew inspiration from professional diving and from cave diving. Procedures, equipment and training plans were copied from cave diving.
In a nutshell, without any special merits and without even realizing it, the "ugly duckling" had turned into something magnificent and wonderful, a sort of hero. Obviously, just as they were not daredevils in the past, they are not heroes today. More than the existential events of cave divers, we are interested in having people acknowledging that the experience needed to operate in submerged closed environments is different from the experience required to make complex, deep immersions in "free" bodies of water like the sea or a lake (Fig. 3).
There is a major difference in approach and mind-set between those who practice cave diving successfully and those who dive in waters where the divers can emerge vertically. The safety of cave explorers depends almost exclusively on their specialized training, on their technical skills, on the quantitative and qualitative adequacy of the equipment, and on the progression procedures they use. When we explore hostile environments, whether it be caves, sunken ships or flooded catacombs, being sure that we can retreat and go back the way we went in depends substantially on what we did before going in and during the penetration phase. For instance, safety is dependent on how the cave diver has positioned and fastened the banal rope

Fig. 2: wreck of the Po hospital ship that sank in 1941 in the Valona bay, and was explored by ASSO in 2009 (photo Gennaro Ciavarella).
Fig. 2: il relitto della nave ospedale italiana Po, silurata nel 1941 nella baia di Valona, esplorato dalla ASSO nel 2009 (foto Gennaro Ciavarella).

that is unrolled and fixated as he penetrates inside the structure and that is to be followed on the way back, often with no visibility at all.
It is therefore for the characteristics in common with these immersions and for the similarity with the closed environments mentioned earlier (caves, springs, shipwrecks) that we can add to this scenario the

Fig. 3: detail from within the Po shipwreck (photo Gennaro Ciavarella).
Fig. 3: particolari all'interno del relitto della nave Po (foto Gennaro Ciavarella).

Fig. 4: getting ready to dive in an underground stream interception of an ancient aqueduct near Grottaferrata - Rome (photo Carlo Germani).

Fig. 4: immersione per la verifica della zona di captazione di un antico acquedotto a Grottaferrata - Roma (foto Carlo Germani).

submerged artificial cavities, referring to them in this specific case as "confined" submerged contexts (Fig. 4).

Submerged artificial cavities

Speaking about cave diving immersions in artificial areas may be puzzling at first. We are used to cave divers whose feats make laymen and safety experts' hair stand on end for the depth of the immersions, the length of the penetration, and for other technical and environmental characteristics. Therefore it may seem exaggerated to hear that in order to dive into a five metre deep tank or into an ancient emissary, specialized techniques and equipment should be required. But we must not forget that cave diving is a activity at risk, and even when immersions are made in accordance with international standards and within acceptable safety limits, the risks are nevertheless high. Therefore, the operations are conditioned by the constant compromise between risk containment and accomplishment of the mission for the progress of knowledge. The challenge in pursuing this balance is present also in the case of artificial cavities, that are rarely deep but may be extensive and present very specific difficulties.

Experience teaches us that each immersion is different from the others and that every time the diver needs to adapt configuration and progression to the specific situation. The amount of equipment needs to be kept to an absolute minimum because of the risk of getting caught, getting soiled with mud, and because when you emerge from the sump the items the diver carries are heavy and often there is no room where you can leave them; further, when all else goes well, they restrict your movements. In any case, it is necessary to have at least double breathers, a reel with a main and secondary lifeline, a helmet with three or four lights, a knife, a pair of good quality clippers, dry diving suits protected by a speleological suit and another list of indispensable equipment that you would willingly leave at home. In recent years micro-cameras have been added to the helmet (Fig. 5).

From the above description it is clear why at times,

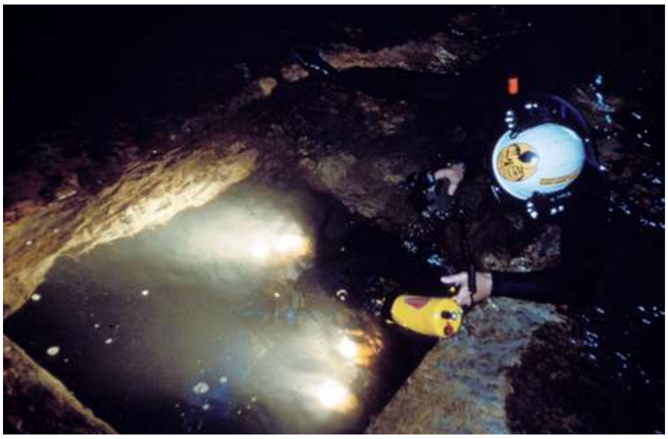

Fig. 5: submerged room under the base of the imperial nymphaeum of the Caves of Pilate (Island of Ponza - Latina) (photo Marco Vitelli).

Fig. 5: la stanza sommersa sotto il basamento del ninfeo imperiale sotterraneo delle "Grotte di Pilato" (Isola di Ponza - Latina) (foto Marco Vitelli).

instead of an immersion, the option of emptying the cavity is taken into account. When the water-filled basin is not extensive, or when the water flow is not high or in polluted settings, pumping out the water may be the only practicable alternative. In a recent exploration carried out by ASSO, we found ourselves in a tunnel that was totally obstructed by more than two metres of liquid mud while the water between roof and mud was about twenty-five centimetres. It was impossible to proceed in immersion and it was impracticable to penetrate the semi-liquid, thick, sticky mud that would have been risky for the divers and for the equipment. We also tried to get through by using professional equipment fuelled by an external air system, video and audio besides back-up cylinders, but we had to give up and proceed to empty the tunnel by means of water pumps (Fig. 6).

Even when the solution is to pump out the water, besides taking into account the aspects related to scientific research and protection of the item, safety and stability of the structure must be assessed. Distance and difference in height need to be considered, in order to establish the characteristics of the pump; electrical pumps and their cables need to be examined carefully; account must be kept of the fact that internal combustion engines are noisy, they vibrate and produce exhaust gases that do not make

Fig. 6: workstation that fuels, detects and controls the breathing mixture and the audio and video signals (photo Marco Vitelli).
Fig. 6: la stazione che alimenta, rileva e controlla la miscela di respirazione e riceve i segnali audio e video (foto Marco Vitelli).

them eligible for being used in closed spaces. These are only a few of the conditioning factors that need to be considered. Before taking action you must check that the place for disposal of the water is suitable both in terms of quantity and quality: otherwise you have the risk of being charged with dumping or unauthorized discharging of polluted water. In various situations, in spite of the fact that the places are far from being a Garden of Eden, a large amount of time may be spent in the uneventful attempt at identifying what public body has competence for issuing the authorization to discharge the liquid contained in ancient items into the sewers.
When assessing any water pumping operation, account must be kept also of the sediments that remain in situ. By protecting the tip of the water pump or of the suction dredge (an aspirator used in underwater archaeological excavations) with a sieve you will avoid inadvertently sucking obstructing particles, but as much mud as possible needs to be removed, above all if the layer of mud is thick (Fig. 7). For cases in which there is a large body of water lying over the sediment, the site is preferably kept underwater because only in this way is an immersion practicable, since it would be impracticable to operate in a deep semi-liquid muddy environment. The sediment that remains after the water is removed will tend to dry in time and solidify thus making removal extremely difficult and virtually impossible once it turns into a dry and compact layer. Direct experience in this sense was acquired by ASSO during the exploration of the Major Cistern of Villa dei Quintili in Rome.
In the case of artificial caves, speleological underwater explorations are aimed at checking old wells, cisterns, underground aqueducts, burial places, effluents, abandoned mines and other submerged areas that are of interest mainly for understanding construction techniques and for studying the origin of their use, as well as for the possibility of finding items belonging to the facility, to those who frequented it or that ended up there for any of a variety of reasons.
These areas may be of interest also for their biological and archaeological contents, and studying the remains of soil and sediments, or concretions or any remains of anthropogenic origin and other human traces, may be of great interest.

Risks associated with the underwater speleological exploration of artificial cavities

As it can be understood, rarely does depth constitute a problem in the context of research in artificial cavities, while the main difficulties are associated with the quality of the water in terms of visibility and degree of pollution.
Visibility is frequently limited or prevented by the suspensions that are present or by the particles stirred up by the diver's movements that are always close to the bed or to the walls because of the shallowness of the water. Divers are always very careful not to raise mud or silt, but the narrow spaces and the deposits that

Fig. 7: sometimes pumping out the water is not enough... (photo Carla Galeazzi).
Fig. 7: talvolta togliere l'acqua non basta... (foto Carla Galeazzi).

are often impalpable defy such efforts. Besides being an obstacle to progression, poor visibility complicates documentation and surveying. In some cases we were compelled to use, with additional problems, diaphragms containing clean water between ourselves and the area being drawn or photographed. In two cases a Ruoff pipe was used, that is a rigid pipe with straight line of one-inch holes into which clean pressure water is pumped that creates a transparent veil between the surveyor and the object being examined. In another case, a plexiglass pyramid containing clear water was positioned between the photographer and the object with huge efforts that did not prove to be very satisfactory.

In addition to the risks we share with our non-diver colleagues like collapses and slides, this type of immersion entails additional complications. Mainly in the form of heaps of rubble, natural obstructions that formed after the item was produced, presence of unbreathable gases that may be present beyond a sump, shortness of breath and, as said earlier, polluted waters.

As regards the accumulation of materials and rubble, divers must use good common sense and take all the precautions they would take in dry or above water areas: never touch unstable piles, never force your way through areas where a slump could obstruct the cavity making it impossible for the diver to make his way back.

When open circuit systems are used for immersions, as in most cases in artificial cavities, it must be remembered that our bubbles could cause the detachment of mud and rubble from the upper layers.

The more dangerous rubble and materials include wires and cables that are often made of iron, and residual pieces of plastic and metal. Hence the need to always carry an electrician's clipper with blades that meet without overlapping and be skilled at using it. Unlike a knife, a clipper can be used single-handedly, without the need to hold the item being cut with the other hand; it easily cuts metal cables, roots and many other materials.

For instance, mention can be made of one of the immersions in the emissary of Lake Albano (Fig. 8). We had to get past a large concretion that obstructed a half submerged pipe after partial emptying, and were compelled to force our way into a passageway that was less than one metre wide and three metres long. Besides various types of wastes, the main problem was represented by the many nylon fishing threads that had been driven into the pipe for about 800 metres by the lake waters. Some threads were quite thick and because of the almost total absence of visibility they got entangled with the lights on our helmets and the cylinder protection, dragging along other threads, plastic bags and… a plastic rocking horse. Pulling or tugging at the threads would not have solved the problem but would probably have made it worse. Instead the clipper solved the problem in a matter of minutes.

Fig. 8: breathers, gas detectors, cameras and other equipment are transported to the point of immersion on two dinghies (photo Marco Vitelli).
Fig. 8: respiratori, rilevatori di gas, telecamere e altre attrezzature trasportate al luogo di immersione su due canotti (foto Marco Vitelli).

Fig. 10: Misericordia Church at Foggia: instrumented inspections of the "well of the dead" (photo Gennaro Ciavarella).
Fig. 10: ispezioni strumentali nel "Pozzo dei Morti" della Chiesa della Misericordia a Foggia (foto Gennaro Ciavarella).

Another kind of entanglement that requires attention is with one's lifeline. Even though care is always taken to avoid getting it tangled, there may be situations in which it is indispensable to use a "disentanglement" technique that cave divers must be able to do with their eyes closed. It consists in cutting the lifeline after connecting the upstream and downstream sections from the cut to robust elastic tubes. This enables to recover the line and prevent it from disappearing into the darkness with a very risky elastic rebound effect.

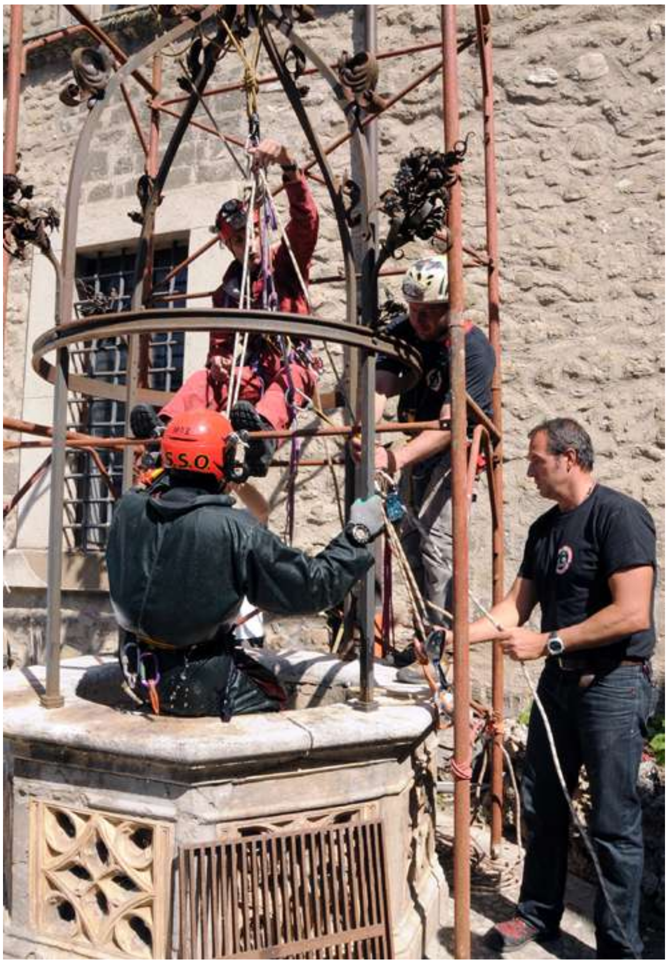

Fig. 9: starting for a dive into the Palazzo Brancaccio's well in San Gregorio Da Sassola - Rome (photo Marco Vitelli).
Fig. 9: pronti all'immersione nel pozzo di Palazzo Brancaccio a San Gregorio Da Sassola - Roma (foto Marco Vitelli).

Limitations and subjective and objective risks

A few words are given in this section about shortness of breath. This is one of the risks that all cave divers must be trained to prevent, and if it does occur he must know how to handle it. Thick dry suit, cumbersome equipment, no visibility, making one's way through an often fettered milieu, may create the preconditions for shortness of breath that if uncontrolled may lead to disastrous consequences even in shallow waters.

Another element that must not be underestimated is the possibility of running into areas saturated with harmful gases or, often, with a high concentration of carbon dioxide. Cave divers face these risks more than other divers because they may emerge in places that are isolated from the general context where there may be gases due to the decomposition of organic materials (animals, wood, etc.), to civil or industrial wastes, thermal or volcanic activity, or other causes related for instance to closed mines. This is the reason why, when the diver emerges he continues to breath from his air reserve until the values measured by the multi-gas detectors, that are carried inside watertight containers, indicate acceptable parameters.

Environmental pollution

All the technical problems and risks analysed so far become of secondary importance in the presence of pollution, the factor that more than any other conditions the researches carried out in hypogeal structures of anthropogenic origin.

Tunnels, wells and other underground spaces are frequently directly and indirectly the receptacles of rain and runoff waters and waste of different kinds. In some cases, the environmental condition is so evident that it does not require any special evaluation. The pollution induced by urban and

Fig. 11: a well camera that is to be integrated with a light source. Alternately, if size allows, a protected camera endowed with lights can be used (photo Mario Mazzoli).

Fig. 11: una telecamera da pozzo da integrare con una fonte di luce. In alternativa, se la dimensione lo consente, può essere utilizzata una telecamera scafandrata in una custodia subacquea dotata di illuminatori (foto Mario Mazzoli).

Fig. 12: the underground stream interception of the Domusnovas aqueduct (Sardinia) connected to the "Su Stampu de Pireddu" cave spring (photo Marco Vitelli).

Fig. 12: la captazione dell'acquedotto di Domusnovas (Sardegna), collegato alla sorgente sotterranea della grotta di "Su Stampu de Pireddu" (foto Marco Vitelli).

industrial settlements, farming activities, materials dragged by rain and wind, leakage from unsuitable or ill-maintained sewers and other evident causes may come to add to the more subtle and unknown sources, the so-called '*not points*' (Fig. 9).

Water analysis is an indispensable preliminary support for underwater explorations. Chemical physical, biological, toxicological and bacteriological tests are mandatory. The reliability of results is subject to the sampling method and to the credibility of the laboratory that conducts the analyses. In general the parameters that are evaluated are the organoleptic parameters (smell, flavour, colour and muddiness); chemical and physical parameters (pH, conductivity, temperature, hardness, etc.) but in our specific area they are to be accompanied by tests on undesirable or toxic substances (nitrates, iron, ammonia, arsenic, lead, pesticides, etc.) and by microbiological tests (coliform bacteria, faecal streptococcus, etc.).

While there are not many chemical substances that can give rise to acute intoxications, except for cases of massive contamination, the main risk is due to microbiological contaminants among which the Hepatitis A virus is one of the most dangerous forms of virus.

Another aspect to be monitored, even when the waters have values that are below the safety limits, is stirring the mud with the flippers. Divers may come into contact with pollutants contained in the sediments raised by the flippers.

For these reasons when there are doubts about the waters it is absolutely necessary to perform tests. Tests must always be made of waters in urban areas, and if there are risks of infection the water of the submerged area must be pumped out, and, if this is not possible, diving equipment must be used that ensures that the diver does not come into direct contact with the water. As regards pumping out water from an area, as said earlier, polluted waters are to be treated in accordance with the relevant disposal methods, and procedures must be adopted to protect the technicians and pumps, and after the operation equipment, hoses and outfits must be disinfected. These are not operations easy to be carried out. Immersions with equipment that prevents the diver from coming into contact with the water require the use of complex devices, a high level of technical specialisation in preparing the activity and logistic facilities that are not always compatible with the situation. Dry suits are used and deep-sea diving helmets linked to the distribution unit through an "umbilical cord" that transports the breathing mixture and audio/video signals. A cylinder carried by the diver

on his back ensures a reserve for emergency conditions, and connection with the workstation enables the diver to talk to the ground staff and to send camera images.
This type of apparatus is cumbersome and makes movements awkward, and the umbilical cable is an obstacle to movement; hence, it is not advisable to exceed distances of 100/150 metres. Even these operations envisage protection of ancillary staff and a lengthy disinfection procedure of apparatuses and equipment.
On the basis of the above, and notwithstanding the type of immersions made, divers should consider vaccination, in particular against tetanus, typhus and Hepatitis A.
In the case of polluted waters with acceptable visibility, inspections may be carried out by using wire-guided devices or special cameras (Figs. 10 and 11). In wells and cisterns the results are generally good while this type of equipment is hardly ever useful in narrow tunnels where they could get jammed and compel cave divers to intervene to recover them.

Legal aspects and liability

Immersions have the aim of studying, investigating, verifying, monitoring and exploring; for these reasons, cave divers are constantly faced with situations that cannot be envisaged in training manuals. Safety therefore can only be guaranteed by complying strictly with international standards and with general prevention and protection criteria.
Cave diving exceeds the limits of sports immersions and can be easily coded as “professional”. Consequently the people in charge of the activity must prove they have specific skills and that they deliver adequate on-going training for their divers whose health must be monitored regularly. Even in the rare case in which a magistrate were to consider an activity of this type as a “sport” activity the member of the team who has greatest expertise, or the team leader, also holds civil and criminal liability for the whole team (Fig. 12).
Therefore, also from the legal point of view it is important to be in a position to demonstrate that attention has been paid to attenuating all the possible risks. In summary, the explorer makes immersions after an appropriate preparation and is aware that in the course of the exploration he runs the risk of accidents and pathologies caused by physical, mechanical, biological or chemical agents. Consequently, also from the legal standpoint it is of critical importance that the organizers make sure that the exploration team is aware of, and ready to comply with, the written prevention and protection procedures which provide for all the functions linked to the organization of immersions, to their correct implementation and relevant accountability. Prior risk assessment is absolutely mandatory together with the identification of prevention and protection measures to be adopted for divers and for all the people providing support and assistance from the ground.

Conclusions

In spite of all the limitations presented in this paper, cave divers are absolutely necessary in the exploration of underwater artificial cavities. Today additional support comes from the new technologies for data gathering and for immersion, as for instance re-breathers, but there is an unquestionable need to have recourse to specialists who besides having specific competence and skills also know how to do teamwork.

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