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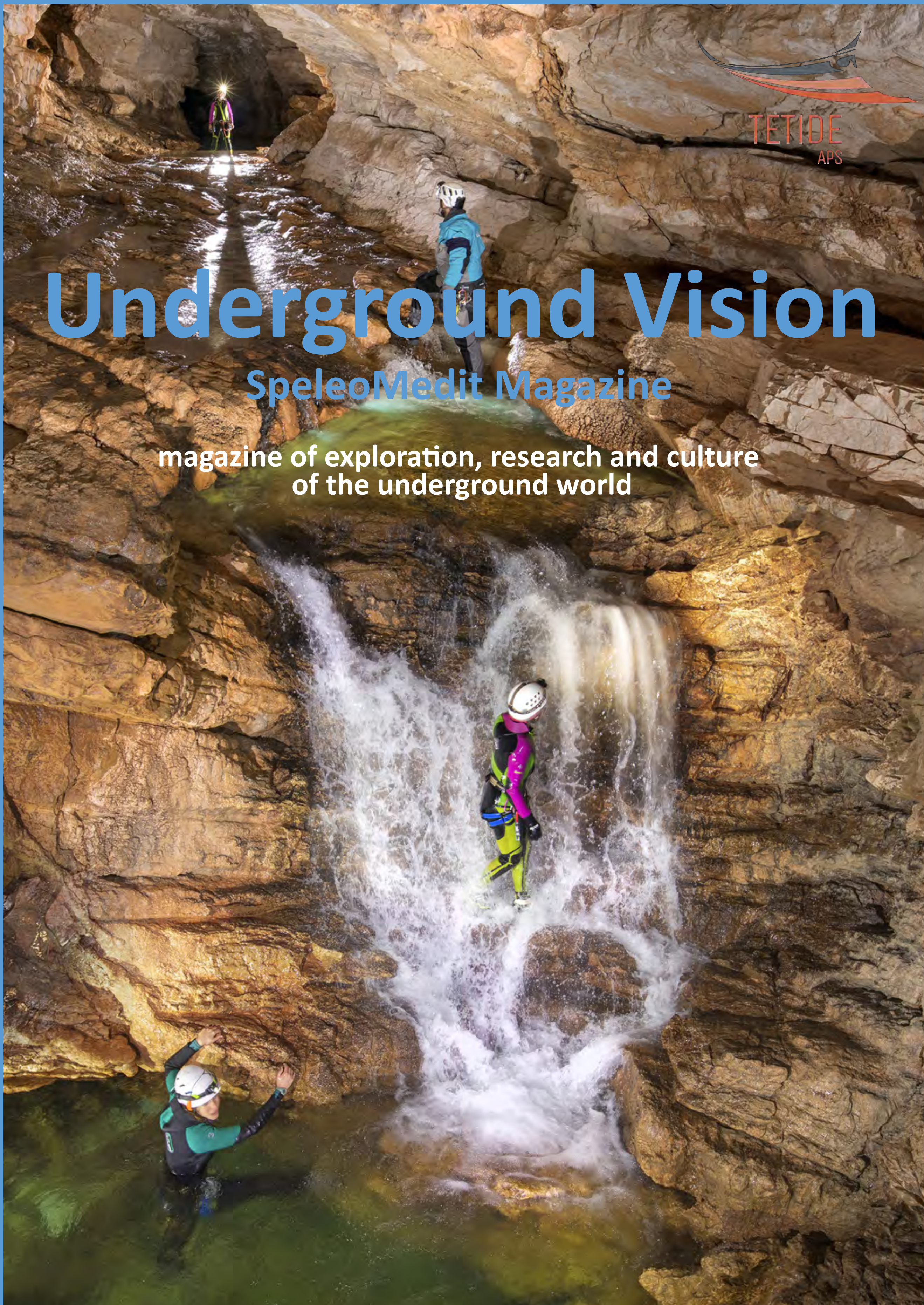

Underground Vision

SpeleoMedit Magazine

magazine of exploration, research and culture of the underground world

n 3 September 2026

https://speleomedit.tetide.org/magazine/

ubmission Guidelines for Authors: Technical Specifications

The Editorial Board of SpeleoMedit Magazine requires strict adherence to the following technical parameters to ensure the highest quality of publication for all submitted content (exploration reports, scientific notes, and essays).

I. Manuscript and Content Separation

The main manuscript must be submitted in an open, unformatted text format (e.g., standard .txt or a clean, non-styled .docx). This is to facilitate typesetting.

Content Separation: All graphical elements (images, maps, tables) must be separate from the main text. Do not embed them.

Placement Markers: Use clear in-text markers (e.g., [INSERT FIGURE 1 HERE]) to indicate the desired position of each graphic.

Citations: Bibliography must follow a standard academic style (e.g., Harvard, Vancouver) at the manuscript's end.

II. Visual Media and Quality Control

All visual materials (photographs, maps, drawings) must be supplied as individual files and meet these minimum criteria:

Resolution: Images must possess a minimum resolution of 300 dots per inch (dpi) at the physical dimensions intended for print reproduction. Low-resolution files will be rejected.

File Formats: Accepted formats are high-quality raster files (JPEG minimum compression, TIFF, PNG) or appropriate vector formats (EPS, AI) for maps and diagrams.

File Naming: Files must be named logically and sequentially (e.g., ArticleTitle_Fig01.jpg).

III. Caption and Credit Submission

Separate File: Captions and all necessary credits must be compiled in a single, separate, unformatted text file.

Content: This file must list the sequential marker, the full descriptive caption, and all credits (Photographer/Creator Name, Affiliation, Copyright/License details) for every submitted visual element.

Submissions that fail to meet these technical specifications will not proceed to the editorial review stage.

On the cover: Photo collage Victor Ferrer

Graphic Francesco Maurano

Tetide APS (Eds)

Underground Vision - SpeleoMedit Magazine

Magazine of exploration, research and culture of the underground world

Underground Vision

SpeleoMedit Magazine

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Editor Tetide APS

Tetide APS
Caselle in Pittari (SA), Italy
September 2026

In the next issue
CYRENAICA KARST PROJECT

Rosario Ruggier, Abdelsalam Elshaafi, , Awad Bilal, Fathi Salloum, Saad Elshari

A research campaign on the karst geomorphology and caves of Jabal Al Akhdar (Green Mountains) began in 2007 through an agreement between the University of Benghazi in Libya and the Hyblean Center of Speleo-Hydrogeological Research in Ragusa, Italy.

The main goal of the project is to develop a speleological model explaining the evolution of caves in relation to tectonic activity and climate changes in the Tethyan-Mediterranean region since the end of the Cretaceous. The research also has practical objectives, such as identifying and protecting new water resources, mapping areas potentially at risk of instability or sinkholes, and establishing important karst geosites and a possible Geopark.

Field investigations were carried out between 2007 and 2009 and resumed in 2022–2026. They focused on several karst areas, including Benghazi, Sousa, El Marj, Al Baydah, Darnah and Tobruk.

In Benghazi, researchers studied large collapse dolines connected to underground groundwater drainage systems. Particular attention was also given to the Lethe karst system, which contains a large underground lake and has historical importance because it was used for tourism during the Italian colonial period.

Near Sousa, the Brak Notta karst system was investigated. It includes a collapse doline and two large doline-lakes connected by a tectonic structure. These features influence the movement of brackish groundwater between the sea and the inland areas, depending on tidal variations.

In the elevated areas of Al Baydah and the El Marj plateau, researchers identified large dolines and swallow holes within a typical cockpit-karst landscape. In the Darnah plateau, the exploration of a complex cave system also led to the discovery of paleontological and archaeological remains.

The investigations are still ongoing. Their main purpose is to understand how the caves and karst landscape of Cyrenaica developed in response to tectonic activity and climatic changes during the Plio-Pleistocene.

Hawa Al Gaigab cave

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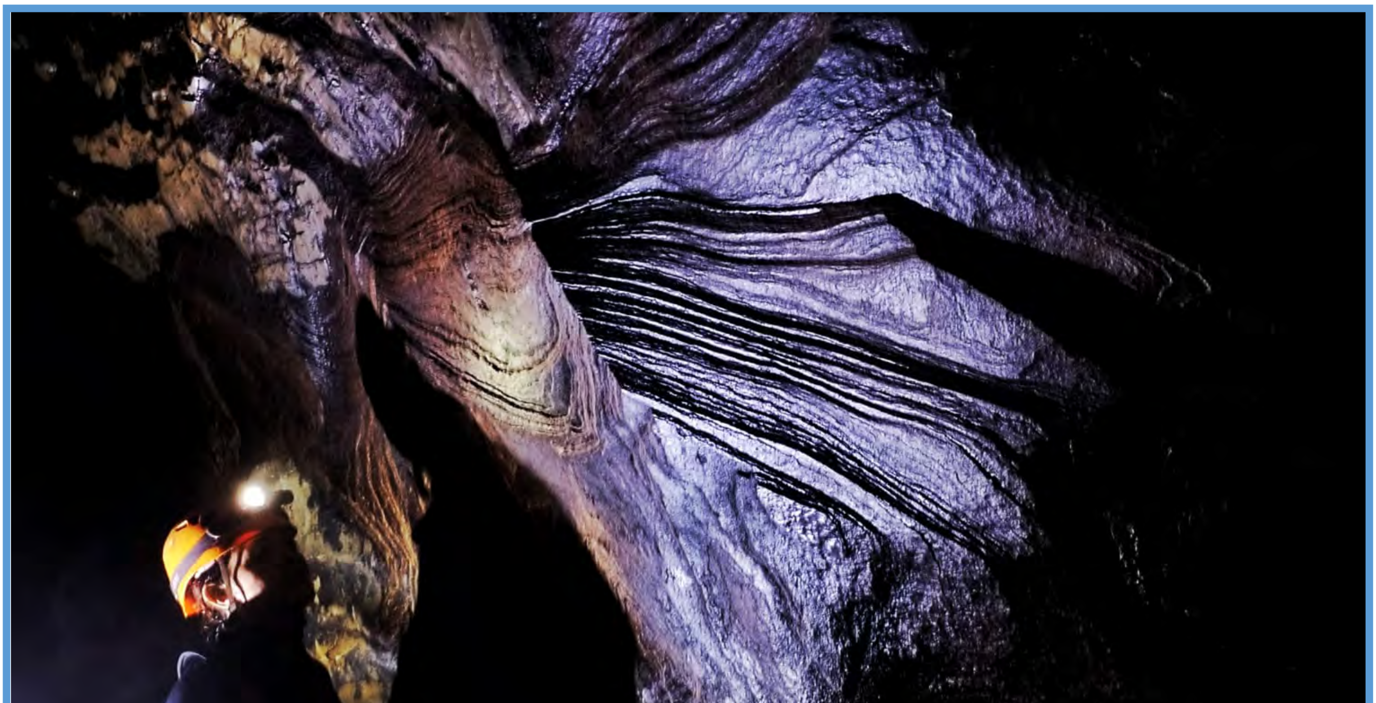
EDITORIAL
LEARNING TO SEE IN THE DARK

Ferdinando Didonna
vice-presidente Tetide APS ferdinando.didonna@tetide.org

There is a moment, upon entering a cave, when the surface world slowly ceases to exist.
The light changes, sounds grow muted, and distances become hard to perceive. What remains before us is rock, water, darkness, and that distinct sensation accompanying every exploration: the awareness of having stepped into an environment governed by its own rules.
It is precisely from this feeling that this fourth issue of **Underground Vision** is born—welcoming our readers into the autumn season following a vibrant summer of field discoveries and international projects.
We have chosen to tell the story of speleology through diverse perspectives because we believe a cave is never just a place to cross. It is an environment to observe, study, document, and above all, learn to understand.
Photography is perhaps one of the most immediate mediums for expressing this relationship with the subterranean world. During the workshop with Robbie Shone on Mount Cucco, eleven speleologists from around the globe focused on the art of "painting with light." Yet before mastering the technique, they learned to observe—to pause, to read spaces, shapes, and proportions before ever pressing the shutter. It is a lesson that lies at the very heart of speleology: before we can see, we must learn how to look.
And looking means noticing what usually remains invisible.
Beneath the surface lies a realm of life extraordinarily adapted to darkness—fragile, rare, and often understudied. The Italian "Cave Animal of the Year" campaign reminds us how vital it is to bring this biodiversity out of the dark, turning scientific research and citizen science into powerful tools for awareness and protection of caves and karst.
Yet the underground world also speaks directly to the changes occurring on the surface.
The Grotta della Neve in the Cantari Mountains, with its perennial ice, stands as a crucial natural observatory. Monitoring its interior allows us to read—through ice deposits and subterranean microclimates—the direct signals of a changing climate that does not stop at the cave entrance. The subsurface is not isolated from our planet; it is one of its most sensitive indicators.



Bussento resurgence (Ph Giovanni Zaccaria)

Because it is such a delicate ecosystem, exploration demands both awareness and preparation. The experience documented on the island of Lastovo reminds us that an apparently simple, harmless cave can harbor hidden hazards. The presence of high CO^2 concentrations and the resulting oxygen depletion bring us back to a fundamental principle of our discipline: exploration can never be separated from risk assessment and scientific knowledge.

Hand in hand with safety goes deep research. From the Devil's Well in Vouliagmeni to the massive Spanish karst networks of the Cueva de los Chorros, exploration evolves far beyond the search for a new passage. Siphons, water channels, geological structures, and vast underground networks compel us to ask broader questions about how entire karst ecosystems function.

When a cave preserves traces of human history, the journey takes on yet another dimension. At Kocain in Turkey, the sheer scale of the cavity lives alongside inscriptions and artifacts that span centuries. The cave transforms into an archive—holding records of geology, water, fauna, and human legacy.

It is this very complexity that we have gathered in this fourth edition. From Italian peaks to Croatian islands, from Greece and Spain to Turkey and Morocco, these pages capture diverse environments, people, research, and experiences. Bound together by a single principle: speleology is a way of knowing.

In this context, underground photography gains an even deeper purpose. The work of uPIX Underground Photography demonstrates how light becomes a tool to reveal the unseen while conveying the fragility of subterranean spaces. Photographing a cave is not merely about creating a striking image; it is about sharing these hidden worlds with those who may never see them, inspiring a collective desire to protect them.

This is why we named this publication ***Underground Vision***. Not simply because we speak of what lies beneath our feet, but because we believe the underground world teaches us a different way of seeing the planet itself.

To enter a cave is to navigate a gallery, descend a pitch, or cross a siphon. But it is also to observe a living organism, read a rock layer, measure a temperature, recognize a hazard, interpret a trace of the past, and document environmental change. It is the synthesis of experience, curiosity, and knowledge.

Perhaps that is the deepest meaning of exploration: not simply pushing further, but understanding a little better what lies before us.

Because in the dark, seeing is not just a matter of light.

To see is to understand.

Enjoy the reading.

Tounjcica cave (Ph Dinko Stopic)

A HAZARDOUS STRATIFIED CAVE ATMOSPHERE IMMEDIATELY BELOW A LARGE ENTRANCE: FIELD OBSERVATIONS AND HUMAN RESPONSE FROM LASTOVO ISLAND, CROATIA

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ABSTRACT

During exploration and documentation activities in a vadose cave section with pronounced pit-like morphology, elevated carbon dioxide concentrations were recorded near the entrance using a portable gas detector. Measurements exceeded 10,000 ppm CO_2 at approximately one meter below the surface, while flame extinction tests indicated locally more oxygen-depleted conditions at 1.5 m deep. During photographic documentation involving artificial smoke generation, we experienced physiological and neuropsychological symptoms consistent with hypercapnia and environmental stress exposure.

INTRODUCTION

Caves may act as natural reservoirs of carbon dioxide (CO_2) or be connected to natural CO_2 sources. Atmospheric CO_2 concentrations are currently approximately 420–430 ppm, whereas higher concentrations are commonly recorded in enclosed environments, including caves. In most caves, elevated CO_2 levels do not pose a significant risk to visitors. However, specific geological and ventilation conditions may promote the accumulation of CO_2 to hazardous concentrations, particularly in poorly ventilated chambers and low-lying passages. This condition, commonly referred to by cavers as “bad air,” is often associated with restricted ventilation and, in some cases, gas stratification that produces abrupt changes in air composition. Elevated CO_2 concentrations may also be accompanied by reduced oxygen levels, increasing the risk of both hypercapnia and hypoxia during cave exploration and scientific fieldwork.

In this paper, we document a case of hazardous cave atmosphere characterized by elevated CO_2 concentrations and reduced O_2 levels within a vertical pit. These conditions were detected at a shallow depth immediately below a wide cave entrance, in an area that would normally be considered well ventilated and relatively safe for exploration. The occurrence of a dangerous atmosphere under such apparently favorable conditions highlights the difficulty of recognizing the hazard based solely on cave morphology or proximity to the surface. Our observations demonstrate that potentially life-threatening concentrations of CO_2 and oxygen depletion may develop even in cave sections that appear accessible and benign, emphasizing the importance of awareness, appropriate training, and atmospheric monitoring equipment during cave exploration and scientific field investigations.

CAVE SETTING AND RESEARCH BACKGROUND

The study was conducted on Lastovo Island, Croatia, where speleological investigations are carried out systematically in support of ongoing archaeological research. As part of this documentation effort, both horizontal caves and vertical pits have been surveyed and documented During previous expeditions, elevated carbon dioxide (CO_2) concentrations were recorded in several caves across the island, including both horizontal and vertical ones, indicating that cave-atmosphere hazards may be relatively common in the area.

During summer of 2026, when the most recent field campaign took place. measurements obtained in previously investigated horizontal caves revealed lower CO_2 concentrations than those recorded during earlier visits. Consequently, attention was directed toward a vertical pit in the northern part of the island where elevated CO_2

concentrations ("bad air") had been documented during past explorations. In addition to atmospheric measurements, photographic documentation was planned to record the invisible boundary separating the lower stagnant CO_2-rich air mass from the overlying cave atmosphere.

The observations were made within a confined chamber located in the upper part of the pit, close to the cave entrance. Despite the presence of a wide entrance and the short distance from the surface, the passage exhibited limited air circulation due to its morphology and the presence of a local topographic depression capable of trapping dense air masses. These conditions favored the accumulation of CO_2-rich air near the floor and the development of a stratified atmosphere, characterized by distinct vertical gradients in gas composition.

During the field investigation, two researchers remained in the vicinity of the affected zone for approximately 30 minutes while documenting the atmospheric conditions and the stratification boundary. Both individuals subsequently experienced symptoms consistent with exposure to elevated CO_2 concentrations and reduced oxygen levels.

METHODS

Atmospheric carbon dioxide (CO_2) concentrations were measured using an Extech CO250 indoor air quality monitor. Oxygen levels were assessed in the field using the empirical Bic lighter test, whereby flame behavior was used as a qualitative indicator of oxygen depletion. A standard butane lighter flame typically goes out when oxygen levels drop below 13% to 15%. Although not intended as a quantitative measurement, the test provided a rapid indication of reduced oxygen availability within the affected zone. In addition, the physiological response of the participants was evaluated immediately after exiting the cave using an Apple Watch, which provided estimates of peripheral oxygen saturation (SpO_2) and heart rate.

The geometry of the cave passage was documented using a built-in mobile-device LiDAR sensor, and three-dimensional models were generated with the Polycam application. The resulting models were used to characterize the morphology of the entrance area and the vertical shaft where atmospheric stratification was observed.

To visualize airflow patterns and identify the boundary between atmospheric layers, smoke was generated and released within the shaft. A method used also in investigations of smoke stratification in archeological sites (e.g. Fuente-Fernández, 2022). The movement and accumulation of smoke were documented through photographs and video recordings. This procedure enabled the visualization of cave-air stratification and the delineation of the interface between the denser, CO_2-rich air mass and the overlying atmosphere.

THE BOUNDARY

A distinct atmospheric boundary was observed within the entrance shaft. Carbon dioxide concentrations began to increase immediately below the entrance, exceeding 1,000 ppm within the upper part of the shaft. Approximately 1 m below the entrance, CO_2 concentrations exceeded the upper measurement limit of the Extech CO250 instrument (>10,000 ppm). At a depth of approximately 1.5 m, the Bic lighter test failed to produce ignition, indicating oxygen depletion within the lower air mass.

Smoke-tracer experiments revealed a well-defined interface separating the upper cave atmosphere from the denser stagnant layer below. The transition occurred over a relatively short vertical distance and was characterized by an abrupt deterioration of air quality. The observed stratification was sufficiently sharp that atmospheric conditions changed from apparently normal near the entrance to potentially hazardous within less than 2 m of vertical descent.

The position of the boundary was sufficiently stable to permit photographic documentation using smoke tracers (Fig. 1), indicating limited mixing between the upper and lower air masses during the observation period.

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Fig.1. Atmospheric boundary identified by smoke-tracer experiments in the entrance shaft. Smoke released into the pit remained trapped within the lower air mass, revealing a sharp interface between the stagnant CO_2-rich atmosphere and the overlying air (photo credit Sotirios Kountouras). Carbon dioxide concentrations exceeded 10,000 ppm below the boundary, while oxygen depletion was indicated by failure of the Bic lighter test

PHYSIOLOGICAL RESPONSE AND PARTICIPANT OBSERVATIONS

Both participants reported symptoms consistent with exposure to an atmosphere characterized by elevated CO_2 concentrations and oxygen depletion. The most prominent symptoms included:

air hunger (dyspnea),

anxiety and a strong urge to leave the CO2 enriched area,

derealization and cognitive fog.

Additional symptoms were reported with varying intensity and included:

nausea,

headache,

disorientation,

fatigue and post-exposure somnolence.

Symptoms improved substantially following evacuation from the cave and subsequent exposure to fresh air. No persistent respiratory impairment or other long-term effects were observed.

It is noteworthy that both participants were highly experienced in cave exploration and had extensive training in speleology, diving, and, in the case of one participant, cave diving. Both had previously worked in cave environments affected by hazardous atmospheres, including elevated carbon dioxide concentrations, oxygen depletion, and hydrogen sulfide. Consequently, the observed psychological and physiological responses cannot be attributed to inexperience or unfamiliarity with underground environments.

Fieldwork began with atmospheric assessment, including measurements of carbon dioxide concentrations and identification of the oxygen-depleted zone using the Bic lighter test. During the first 20–25 minutes of exposure, neither participant reported significant discomfort or anxiety. Subsequently, however, both experienced a progressively increasing urge to leave the area despite the absence of any obvious external trigger. This feeling was followed by escalating anxiety, which ultimately led to the decision to terminate the investigation and exit the cave. During this period, both participants reported derealization and cognitive impairment, characterized by difficulty concentrating and altered perception of the surroundings. These effects persisted for approximately one hour after leaving the cave before gradually resolving.

Following evacuation from the cave, one participant recorded peripheral oxygen saturation (SpO_2) using an Apple Watch (Fig. 2). The initial measurements were lower than the values typically recorded for the same individual during the preceding seven-day period. The lowest observed value was 88%, whereas most measurements during the reference period ranged between approximately 91% and 98%, with typical values in the mid-to-high 90% range. Subsequent measurements showed a gradual return toward the participant's usual SpO_2 levels following exposure to fresh air. Although smartwatch-based SpO_2 measurements should be interpreted with caution and are not a substitute for medical-grade pulse oximetry, the observations are consistent with the transient physiological effects reported by the participant following exposure to the cave atmosphere.

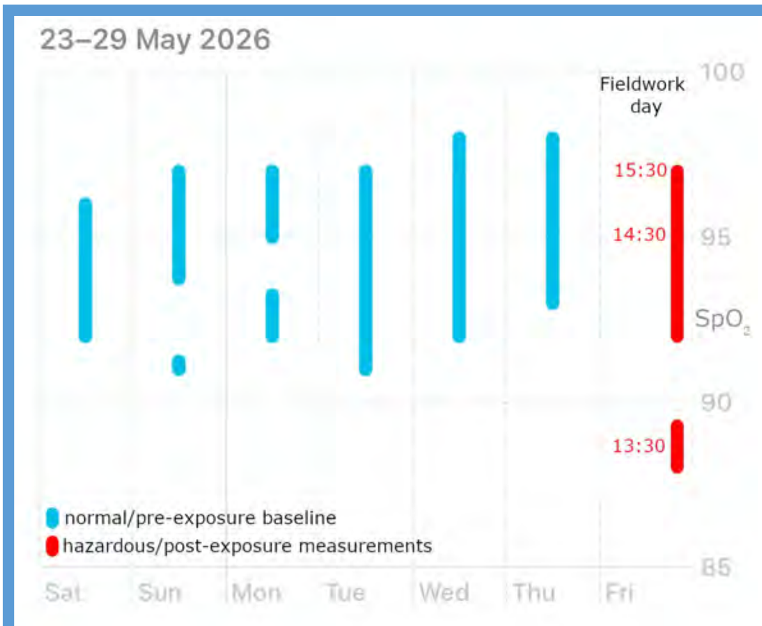

Fig.2: Comparison of baseline and post-exposure peripheral oxygen saturation (SpO_2) values for one participant. Baseline measurements (blue) correspond to the six-day period preceding the field investigation on Lastovo Island. Post-exposure measurements (red), collected immediately after exiting the cave, show a transient decrease in SpO_2 to 88%, followed by recovery toward baseline values (93% and >95%) during the following two hours. These observations are consistent with the temporary physiological effects associated with exposure to elevated CO_2 concentrations and reduced oxygen availability in the cave atmosphere. Measurements were obtained using an Apple Watch and are presented as supportive evidence of physiological response.

DISCUSSION

The field observations and subsequent physiological data document a classic case of localized, density-driven atmospheric stratification within a vertical vadose setting. Although molecular diffusion theoretically promotes the mixing of gases over time, localized accumulations of carbon dioxide occur when the rate of gas influx, either via biogenic soil-air pathways or structural ground-water degassing, exceeds the mechanical ventilation rate of the cave passage (James, 1977; Halbert, 1982).

The morphology of the Lastovo Island pit acts as a highly efficient structural trap. Because carbon dioxide has a density approximately 1.5 times that of ambient air, micro-topographic depressions and dead-end vertical shafts with restricted barometric or convective circulation readily collect descending, dense air masses (Smith, 1999). The sharpness of the boundary observed during the smoke-tracer experiment, where air quality deteriorated drastically over less than 0.4 meters of vertical descent, indicates a highly stable stratification layer sustained by minimal kinetic mixing. This structural phenomenon aligns perfectly with "Type 1 Foul Air" dynamics historically documented in vertical limestone shafts, where carbon dioxide concentrations can rapidly exceed baseline thresholds while concurrently displacing ambient oxygen and nitrogen (James and Dyson, 1981). However, the studied case falls well in "Type 2 Foul Air" caves, where low oxygen levels drop below the normal ones.

The abrupt failure of the standard butane lighter to ignite at 1.5 meters depth provides a reliable qualitative proxy for evaluating severe hypoxia. Standard butane diffusion flames typically undergo complete extinction when ambient oxygen concentrations drop below 13% to 15% by volume. In standard unpolluted atmospheres, an oxygen decline to 15% represents a severe hypoxic hazard. However, within a cave-air matrix where oxygen depletion is driven by the active addition of soil-derived carbon dioxide rather than simple nitrogen displacement, the physiological hazard is compounded exponentially by hypercapnia (Halbert, 1982).

The rapid onset of dyspnea, acute anxiety, cognitive fog, and derealization reported by both participants highlights the profound neuropsychological component of acute hypercapnia exposure. While the Extech CO250 instrumentation maxed out at its operational ceiling of 10,000 ppm (1%), the severity and rapid evolution of the symptoms strongly imply that actual toxic concentrations within the stratified zone were substantially higher, likely operating within the 3% to 5% range.

At these elevated partial pressures, carbon dioxide acts as a potent central nervous system stimulant and independent stressor before profound systemic hypoxia takes effect. The sudden, untriggered urge to evacuate the area is a primitive, highly conserved physiological defense mechanism mediated by central chemoreceptors sensitive to dropping blood pH and respiratory acidosis (Smith, 1999). Furthermore, the introduction of artificial smoke for photographic documentation likely exacerbated the physiological stress loop. Particulate inhalation, even if non-toxic, induces immediate sensory irritation and airway resistance, which amplifies the subjective perception of air hunger (dyspnea) already accelerated by hypercapnia.

The post-exposure pulse oximetry tracking via smartwatch confirms a noticeable transient dip in peripheral oxygen saturation down to 88%, which required up to two hours in open atmospheric conditions to fully recover to standard baselines. While wrist-bound optical sensors are subject to local variables such as high cave humidity or peripheral vasoconstriction from damp environments, the observed curve remains a valuable corroborative indicator of the lag in physiological recovery following acute respiratory distress.

Safety Implications

This incident emphasizes the importance of:

continuous CO_2 and O_2 monitoring,

avoidance of prolonged work in low-ventilation depressions,

immediate evacuation upon symptom onset,

and cautious interpretation of subjective symptoms during cave exploration.

Flame extinction in confined cave sectors should be considered a serious operational warning sign rather than curiosity.

CONCLUSION

The described event represents a field example of hypercapnic cave exposure in a poorly ventilated vadose environment. Beyond the direct physiological effects, the incident illustrates how elevated CO_2 concentrations can significantly impair perception, cognition, and decision-making during underground exploration.

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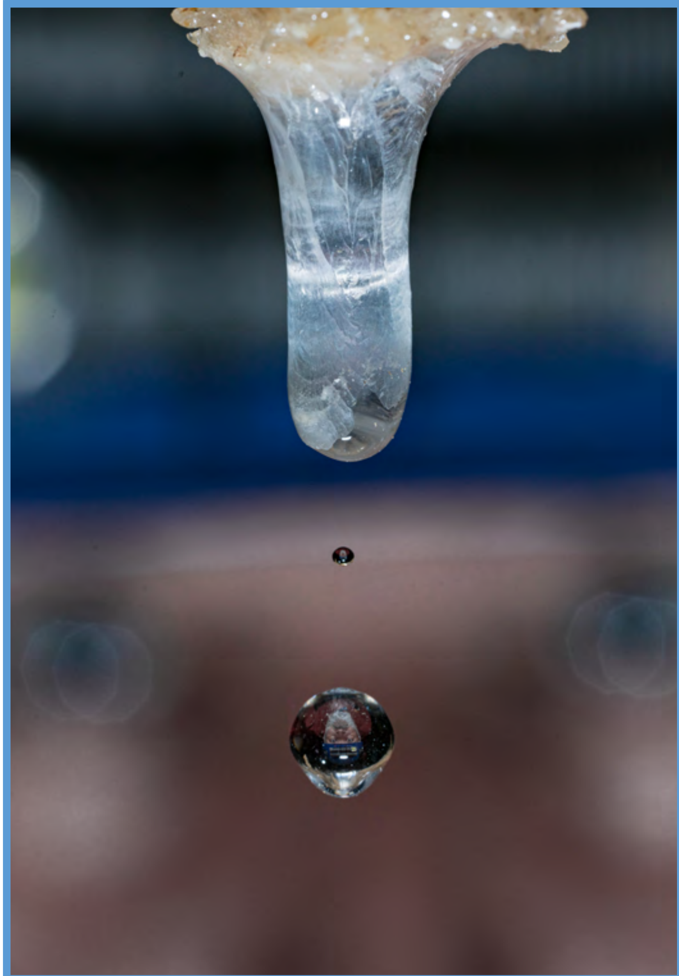
MEDITERRANEAN PHOTOGRAPHERS
UPIX - UDERGROUND PHOTOGRAPHY (ITALY)

uPIX Underground Photography was formally founded in 2016 by a few friends with a shared passion for speleology and photography. Their primary goal was to narrate and document wonderful, often inaccessible environments, bringing their emotions “to light” through photographs.

The team has historically composed of four speleologists: Valeria Miele, Alberto Di Fabio, Luca and Marco Castellani.

We always present ourselves as a team because we believe that teamwork and the synergy of skills bring out the best in achieving our goals.



Drop and reflection. Flash lighting.

Cueva Coventosa,Spain). LED lighting.

We have approximately 20 years of different speleological experience: continuous personal training, participation as instructors in speleology courses to train young speleologists, organization and participation in exploratory camps in Italy, our home country, as well as in non-European countries, technical rescue training, and collaboration with various academic figures in the scientific field.

Given the objective difficulty to describing caves and, more generally, natural and artificial cavities, our aim is to show the underground world beauty through our photographic work, and, if it is possible, to transfer even a small part of the emotions that drive us to cross what we like to call the "threshold of darkness."

When we began our photographic career, we didn't have enough equipment, and the only technique that allowed us to achieve pleasing results was Light Painting. Sometimes friends would lend us old and heavy homemade lights.

The limitations were considerable, so we worked hard on the details.

The availability of affordable LEDs allowed us to completely change our approach and develop our own personal style, which today makes us immediately recognizable to the international speleological community... but it was just the beginning...Flash lighting.

Since then, many things have changed; we self-financed and gradually began to purchase the equipment necessary to grow technically. (Forat Micó, Spain). Salt Cave. LED lighting.

We began to follow many photographers with admiration, who became our references, and who today are also great friends. Friendship is the most important value, and it is the foundation of our "success."(Cueva Cayuela, Spain). Panoramic view. LED lighting.

Today, we work with lights, flashes, reflective surfaces, lasers, and UV, depending on the environments and scenes of interest, in caves, mines, aqueducts, places of worship, and artificial cavities in general.(CuevaMur, Spain). LED lighting.

In the last two years, we have been irresistibly attracted to the use of UV light because it allows us to see the underground world in a completely different way, and it gives us the opportunity to correlate the different inorganic and organic forms of carbon. (Grotte de l'Aspergue, France). LED lighting.

The expressions of esteem and appreciation received over the years have been and continue to be the greatest motivation to strive always to do better. (Coventosa, Spain). LED lighting.

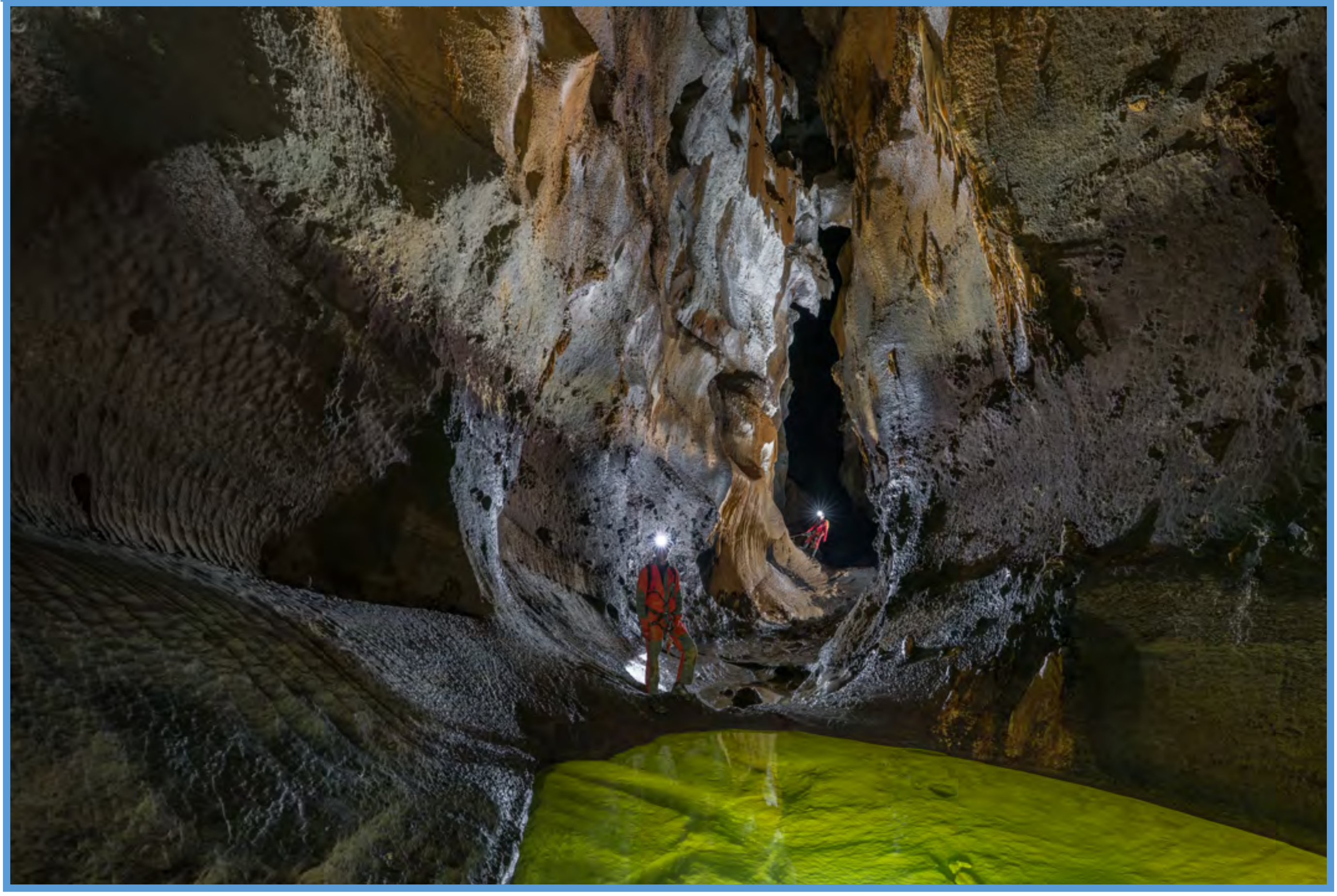
We currently have important partnerships that meet some of our technical needs, for which we are extremely grateful. (Forat Micó, Spain). Salt Cave. LED lighting.

We have organized several speleological-themed photography exhibitions and participated in exhibitions organized by third parties, which have been very well successfully. (CuevaMur, Spain). LED lighting.

We have also received numerous awards, but we will limit ourselves to mentioning that some of our photographs have been selected by UNESCO to promote the recently established Maiella Geopark. (Cueva Cayuela, Spain).

(Cueva Coventosa, Spain). LED lighting.

One of the achievements we are most proud of, is that our work has helped to communicate the fragility of underground environments to observers outside of the speleological world, and to raise awareness local administrators regarding the responsible and sustainable use of these environments. (Forat Micó, Spain). LED lighting.



For the more curious: uPIX stands for uNDER PIXel. (Cueva Coventosa, Spain). LED lighting.

Grotta della Lupa in Maiella, Abruzzo- Italy),. LED lighting.

THE DEVIL'S WELL IN VOULIAGMENI, GREECE: A HYDROGEOLOGICAL ENIGMA AND THE CHRONICLE OF ITS EXPLORATION

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ABSTRACT

The "Devil's Well" ("Pigadi tou Diavolou"), also known as the "Well of Vouliagmeni", lies at the 2nd Limanaki of Vouliagmeni in Attica, Greece. It is a rare, possibly unique karst feature: instead of discharging fresh or brackish water into the sea, as submarine springs (vruljas) normally do, it draws seawater permanently underground at an estimated two cubic metres per second. This paper sets out the chronicle of the underwater explorations carried out at the site, principally by the Hellenic Speleological Exploration Club (SP.EL.E.O.) in 1989 and 2007, describes the technical problems posed by the hydrodynamic conditions, and reviews the three interpretations that have been advanced for the phenomenon. It argues that a geothermally reinforced hydraulic ejector — a natural Venturi — offers the most coherent explanation, examines why the intensity of the inflow varies unpredictably, and proposes a management scheme combining physical safety infrastructure with permanent instrumental monitoring.

INTRODUCTION

Cave diving in the Mediterranean karst calls for a combination of technical diving competence and speleological training. Since 1982 SP.EL.E.O. has applied strict protocols to submerged environments on the principle that a flooded cave system is not an extension of an open-water diving area, and requires different training. The Devil's Well is an extreme illustration of that principle.

The 2nd Limanaki of Vouliagmeni from the air. Eleven metres beneath the calm water of this enclosed bay lies the entrance to the Well; a dive team is visible above it.

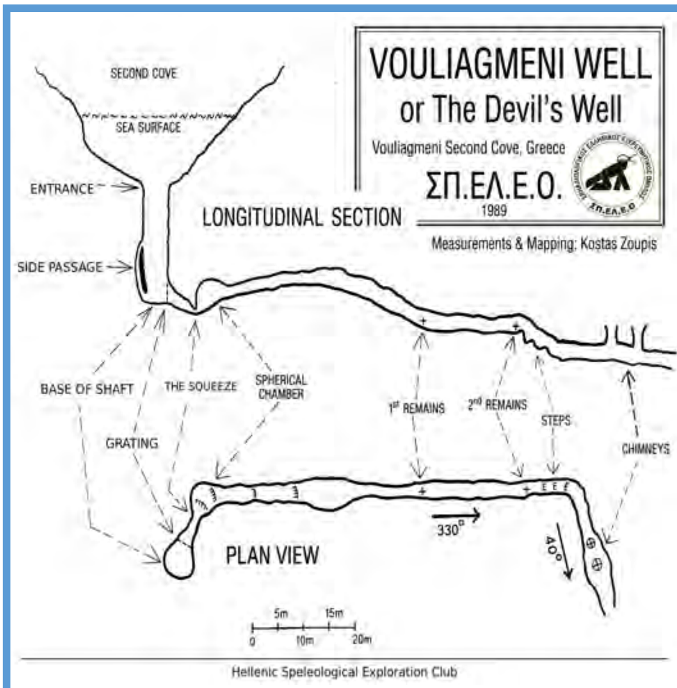
Creator: StrangeTraveler 2026

The site inverts the usual coastal-karst pattern. Where a vrulja discharges groundwater into the sea, the Well swallows the sea. The inflow is continuous, year-round, and strong enough that the practical problem for a diver is not entering the cave but leaving it. Penetration therefore requires rigging, drawn from dry caving rather than open-water practice: a static kernmantle rope rather than a conventional fine guideline, and mechanical rope clamps attached to the diver's harness, so that the exit can be made hand-over-hand against the current.

LOCATION AND MORPHOLOGY

The entrance lies at a depth of 10 to 11 metres in the sheltered bay of the 2nd Limanaki, Vouliagmeni, and takes the form of an almost perfectly circular vertical shaft.

The shaft descends as a cylindrical conduit to 28–29 metres, where the character of the cave changes abruptly and a horizontal passage opens. A side opening at 15 metres forms a small parallel shaft that rejoins the main conduit at about 25 metres, just before the grating.



The first systematic survey of the Well: section and plan showing the entrance shaft, the grating, The Squeeze, the spherical chamber and the main conduit as far as The Chimneys, with the two positions at which the remains of the 1978 divers were found.
Creator: Measurements and mapping by Kostas Zoupis, SP.EL.E.O. exploration team, 1989. Redrawn in 2026 from the original survey.
Affiliation: SP.EL.E.O. - Hellenic Speleological Exploration Club
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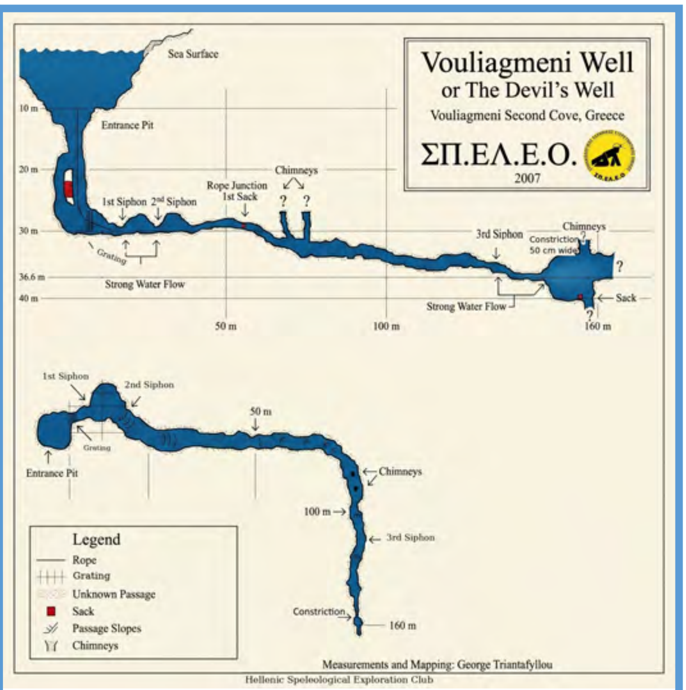

The 2007 survey of the Well. Above, the vertical section with depths, the three siphons, the zones of strong flow, the 50-centimetre constriction and the deep shaft beyond it at -40 m. Below, the plan, showing the entrance pit, the grating, the chimneys and the terminal constriction at 160 metres.
Creator: Measurements and mapping by George Triantafyllou, 14 October 2007
Affiliation: Joint SP.EL.E.O. / Cave Diving Group expedition, 2007
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Five to seven metres into the horizontal section the passage contracts sharply at the point known as The Squeeze: height reduced to 80 centimetres, width to 1.5 metres, over a length of some 1.5 to 2 metres. The constriction accelerates the flow and produces the suction for which the site is notorious.

Beyond it the cave opens into a spherical chamber four metres across, with strong rotational movement and eddies. From this chamber the main conduit runs on an azimuth of 330°, rising initially to 25 metres depth before widening. At a linear distance of 70 metres from the metal grating the floor begins to slope down forming steps, reaching 37 metres. Between 80 and 90 metres the direction changes to azimuth 40°, the passage widens to 4–5 metres, and two upward openings appear in the ceiling — The Chimneys.

The 2007 expedition extended this picture. At roughly 160 metres from the grating and a depth of 36.6 metres the conduit is interrupted by a second, vertical constriction of 6 metres, with a diameter of 50 centimetres. Beyond it the space opens into a sediment-filled shaft descending to approximately 42 metres, with a further restriction two metres across. At this point the conduit divides and the current splits, running simultaneously downwards into the new shaft and across towards the opening.

Plotted on a satellite image, the geometry of the system becomes plain. From the entrance in the bay the cave runs inland, beneath the neck of the headland rather than out under the gulf, and its final surveyed section turns onto the line of a linear structure visible on the surface, most probably a fault. If the passage is guided by that structure, its continuation beyond the point reached in 2007 should follow the same line.

The surveyed plan of the cave laid over a satellite view of the 2nd Limanaki. The scale and the bearings are correct; the width of the passage is schematic. The cave is seen to run inland, beneath the neck of the headland, and its final section turns onto the line of a probable fault visible on the surface.
Creator: Thomas Theodosiadis, on a Google Earth base
Affiliation: SP.EL.E.O. - Hellenic Speleological Exploration Club 2026

THE CHRONICLE OF EXPLORATION

September 1978: the tragedy and the name

In September 1978 the system took the lives of three young American divers from the nearby Hellinikon military base: Donald Michand, aged 32, and the brothers Jan and Mark Granroth, aged 20 and 19. They were competent open-water divers with no cave training and no knowledge of the inflow. Their disappearance was discovered when their clothes were found on the shore; they had already passed the first squeeze and been trapped inside. The search and rescue effort mounted by the port and military authorities failed — the equipment of the period was simply not capable of working against the current. The bodies could not be located for months, and it was in that interval that the name "the Devil's Well" became fixed in local usage. To prevent further accidents the authorities closed the mouth of the horizontal section with a heavy metal grating.

1989: the first systematic exploration and survey

The work grew out of a broader research programme on the hydrological phenomena of the Vouliagmeni area proposed to the SP.EL.E.O. board by Iakovos Karakostanoglou in 1988. In April and May 1989 a large surface support team and a small selected diving team carried out four official expeditions. The cave divers Dimitris Kompiliris and Giannis Spinos succeeded in breaking through the front of the current and passing the squeeze.

On 6 May 1989 the team — Vaggelis Vroutsis, Spyros Georgiou, Kostas Zoupis, Kompiliris, Spinos and others — used caving ascenders locked onto a 100-metre rope rigged as a fixed lifeline to reach 100 metres of penetration at a depth of 38.5 metres. During these dives the remains of the 1978 divers were located. One of their cylinders was recovered and still held 50 atmospheres of air: the men had not run out of gas. They had been trapped by exhaustion, unable to make headway against the eddies and the force of the water.

2006: recovery of the 1978 divers

In 2006 a team of Hellenic Navy divers — Kostas Lazanas, Thanasis Liosis and Makis Themelis — carried out the difficult dive that finally recovered the remains of the American divers, which were handed over to the United States Embassy. The operation was not exploratory, but it demonstrated the level of training the site demands.

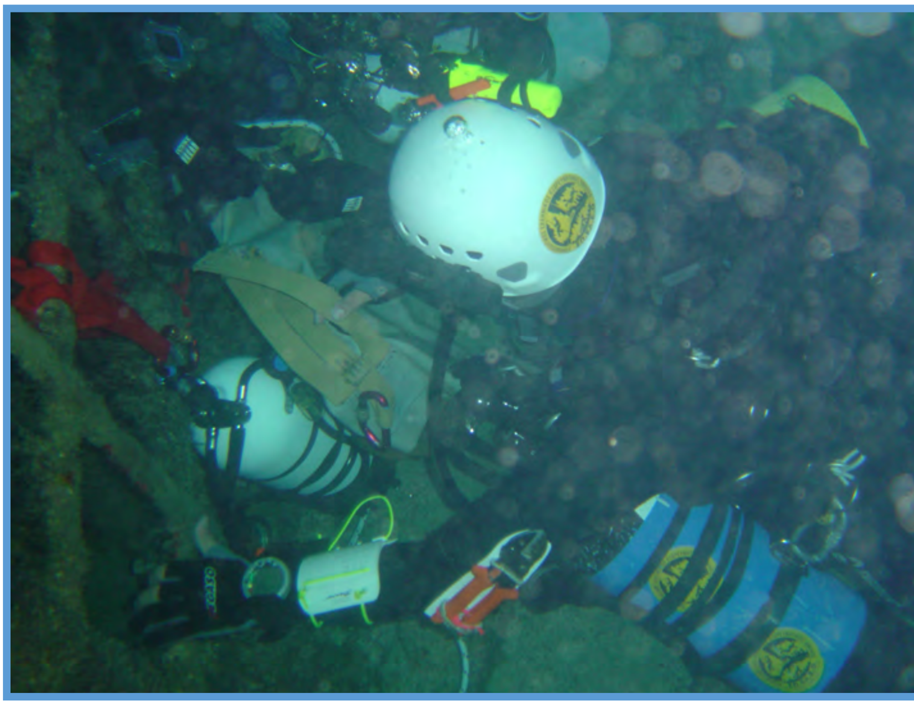
October 2007: international collaboration and 170 metres

The return of SP.EL.E.O. to the Well in October 2007 followed a period of close cooperation with the British Cave Diving Group (CDG), built up after the 2005 International Congress of Speleology in Greece. The expedition was organised by SP.EL.E.O. and led by Vasilis Trizonis. The diving team comprised Trizonis, Giorgos Triantafyllou and Elena Lalou (safety diver), together with Andy Judd — a member of both SP.EL.E.O. and the CDG — and Mike Thomas of the CDG. Surface support was provided by Stergios Theodosiadis, Stavros Triantafyllou and Jenny Lalou. The team worked with high-power LED lighting, side-mount configurations and closed-circuit rebreathers.

On the first penetration Trizonis led with back-mounted cylinders, laying the first 100 metres of line, with Triantafyllou following with side-mount, carrying the next 100 metres, and Thomas and Judd behind with rebreathers. The exit took nearly three hours. The rebreather units proved bulky in the current; Triantafyllou lost the mouthpiece from his regulator and Trizonis lost his line cutter.

The following day a targeted push was made by Triantafyllou, chosen for the low profile of his side-mount rig, supported by Thomas. At about 160 metres from the grating and 36.6 metres depth he located the vertical constriction, 50 centimetres wide, and passed it by pulling the rope in, then tying it to his wrist and allowing the current to carry him through.

Beyond it he made the most consequential observation of the expedition. The current divided. The main and more



Giorgos Triantafyllou with side-mount configuration, photographed in front of the grating on the way out from the final push. Behind him Mike Thomas is recovering the last section of line into a tackle bag. The low profile of the side-mount rig is what allowed the 50-centimetre constriction to be passed.
Creator: Elena Lalou
Affiliation: SP.EL.E.O. / Cave Diving Group expedition, October 2007

forceful body of water ran downwards into the new shaft, carrying with it the sand, debris and shell fragments stripped from the walls; Triantafyllou found nothing resembling a floor. The flow towards the opening across was distinctly weaker, which suggests that this opening functions as a bypass, analogous to the small parallel shaft near

the entrance. The downward branch, in other words, appears to be the actual continuation of the system.
The expedition added roughly 70 metres of new survey to the 1989 plan and confirmed that the conduit extends at least 170 metres from the entrance. The maximum depth recorded was 42 metres, by Judd. This remains the farthest point reached by a diver.

2018 and after

In 2018 a team led by the technical diver Antonis Grafas, with E. Kranidiotis and L. Koutalas, carried out an organised penetration for the purpose of filming a documentary. They advanced to 145 metres of development in the chamber they called the Great Chamber and brought back visual material of rare quality. In late March 2026 a further fatal accident occurred at the site; no official findings have been published.

INTERPRETATIONS

The heat is not local to Vouliagmeni. To the west, at Sousaki, near Agioi Theodoroi, fumaroles still vent carbon dioxide and hydrogen sulphide; to the south-west, the volcano of the Methana peninsula last erupted around 230 BC. These are the two westernmost centres of the South Aegean volcanic arc. To the south-east, on Kythnos, lie the only thermal springs in the Cyclades, at 40.5 and 52.5 °C. Vouliagmeni does not lie on the arc, which passes south of Attica, but sits within the same belt of elevated heat flow and active extensional faulting — enough to account for warm water at depth beneath Hymettus.
Three explanations have been proposed over the decades for a natural pump that draws in an estimated two cubic

The regional setting. In red, the Well and Lake Vouliagmeni; in green, Mount Hymettus, whose meteoric water feeds the system. The purple circles mark the Sousaki - Agioi Theodoroi field and the volcanic peninsula of Methana, the two westernmost centres of the South Aegean volcanic arc; the purple arrow points to Kythnos and its thermal springs. Vouliagmeni lies north of the arc itself, within the same belt of elevated heat flow and active extensional faulting.

Creator: Thomas Theodosiadis

Affiliation: SP.EL.E.O. - Hellenic Speleological Exploration Club 2026

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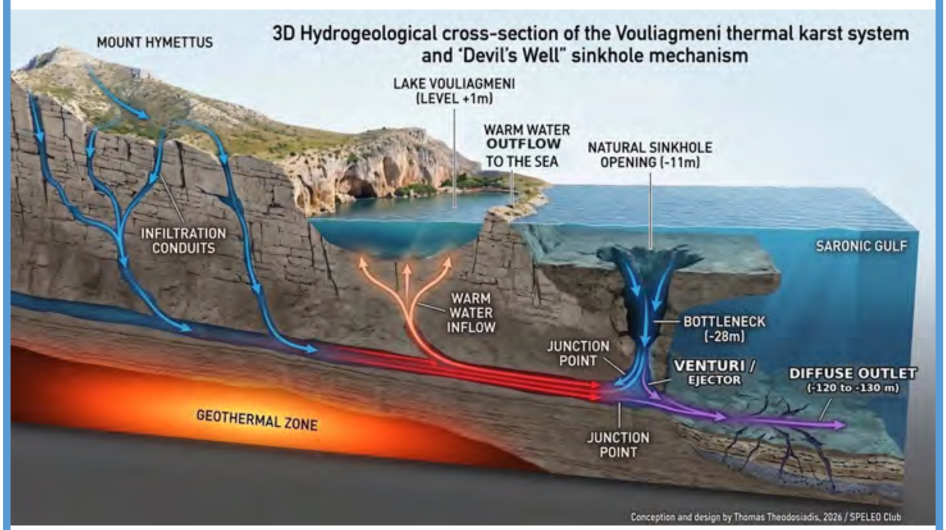
metres of seawater per second.

The geothermal theory (a thermal U-tube). The karst system is treated as a giant U-shaped conduit. Cold, dense seawater entering the Well at 15–18 °C forms the heavy limb. Deep beneath the mountain it meets the geothermal anomaly described above; it warms, expands, becomes lighter and rises towards the surface, for instance at Lake Vouliagmeni. The continuous upward escape acts as a piston, and the space it leaves draws in fresh cold water.
Objection: Thermal expansion produces a slow convective movement, not a violent flow. It is doubtful that it can generate the mechanical energy needed to sustain 2,000 litres per second. A volume of that order — 172,800 cubic metres per day — would also have chilled the geothermal reservoir long ago, unless a heat source of near-volcanic scale existed beneath Vouliagmeni, which the geology does not support.

The marine current theory (a hydrodynamic U-tube). Here the conduit is a continuous pipe discharging at some deeper, unknown point in the Saronic Gulf, and a strong permanent sea current passing over that outlet creates suction by the Bernoulli effect.
Objection: The Saronic Gulf is an enclosed, shallow basin. It has none of the powerful, permanent submarine currents that would be needed to run such a pump 365 days a year.
Both explanations rest on the same physical law. Bernoulli's principle states that in a moving fluid the pressure falls where the speed rises. A Venturi is an arrangement in which that happens: a conduit narrows, the fluid accelerates through the constriction, and the pressure there drops below the pressure outside. When a second opening meets the conduit at that point, the higher pressure outside pushes fluid in and the passing stream carries it away — what engineers call an ejector or jet pump. The two theories therefore differ not in the physics but in what causes the accelerating: a sea current passing over an outlet on the sea floor, or the underground river passing beneath the Well.

The hydraulic ejector theory (Venturi effect with geothermal reinforcement). This is the interpretation SP.EL.E.O. considers most consistent with the evidence. Rainfall infiltrating the Hymettus massif acquires substantial hydrostatic head from the elevation difference and moves seaward as a fast underground river. Where it crosses the Vouliagmeni geothermal field it is heated, expands and accelerates further. Passing beneath the vertical shaft of the Well, this fast, warm flow generates a strong local pressure drop — a Venturi — which continuously entrains seawater from the surface and carries it away as a brackish mixture towards submarine outlets on the floor of the Saronic Gulf.



Hydrogeological model of the natural ejector. Meteoric water from Mount Hymettus descends under hydrostatic head, is heated and accelerated at the geothermal zone, and generates a pressure drop beneath the vertical shaft of the Well that continuously entrains seawater. The mixture is thought to leave through diffuse outlets in the floor of the Saronic Gulf. Schematic, not to scale.
Creator: Thomas Theodosiadis
Affiliation: SP.EL.E.O. - Hellenic Speleological Exploration Club 2026
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AGE OF THE SYSTEM, AND WHERE THE WATER GOES

The conduits were almost certainly formed in air, long before the sea covered them. That places their formation in the Pleistocene, when water locked in the continental ice sheets held sea level in the Saronic Gulf some 120 to 130 metres below the present shoreline. The direct evidence is a stalagmite found at a depth of about 100 metres in the neighbouring Lake Vouliagmeni: stalagmites form only in air.

That sets a working limit on the system. The deepest part of the ancient network — and therefore the deepest plausible position for its submarine outlets today — should lie in the 120–130 metre band.

Where the water re-emerges remains unresolved. If the discharge were a single point source, the volume involved would produce a submarine jet large enough to have been noticed long ago in a gulf as heavily trafficked and as well charted as the Saronic. No such feature has been reported. The likelihood is therefore that the outflow is diffuse, seeping out through an extended network of smaller fissures beneath thick marine sediment — which would make it very difficult to locate without targeted tracer work.

WHY THE FLOW VARIES

Divers have observed for decades that the intensity of the suction is not constant. It fluctuates in ways that make penetration feasible on one day and fatal on another. The system behaves as a strongly non-linear one, with at least six interacting influences.

Seasonal recharge. Heavy rain, and what little snowmelt Hymettus still produces, raises the hydrostatic head, accelerates the underground river and maximises the Venturi suction. Summer drought weakens it.

Barometric and tidal variation. High tide and low atmospheric pressure increase the weight of the water column above the entrance, pressing seawater inward more strongly.

Blockage and morphological change. The inflow drags in sand, sediment and human debris, including tyres. If this material temporarily obstructs the throat of the ejector, the flow drops sharply and then returns in a sudden surge once the obstruction clears.

Seismic and tectonic activity. Even imperceptible micro-earthquakes displace deep rock, opening fissures or pinching conduits and altering flow velocity abruptly.

Geothermal fluctuation. Variation in temperature at depth changes the rate of upward movement and with it the strength of the suction.

Abstraction. Boreholes serving water supply and irrigation in the wider area remove the fresh water that drives the pump, and can be expected to weaken the phenomenon over time.

CONCLUSIONS AND PROPOSALS

Beyond 170 metres the hydrogeological analysis suggests that the cave does not necessarily close but continues to deepen towards the 120–130 metre zone. That raises a legitimate question: given the force of the flow, and given the losses the site has caused, is there sufficient scientific reason to continue pushing the cave with divers? A more productive objective would be to locate the submarine outlet in the Saronic Gulf, if it can be detected at all.

A two-part management scheme is proposed for the site.

Safety infrastructure. The vertical zone, from the entrance to 30 metres, should remain open as a recreation and training area for free divers and scuba divers, served by a permanent surface platform and a fixed heavy descent line in the centre of the shaft. The original iron grating is now corroded and no longer serves its purpose; an inspection in March 2026 also found that the mouth of the horizontal section has widened appreciably in height. It should be replaced with a heavy stainless steel grille incorporating a gate. Access beyond that gate would be restricted to scientific teams, on submission of a documented programme approved by the Hellenic Speleological Federation, the Port Authority and the municipality.

A permanent submarine observatory. A fixed instrument array should be installed at the point where the violent flow begins: a three-dimensional acoustic Doppler current profiler to map the eddies, CTD sensors for conductivity, temperature and depth, turbidity sensors to record transported sediment, and hydrophones for acoustic and micro-seismic monitoring of the conduit. Continuous recording would allow the fluctuations in suction to be correlated directly against rainfall on Hymettus, tidal phase, local barometric pressure, surface currents in the Saronic Gulf and micro-seismicity on the local fault. A multi-parameter record of that kind is the only realistic route to understanding the behaviour of the system.

AUTHOR'S NOTE

The material, technical descriptions and archival research presented here are drawn from the author's forthcoming book on the exploration of the Vouliagmeni Well (expected late 2026 – early 2027).

ABOUT THE AUTHOR

Thomas Theodosiadis is a caver and cave diver with some four decades of field experience, and an independent researcher. He works on the history of caves and speleology, and on the people connected with them. In recent years he has been writing on cave-related subjects, and intends to publish his research in book form. He is a member of SP.EL.E.O. (Hellenic Speleological Exploration Club).

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MEASURING CLIMATE CHANGE: THE SNOW CAVE IN THE CANTARI MOUNTAINS (Simbruini Mountains Regional Park)

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INTRODUCTION AND HISTORICAL CONTEXT

Grotta della Neve (LA 103), located on the slopes of Monte Piano at approximately 1594 m above sea level in the Monti Simbruini Regional Park (Lazio, Italy), is one of the rare documented cases of an Apennine cave hosting perennial ice. The only available research dates back to the work of Scotoni (1972), where for the first time an accurate description was made of the presence, at the bottom of the cavity, of a large sheet of compact ice (see the contemporary survey in Fig. 1).

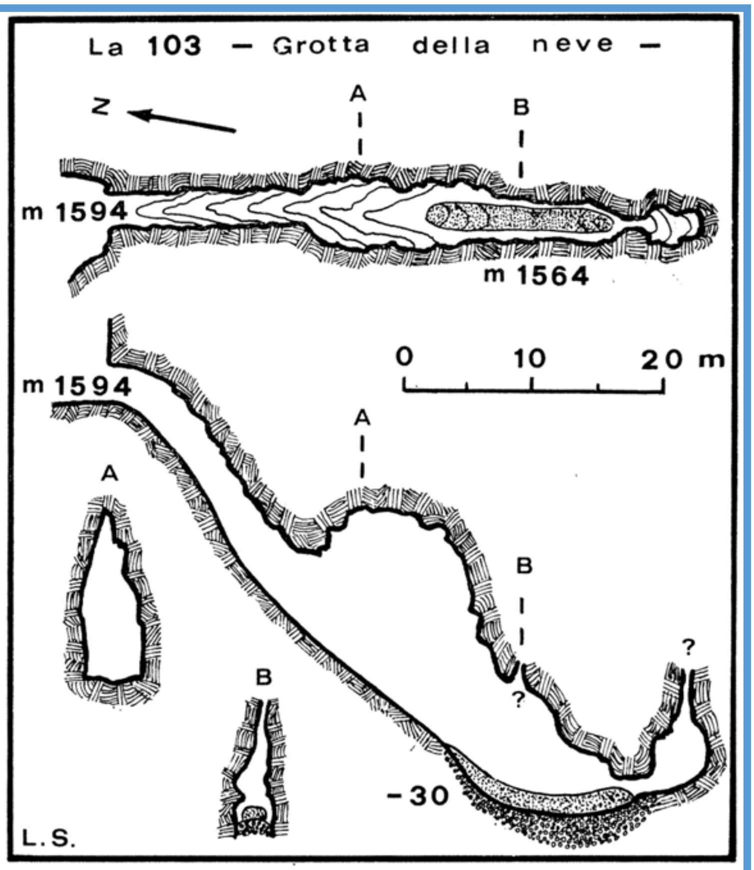


Fig. 1: Historical topographic survey of the cavity (1971). Plan, section, and transverse profiles illustrating the "sack" morphology of the cavity and the location of the original glacial fossil deposit. (From: Scotoni, 1972).

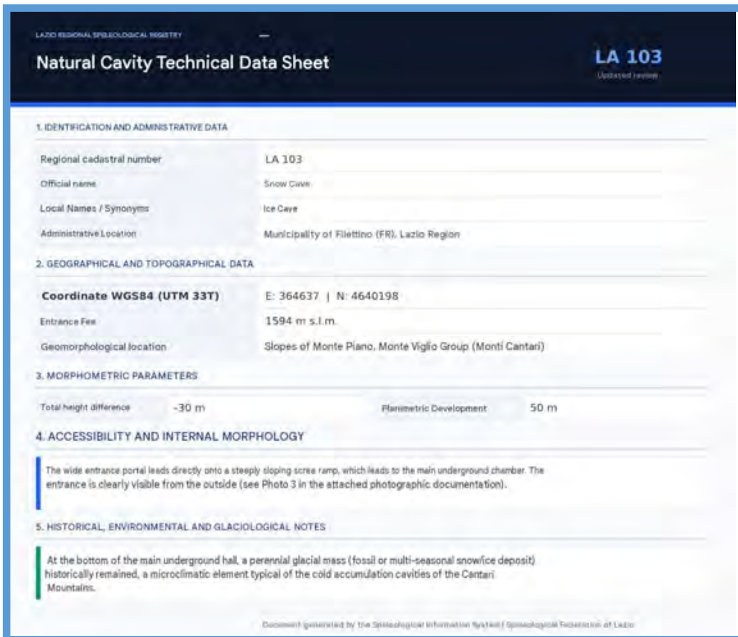
This cave, like other Apennine caves, was used for the ice trade since ancient times, and this practice continued, for local use, until the 1950s. Reliable documents relating to the use of this cave for the ice trade date back to the early 17th century (State Archives of Rome, Chamber II, Snow and Ice, folder 3). A 1615 exclusive contract for the collection and trade of snow explicitly mentions "the ice that is naturally produced in Filettino ." Until 1948, the extracted ice was used primarily for food and medical purposes in the municipality of Filettino (FR, Lazio, Italy), although in the past it was traded and transported to very distant locations.

To date, no recent data exist on the evolution and consistency of the ice deposit in this cave. Therefore, verifying the presence of ice in this cavity and assessing its current size becomes crucial and interesting. Its disappearance or drastic reduction would clearly demonstrate the effects of global warming, even in an environment like the underground, which is known to attenuate the large temperature variations to which surface environments are subject.

Morphologically, the cave has the typical shape of a hypogean icebox. The entrance chute, created by an ancient structural collapse, slopes abruptly inward, creating a geometry that acts as a true "cold air trap." This mechanism traps the harsh winter temperatures at the bottom of the cavity, isolating a mass of perennial ice that can stably withstand summer heat waves.

GEOGRAPHICAL FRAMEWORK AND CADASTRAL POSITIONING

In order to ensure correct scientific identification and avoid historical archival confusion that in the past has led to erroneous overlaps with other nearby caves (such as LA 2463), the official specifications verified by the Regional Registry of Caves of Lazio are reported below:



LAZIO REGIONAL SPELEOLOGICAL REGISTRY

Natural Cavity Technical Data Sheet

LA 103

Updated review

1. IDENTIFICATION AND ADMINISTRATIVE DATA

Regional cadastral number	LA 103
Official name	Snow Cave
Local Names / Synonyms	Ice Cave
Administrative Location	Municipality of Filettino (FR), Lazio Region

2. GEOGRAPHICAL AND TOPOGRAPHICAL DATA

Coordinate WGS84 (UTM 33T)	E: 364637 | N: 4640198
Entrance Fee	1594 m s.l.m.
Geomorphological location	Slopes of Monte Piano, Monte Viglio Group (Monti Cantari)

3. MORPHOMETRIC PARAMETERS

Total height difference	-30 m	Planimetric Development	50 m

4. ACCESSIBILITY AND INTERNAL MORPHOLOGY

The wide entrance portal leads directly onto a steeply sloping scree ramp, which leads to the main underground chamber. The entrance is clearly visible from the outside (see Photo 3 in the attached photographic documentation).

5. HISTORICAL, ENVIRONMENTAL AND GLACIOLOGICAL NOTES

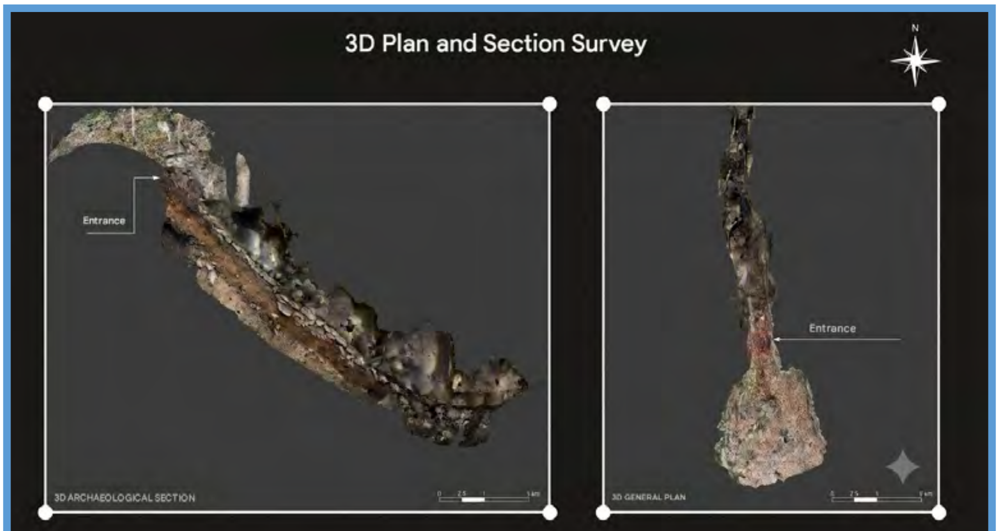
At the bottom of the main underground hall, a perennial glacial mass (fossil or multi-seasonal snowfice deposit) historically remained, a microclimatic element typical of the cold accumulation cavities of the Cantari Mountains.

Document generated by the Speleological Information System / Speleological Federation of Lazio

Extract from the technical data sheet of a natural cave (LA 103 - Grotta della Neve). Geographical context, cadastral data, and key morphometric parameters of the cave located in the municipality of Filettino (FR). (Source: Lazio Regional Speleological Cadastre / Lazio Speleological Federation).

Entrance portal to the Grotta della Neve in the Cantari Mountains. External view of the narrow entrance fissure and the steep entrance scarp that creates the May 2026 cold air trap. (Ph G. Catoni)

A total of three visits to the cave were conducted between April 2025 and June 2026. The first visit was conducted on April 26, 2025, the second on June 8, 2026, and the third on June 29, 2026. The overall continuous microclimatic monitoring lasted 408 days.

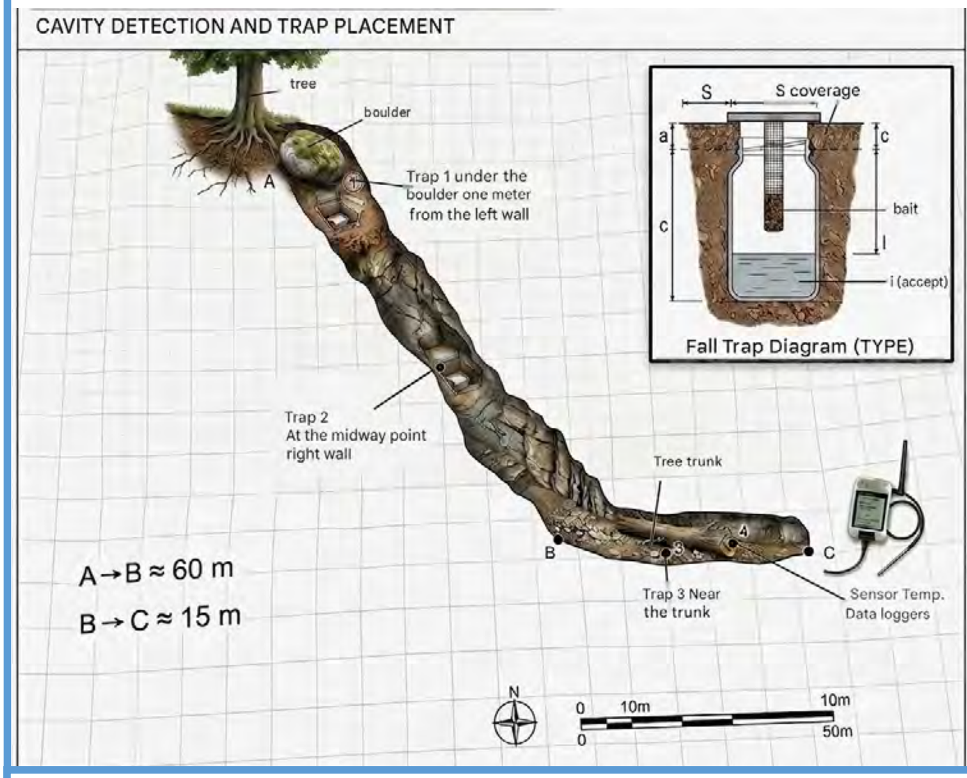


Three-dimensional survey of the Grotta della Neve (LA 103). Plan view and longitudinal section derived from 3D modeling; the volumetric development of the cavity and the steep slope of the access ramp are highlighted. (Digital processing using AI: G. Catoni).

An Elitech RC-51H data logger was used to continuously record temperatures, positioned at the end of the cavity, one meter above the floor. The ice size was assessed using a rigid metal tape measure.

The 3D survey of the cave was performed using the LiDAR sensor of an iPhone 16 Pro, allowing the mapping of the ramp and the terminal hall (see the development of the textured mesh in “3D Model” and at the following link: 3D Model of the Snow Well on

Sketchfab https://sketchfab.com/3d-models/pozzo-della-neve-29b97151d41b4d3bafbfc5bcc030c376).
The fauna sampling and biospeleological surveys were carried out by sight on 06/26/2026 and with the aid of pitfall traps positioned for a period of 40 days in total, specifically from 06/08 to 07/18/2026 (see the instrumental positioning and sampling station diagram).



Schematic cross-section of the underground passageway, showing the positioning of the monitoring equipment. Indication of the location of the data loggers for microclimatic surveys and the biological drop traps along the access ramp. (Graphic processing by AI: G. Catoni).

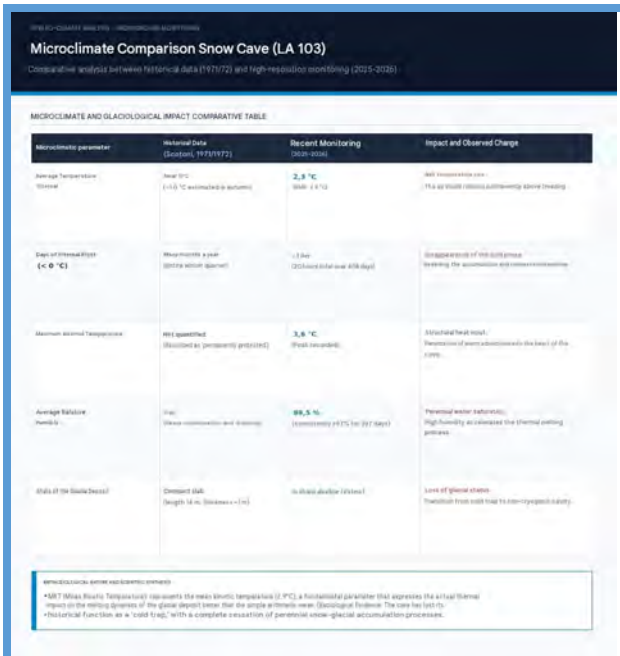
Specimen of underground harvestman (Ischyropsalis sp.). Detail of the biospeleological find made in the deep part of the cave during the 2026 sampling campaign. (Ph G. Catoni).

NOTES ON BIOSPELEOLOGY

Regarding biospeleological aspects, since there is no historical data to allow us to compare any changes in the cave's biocenosis in relation to the evident change in its thermal regime, only the salient data from our observations are reported. Of note is the discovery in the innermost part of the cave of the *Opiliones Ischyropsalis*, a genus of arachnids typical of the Alpine and Apennine regions of Italy, which regularly frequents cold caves on the mountain slopes. The geometrid moth ***Triphosa dubitata*** was also observed in the same area of the cave. This small moth is present in the central Apennines up to the highest altitudes, where it overwinters in natural caves (Mosconi 2008). Finally, the presence of the Trichoptera of the genus ***Stenophylax*** is reported. Specimens of this genus frequently frequent natural caves during the day and in winter, but breed outdoors where water courses are present.

RESULTS AND THERMOMETRIC COMPARISON: 1971 VS 2025-2026

Continuous thermo-hygrometric monitoring and direct comparison with historical measurements highlight the following microclimatic deviations within the underground system, faithfully recorded throughout the entire 408 days of sampling (Graph 1):



Microclimate Comparison Snow Cave (LA 103)

MICROCLIMATE AND GLACIOLOGICAL IMPACT COMPARATIVE TABLE

Microclimatic parameter	Historical Data (Scotoni, 1971/1972)	Recent Monitoring (2025-2026)	Impact and Observed Change
[illegible]	[illegible]	2,3 °C	[illegible]
[illegible] (< 0 °C)	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3,6 °C	[illegible]
[illegible]	[illegible]	99,5 %	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Comparative microclimate analysis and glaciological impact. A brief comparison of historical thermometric data (1971-1972) and recent continuous monitoring (2025-2026) at Grotta della Neve (LA 103). (Digital processing: G. Catoni)

Graph1: Continuous microclimatic time series (2025-2026). Continuous recording of internal temperature (°C) and relative humidity (%RH) parameters inside the cavity, with evidence of temperatures consistently above freezing and high water saturation. (Processing: G. Catoni).

Field checks carried out during the latest monitoring campaigns have highlighted the total disappearance of the historical glacial body on the floor of the hall, reduced exclusively to a small, millimetric and temporary layer of interstitial ice located beneath the debris and collapsed trunks (Photo 1).

Photo1: Condition of the residual glacial deposit (Survey April 2025). Detail of the cavity floor showing the disappearance of the historic slab, reduced to a thin layer of interstitial ice covered by rock debris. (Ph M. Mugione).

DISCUSSION: CORRELATION BETWEEN EXTERNAL MACROCLIMATE AND HYPOGEAL MICROCLIMATE

External Thermal Gradient Change and Comparative Analysis

In the historical study conducted by Lando Scotoni, the estimated average annual external temperature at the cave entrance elevation (1,594 m above sea level) is 5.6°C. Analysis of recent thermo-hygrometric data from the nearby Filettino station (processed and corrected for the 1,594 m above sea level by applying the standard vertical thermal gradient) highlights an external climate pattern profoundly altered by global warming. Averaging the external temperature, the following recent annual values are projected to the cave elevation:

- Annual Average 2023 (1594 m altitude): ~8.11 °C
- Annual Average 2024 (1594 m altitude): ~8.68 °C
- Annual Average 2025 (1594 m altitude): ~8.09 °C

Direct comparison highlights a net increase in the average annual external temperature of between +2.5°C and +3.0°C since the time of Scotoni's survey (1972). This significant atmospheric anomaly has also exerted a linear upward thrust on the underground environment, driving the internal temperature of the Grotta della Neve to the current positive average of 2.3°C. The cavity has thus lost its historical capacity for passive insulation, becoming in tune with the general warming trend of the Simbruini and Cantari massifs.

Analysis of Snow Data and New Scientific Integrations

This study highlights the collapse of the "Snow Cave" geomorphological system as a glacial trap. What was a natural resource of perennial ice for the Filettino community for at least three centuries (from 1600 to the mid-1900s) has now become a cold-temperate cave, where the climate almost no longer allows ice to form and maintain itself throughout the year. The increase in temperatures observed at the bottom of the cave of approximately 1.5°C certainly appears to be the fundamental cause of the disappearance of the ice within it and demonstrates how even the underground environment, albeit with some attenuation, is affected by the changing thermal regime underway in the central Apennines (the complete conceptual framework of the two different seasonal microclimatic responses is summarized in the comparison in Fig. 2).

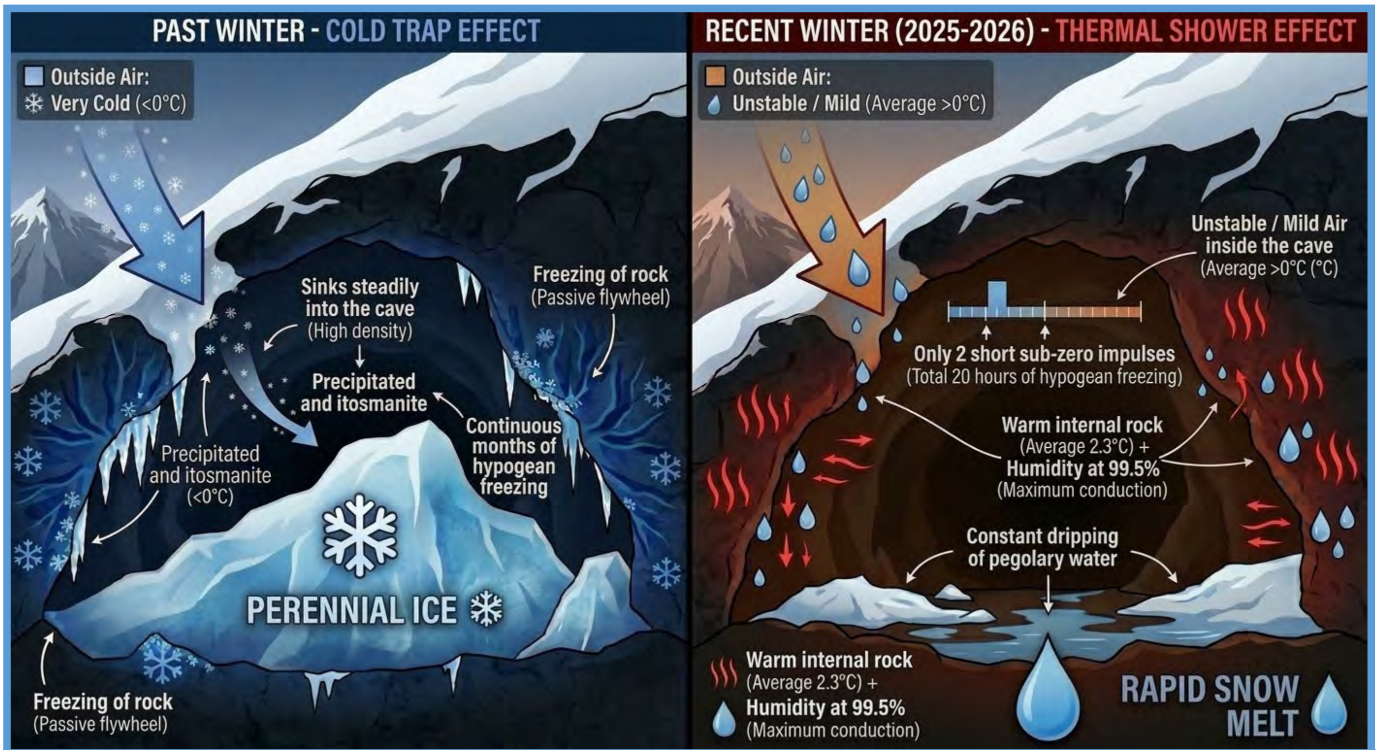
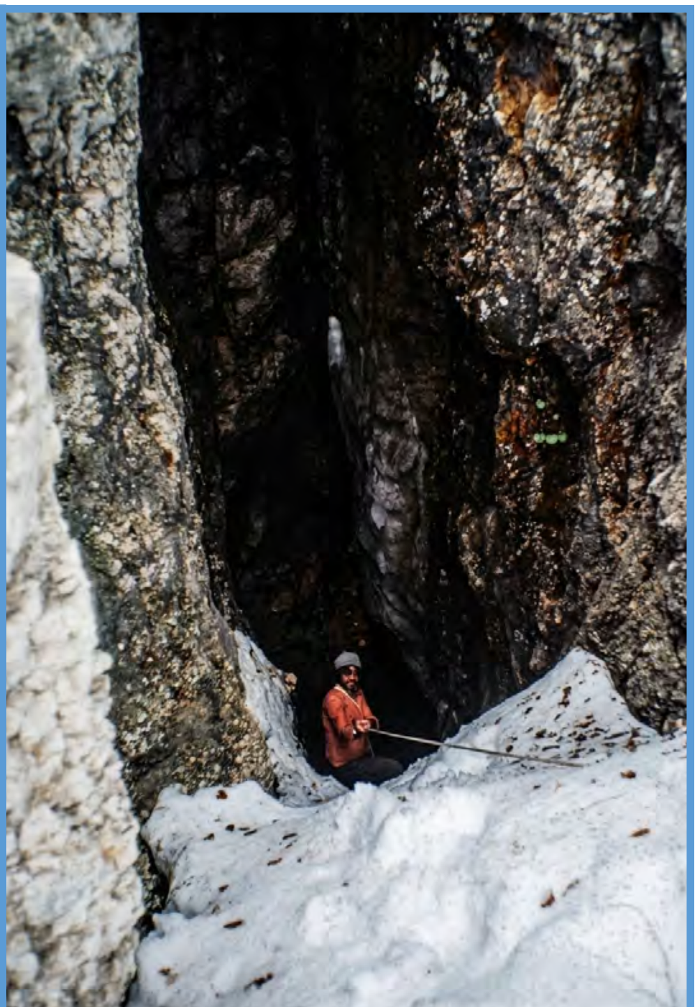


Fig. 2: Conceptual model of microclimatic transition. Schematic comparison between the historical cold trap regime (ice preservation) and the current "thermal shower" regime (accelerated melting of the subterranean mantle). (Graphic processing using AI: G. Catoni).

The increase in temperature in this area of the central Apennines can be deduced by comparing the average winter temperatures of the locality of Filettino for some historical series from the past and recent years. In particular, Scotoni, in his 1972 work, reports an average temperature for this locality in the December-February period of less than 0°C (CNR data 1921-1950). Recent data calculated over 11 years (2015-2025) for the month of January, taken from the website ilMeteo.it , report an average of 2.6°C for the same locality.

A second very important consideration regarding the drastic disappearance of ice in the cave could be related to the significant decrease in snowfall that has afflicted the Apennine areas in recent years. Scotoni also reports for Filettino data taken from the CNR's Average Annual Precipitation Map (1921-1950) , which highlights 17 days of snowfall, lasting approximately two months, and an average depth of 70 cm. The magnitude of these historical winter accumulations is exceptionally confirmed by photographic documentation from the winter of 1984 (Photos 4 and 5), which show the access ramp and the large external portal completely covered by thick layers of snow. Comparable data taken from the website ilMeteo.it report, for the period 2015-2025, an average of only 7.1 days of snow and an average snow depth of just 11 cm.

Underground snow accumulation in the winter of 1984. Archive image showing the massive snow mass along the slope that fed the perennial deposit. (Ph T. Dobosz Archive)



Entrance door to the cave blocked by snow (Winter 1984). Historical documentation of the abundant snow cover outside and at the entrance, testifying to past snow conditions. (Ph T. Dobosz Archive).

Overall, there is little research analyzing historical snow data from the central Apennines; however, a study conducted by the University of Naples Parthenope (Capozzi et al., 2025) analyzed the duration of snow cover in the central-southern Apennines and the number of days with solid precipitation. The research team found that already in the climate period between 1951 and 2001, at stations above 1,000 meters above sea level, a significant reduction in both the number of days with snow cover and solid precipitation had been observed. Specifically, an estimated 3.2 days of reduction in snow cover every 10 years was observed, while a reduction of 1.6 days with solid precipitation every 10 years was calculated for days with snowfall.
Similar and equally alarming conclusions are reported by the CIMA Foundation, which has estimated a drastic reduction in snow water resources throughout the Apennine region, highlighting trends in snow cover that are particularly affecting mid-altitudes and compromising its seasonal persistence in the short and long term.

ACKNOWLEDGEMENTS

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PAINT WITH LIGHT
Four Days Underground with Robbie Shone

Words and photographs by Giacomo Ghiotto

"Sometimes I arrive just when God is ready to have somebody click the shutter."

Ansel Adams

LEARNING TO SEE

There is a tendency to think of cave photography as a highly specialised discipline, one that depends primarily on sophisticated equipment and technical expertise. Four days at Monte Cucco with Robbie Shone suggested otherwise. Cameras, lenses and flashguns are essential, but they are only the means. The real work begins long before the shutter is released. Unlike any other photographic environment, caves offer no natural light. Every highlight, every shadow and every sense of depth must be created deliberately. Nothing is visible until the photographer chooses to reveal it. In that respect, cave photography is less about recording light than about shaping it.

Grotta di Monte Cucco – Costacciaro (PG) Italy (Ph Giacomo Ghiotto)

These ideas formed the basis of a workshop organised by the Federazione Umbra Gruppi Speleologici and Ipogenica APS, bringing together eleven cavers from Australia, Croatia, the Czech Republic, Sweden, Switzerland and Italy. Over four days, Monte Cucco became both classroom and studio, with Robbie guiding us through the practical and creative process behind his images. Those expecting immediate discussions about cameras and exposure settings were quickly surprised. Before anyone unpacked a tripod, Robbie spent time looking. He studied the passage, the relationship between walls and ceiling, the natural lines of the chamber and the way the space unfolded beyond the reach of our headlamps. Only after understanding the cave did photography begin. That approach gradually transformed the way we worked. Instead of searching for spectacular formations, we learned to recognise compositions hidden within the darkness. A chamber rarely revealed itself all at once. It emerged slowly as flashes were positioned, tested and repositioned, each adjustment exposing another fragment of the landscape until the image finally acquired balance.

The process demanded patience. A photograph that might later appear effortless often required an hour of careful preparation. Lights moved by only a few metres altered the mood of a scene entirely, while the position of a single caver could redefine its sense of scale. Nothing underground was accidental. Perhaps the most valuable lesson concerned observation. Rather than trying to illuminate everything, we learned that every photograph depends as much on what remains unseen as on what is revealed. Darkness is not simply the absence of light; it is part of the composition itself. People also assumed a different role. They were rarely the main subject. Instead, they became visual references that gave meaning to the surrounding space. A solitary figure crossing a chamber or standing beneath a towering calcite formation conveyed dimensions that words or surveys alone could never communicate.

Grotta di Monte Cucco – Costacciaro (PG) Italy (Ph Giacomo Ghiotto)

As the practical sessions progressed, another aspect became increasingly clear. Cave photography is inseparable from exploration. Carrying heavy equipment through narrow passages, protecting delicate formations while positioning lights, waiting patiently for everyone to reach the correct position before a long exposure each photograph demanded the same discipline, teamwork and respect that characterise good caving. The camera never replaced exploration; it became another way of participating in it.

Discussions continued well beyond the cave. Evenings were spent reviewing the day's work, comparing different interpretations of the same chamber and questioning the choices behind each frame. Technical issues were certainly addressed, but they rarely dominated the conversation. More often the discussion centred on atmosphere, balance and clarity: what the image communicated rather than how it had been produced. By the end of the first days, it was obvious that mastering equipment was only the beginning. Learning to see required something altogether different: patience, curiosity and the willingness to spend far longer observing a cave than photographing it.

BUILDING AN IMAGE

By the third day, cameras and flashguns had become almost secondary. The mechanics of the process were familiar enough that attention shifted naturally towards something less tangible: the construction of an image. The question was no longer how to illuminate a chamber, but why it should be illuminated in a particular way. Watching Robbie work made that distinction unmistakable. Every location was approached without preconceptions. A chamber that initially seemed spectacular might be abandoned after a few minutes, while an unremarkable passage could become compelling once the right viewpoint emerged. Technical competence was assumed; the real challenge lay in recognising what the cave itself was offering.

One exercise illustrated this perfectly. Nearly an hour passed before a single final exposure was made. Lights were moved repeatedly, shadows softened, a model repositioned by little more than a step, and the camera shifted a few degrees. None of the individual changes appeared dramatic, yet together they transformed the photograph. The strongest images were not built around a single clever idea but through a series of careful refinements, each almost imperceptible on its own. The workshop also revealed how profoundly collaborative cave photography is. Although a finished photograph bears the name of one photographer, its creation depends on an entire team. Someone waits in darkness holding a remote flash, another shields a light to avoid lens flare, while others remain perfectly still during a long exposure. The success of the image depends less on individual talent than on quiet coordination and mutual trust. This effort is largely invisible in the finished frame. What appears to be a naturally illuminated chamber is, in reality, assembled from a carefully choreographed sequence of flashes. During the exposure, the photographer often sees only fragments of the scene. The complete image exists for the first time on the camera screen, bringing together moments of light that were never visible simultaneously to the human eye. Each evening, the day's photographs became the starting point for discussion. Robbie rarely judged an image as simply right or wrong. Instead, he encouraged us to examine the decisions behind it. Was every light contributing to the composition? Did the caver

Grotta di Monte Cucco – Costacciaro (PG) Italy (Ph Giacomo Ghiotto) strengthen the sense of scale, or distract from it? Could removing an element make the photograph more convincing than adding another? Those conversations naturally led to editing. Digital photography encourages abundance, but the workshop argued for restraint. Returning from a cave with hundreds of frames means little if they all describe the same moment. Selecting a small sequence capable of telling a coherent story demands honesty, because photographers remember the effort invested in making an image, while viewers respond only to the image itself.

One evening, the focus shifted from Monte Cucco to South America as members of La Venta presented “Ayuàn Tepui”, their recent expedition to the remote sandstone plateaus of Venezuela. It was a timely reminder that photography occupies a unique place within exploration. Surveys, scientific observations and expedition reports document discoveries with precision, but photographs provide the emotional connection that allows a wider audience to appreciate places they may never experience firsthand. That perspective extends the role of cave photography beyond aesthetics. Images become a means of communication between the underground world and the surface, helping to foster appreciation for environments that are both extraordinary and fragile. In doing so, they also support one of speleology's fundamental responsibilities: conservation. A photograph can inspire curiosity, but it can also encourage respect. By the end of the workshop, the emphasis had shifted almost completely. Technical skills had undoubtedly improved, yet they no longer felt like the main achievement. More important was the growing understanding that a successful cave photograph is not defined by the complexity of its lighting or the sophistication of its equipment, but by its ability to convey the atmosphere of a place honestly. The camera records what stands before it; the photographer decides what deserves to be remembered.

Grotta di Monte Cucco – Costacciaro (PG) Italy (Ph Giacomo Ghiotto)

BEYOND THE PHOTOGRAPH

The final morning was spent reviewing the work produced during the workshop. Seen together, the photographs revealed something we had only gradually understood underground. Although we had often stood in the same chambers and worked with the same subjects, no two interpretations were alike. A different viewpoint, a subtle change in lighting or the position of a single caver was enough to transform the atmosphere of an image. The cave itself had not changed; only the photographer's way of seeing it. That perhaps was the workshop's most enduring lesson. Cave photography is not simply the documentation of an underground landscape, nor is it an exercise in technical virtuosity. It is an act of interpretation. The photographer decides not only what to illuminate, but also what to leave in darkness, creating images that balance information with mystery. The most successful photographs do not reveal everything; they invite the viewer to imagine what lies beyond the edge of the light. The workshop concluded with the presentation of certificates, marking the end of four days that had offered far more than practical instruction. We had learned new approaches to lighting, composition and editing, but those were only part of the experience. More importantly, we had learned to slow down, to observe before acting and to appreciate that every strong image begins with understanding the space rather than the camera.

Looking back, the moments that remain most vivid are not necessarily those when the shutter was released. They are the quiet conversations while refining a composition, the patience required to position lights across a chamber, the silent coordination of a team waiting in darkness for a single exposure, and the satisfaction of watching a photograph gradually emerge on the camera screen. Those moments reflect the essence of speleology itself: exploration achieved through collaboration, curiosity and respect for an environment that demands both.

Grotta di Monte Cucco – Costacciaro (PG) Italy (Ph Giacomo Ghiotto)

Photography has become an essential part of modern cave exploration. It documents discoveries, supports scientific research and allows expeditions to share their work beyond the caving community. More importantly, it creates an emotional connection between hidden places and people who may never have the opportunity to visit them. In doing so, it reminds us that these fragile environments are not simply places to explore, but places to understand and protect.

As we left Monte Cucco, the cameras were packed away, but the most valuable lesson travelled home with us. A successful cave photograph is not measured by the sophistication of its lighting or the perfection of its technique. It succeeds when it communicates something of the atmosphere, scale and quiet wonder of the underground world. The camera is only the instrument; the real craft lies in learning to see.

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Finally, my deepest thanks go to Alessandra and Sofia, whose constant encouragement and support accompany every journey underground.

UNVEILING THE SECRETS OF SUBTERRANEAN LIFE THROUGH THE ITALIAN CAVE ANIMAL OF THE YEAR CAMPAIGN

Ferdinando Didonna[1,2,3] and Luisa Dainelli[1]

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To step inside a cave is to cross a threshold into another world. Beyond the reach of solar radiation, the familiar architecture of life dissolves. There are no seasons here, no green leaves, no sunrise. What remains is a realm defined by absolute darkness, near-saturation humidity, and a stillness that feels almost geologic.

For centuries, human imagination dismissed these subterranean voids as sterile, inorganic spaces — glorified stone vaults where time stands still. But to a biospeleologist, the darkness is far from empty. Within the cracks, pools, and air currents of the karst landscape thrives a highly specialized, fragile biosphere. These organisms do not merely survive in the dark; they have spent millions of years evolving to master it.

To bring this hidden biodiversity into the light, the Società Speleologica Italiana ETS (SSI) launched the national campaign "Animale di Grotta dell'Anno" (Cave Animal of the Year) in 2019, adapting an initiative originally created in Germany in 2009 by the German Speleological Federation (VdHK). Over the past eight years, the Italian project has transformed into an ambitious public science movement.

Through the central digital platform animalidigrotta.speleo.it, technical datasheets, immersive video presentations, interactive educational games, and citizen science monitoring have turned obscure subterranean creatures into global ambassadors for groundwater conservation and ecosystem resilience.

Cave habitats: soil, warter,air. (Ph Francesco Maurano / Official SSI Archive animalidigrotta.speleo.it)

THE ARCHITECTURE OF THE DARK: ECOLOGICAL PILLARS OF CAVE LIFE

Subterranean ecosystems operate under physical constraints found nowhere else on the planet's surface. Without sunlight, primary photosynthetic production is impossible. Energy must either trickle down from the surface or be transported inward by living biological vectors.

The Gatekeepers of Energy in the Twilight Zone

Understanding this fragile energetic balance requires examining how different organisms occupy the underground world: many species use the cave for shelter but must return to the surface at some point in their life cycle. In doing so, they act as living energy pipelines.

Two mating individuals of Limonia Crane Fly (Limonia nubeculosa, 2019 Target Taxon), highlighting boundary fauna inhabiting cave entryways. (Ph Luisa Dainelli)

- **The Twilight Dipteran (*Limonia nubeculosa* – Cave Animal of the Year 2019)**: standing on delicate legs along damp entry walls, this fly served as the inaugural species of the campaign, highlighting the importance of boundary zones between light and darkness.

- **The Bent-Winged Bat (*Miniopterus schreibersii* – Cave Animal of the Year 2022)**: highly migratory bats form large maternity colonies in cave vaults. The organic guano deposited beneath these roosts becomes the fundamental energy engine for a diverse community of cave-dwelling invertebrates, fungi and detritivores.

The Bent-winged Bat (Miniopterus schreibersii, 2022 Target Taxon): its presence in caves is fundamental to supplying organic energy to cave systems via guano deposition. (Ph Fabrizio Darmarin / Official SSI Archive animalidigrotta.speleo.it)

The Tissue Moth (Triphosa dubitata, 2025 Target Taxon) overwintering on a cool, humid cave wall near an entrance zone.
(Ph Fabio Mosconi/ Official SSI Archive animalidigrotta.speleo.it)

• **The Overwintering Moth (*Triphosa dubitata* – Cave Animal of the Year 2025)**: resting on cool, humid walls near cave entrances, these geometrid moths utilize the thermal stability of subterranean entryways to survive harsh winter temperatures, linking forest food webs with the underground realm.

The European Cave Spider (Meta menardi, 2026 Target Taxon) guarding its egg sac in the cave twilight zone. (Ph Enrico Lana/ Official SSI Archive animalidigrotta.speleo.it)

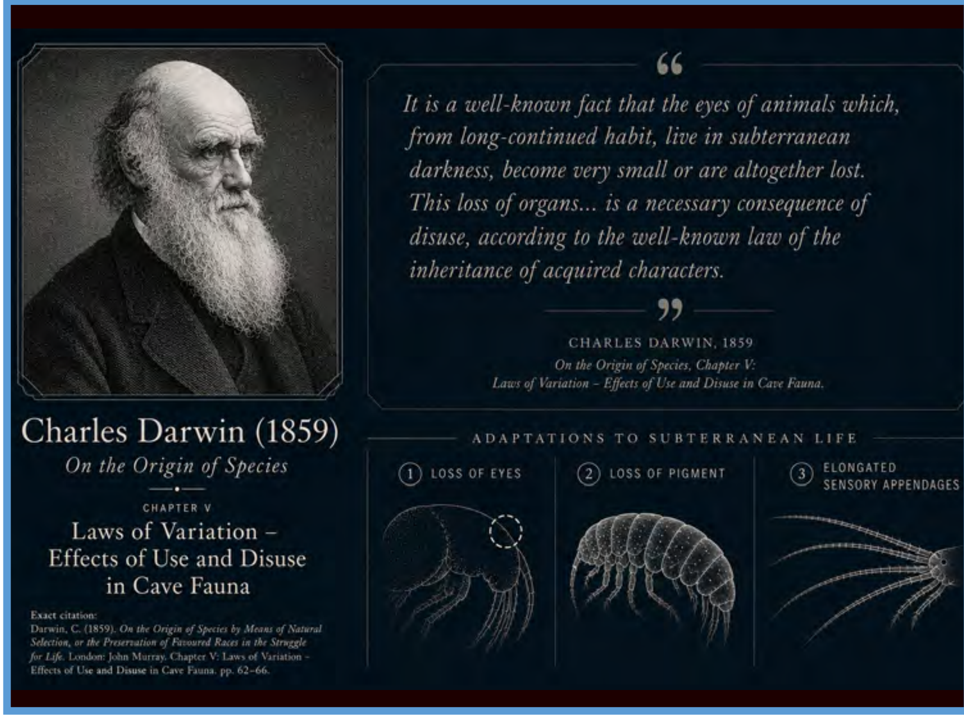
• **The Cave Web Spiders *(Meta menardi & Meta bourneti* – Cave Animal of the Year 2026)**: positioned at the exact border where light dies, these formidable arachnids weave orb webs to capture flying insects drawn toward cave entrances. Their hanging egg sacs (cocoons) act as biological indicators of stable air currents and microclimatic equilibrium. Hundreds of young emerge from the cocoons and, after several molts, disperse outside before eventually returning to other caves.

• **The Cave Salamanders *(Speleomantes spp.* – Cave Animal of the Year 2024)**: these extraordinary lungless amphibians climb vertical cave walls using specialized footpads and project their adhesive tongues with lightning speed to capture prey also in absolute darkness.

Masters of the Deep: Troglobionts and Evolutionary Isolation

In the deep cave zone, where environmental parameters remain constant year-round, dwell the troglobionts. These obligate subterranean species have undergone millions of years of evolutionary modification—a phenomenon known as troglomorphy. The biological mystery of cave adaptation famously caught the attention of **Charles Darwin**. In On the *Origin of Species* (1859), Darwin reflected on the eye loss and elongated appendages of subterranean animals, viewing them as remarkable evidence of evolutionary pressure and adaptation to an environment devoid of light. Today, we know that these species have discarded energetically costly traits like vision (anophthalmia) and skin pigmentation (albinism) while developing hyper-sensitive tactile sensory organs to navigate a world without light:

• **The Ligurian Millipede (*Plectogona sanfilippoi* – Cave Animal of the Year 2020)**: a slow-moving, blind detritivore restricted to the isolated karst networks of Northwestern Italy, exemplifying extreme regional endemicity.



Extreme troglomorphy in action: macro detail of regression features (eye lessness, loss of pigment, and sensory appendage elongation) in a troglobiont invertebrate, illustrating Darwin's theories on subterranean adaptation.
Credit: This infographic was created with the assistance of generative artificial intelligence (AI) for visual composition, illustration, and graphic design. Historical source material and scientific references were independently selected and verified by the authors. The Darwin portrait and quoted material are based on public-domain historical sources.

• **The Apulian Cave Beetle (*Italodytes stammer*i – Cave Animal of the Year 2021)**: A predatory beetle adapted to the flooded and semi-aquatic cave passages of the Murge plateau, illustrating how subterranean evolution branches across land and water.

The Silent Sentinels of Our Drinking Water: Stygofauna

Hidden beneath the dry cave passages lie vast, submerged networks of water known as karst aquifers. The creatures inhabiting these dark aquatic highways are called stygofauna.

The Apulian cave beetle (Italodytes stammeri, 2021 Target Taxon), an endemic predator adapted to flooded cave passages in Southern Italy. (Ph Giovanni Ragone / Official SSI Archive animalidigrotta.speleo.it).

The cave millipede (Plectogona sanfilippoi, 2020 Target Taxon), a blind, depigmented troglobiont endemic to Northwestern Italy. (Ph Valentina Balestra / Official SSI Archive animalidigrotta.speleo.it)

• **The Subterranean Amphipods (*Niphargus spp*. – Cave Animal of the Year 2023)**: translucent, blind, shrimp-like crustaceans that inhabit interstitial groundwater and subterranean streams. Niphargus are vital bioindicators: because they are hyper-sensitive to chemical pollution, agricultural runoff, and oxygen depletion, monitoring their health provides a direct readout of the quality of the freshwater reservoirs that supply millions of human beings on the surface.

A stygobitic amphipod (Niphargus sp., 2023 Target Taxon) in a subterranean stream, acting as a bioindicator for groundwater health. (Ph Andrea Massagli)

GAMIFICATION AND MEDIA: BRINGING BIOSPELEOLOGY TO THE NEXT GENERATION

A central innovation of the Italian campaign hosted at animalidigrotta.speleo.it is its multi-tiered approach to science communication. Recognizing that scientific technicality alone cannot bridge the gap between researchers and the public, the platform integrates engaging multimedia tools designed for diverse audiences:

The European Cave Salamander (Speleomantes sp., 2024 Target Taxon), an endemic terrestrial predator adapted to high subterranean humidity. Collage of various examples of coloration concerning all species of Speleomantes, including hybrids. Credit: Photo by Enrico Lunghi / Official SSI Archive (animalidigrotta.speleo.it).

Educational outreach materials in action: a fanned set of species identification and memory cards from the national "Animale di Grotta dell'Anno" campaign, displaying annual featured taxa such as Limonia nubeculosa (2019) and Plectogona sanfilippoi (2020) used in school toolkits and public engagement events. (Ph Luca Pisani / Official SSI Archive https://speleo.it/site/carte-biospeleo/

Video Mini-Documentaries and Species Showcases

Each annual campaign is accompanied by high-definition video presentations. These short films combine actual cave footage with macro-videography, offering viewers a rare look at live animal behavior in situ — from the wall-climbing mechanics of Speleomantes salamanders to the swimming dynamics of Niphargus in crystal-clear water tables.

Interactive Educational Games and School Toolkits

To engage younger students and tourist cave visitors, the SSI team developed interactive print-and-play materials, digital quizzes, and memory games centered on cave fauna ecology:

- **"Find the Troglobiont" Puzzle Modules**: Games that teach children to identify physical adaptations (e.g., long antennae vs. functional eyes).
- **Food Web Simulators**: Interactive worksheets showing how surface energy flows from bat guano down to microscopic cave fungi and predatory beetles.
- **Citizen Science Field Sheets**: Simplified observation guides distributed to speleological groups, encouraging cavers to log, photograph, and report species sightings without disturbing fragile microhabitats.

PROTECTING WHAT LIES BENEATH

The story of cave animals is ultimately a story about connection. What happens on the surface — from deforestation and pesticide use to groundwater extraction — directly impacts the silent world beneath our feet. Conversely, the health of our subterranean ecosystems dictates the purity of our freshwater springs and the stability of our landscapes.

Through the "Cave Animal of the Year" campaign, Italy has established a blueprint for public engagement in biospeleology. Aligned with the global mission of the UIS Biology Commission, our goal remains clear: to ensure that every cave on Earth is celebrated not only as a geological wonder, but as an irreplaceable sanctuary of evolutionary history.

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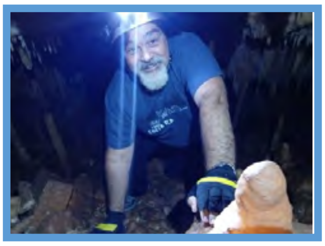
ABOUT THE AUTHORS



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THE LIVING CAVES OF THE UPPER SEBOU IN THE MIDDLE ATLAS: WHERE GEOLOGY, WILD BIODIVERSITY, AND HUMAN MEMORY

Exploring the Sculpted Beauty and Deep History of Morocco's Subterranean World

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ABSTRACT

In the heart of Morocco's Middle Atlas, the Upper Sebou unfolds as a landscape where geological time, water, biodiversity, and human memory converge. Across the fractured dolomitic expanse of the El Menzel Causse, the Sebou River cuts through geological formations spanning hundreds of millions of years, from Palaeozoic and Triassic rocks to extensive Jurassic dolomites that host a remarkable subterranean world. More than 80 cave entrances have been identified across the El Menzel Causse, including numerous cavities along the Sebou corridor, revealing a karst system that remains incompletely documented and has been shaped by structural discontinuities, groundwater circulation, dissolution, and progressive river incision. Among the region's numerous springs and groundwater outlets, Aïn Sebou, with an average discharge of approximately 2,500 L s^{-1}, provides a major surface expression of the hidden hydrological system. Water infiltrates the fractured dolomites, follows concealed pathways, and eventually re-emerges at the surface, while the progressive incision of the Sebou has left some former subterranean passages perched above the modern river. Yet the Upper Sebou is more than a karst landscape. Riverbanks, springs, rocky cliffs, dolomitic slopes, Mediterranean vegetation, and cave entrances form an interconnected ecological mosaic. Species such as Capparis spinosa L. occupy rocky fissures and cave thresholds, illustrating the ecological connectivity between surface habitats and the cave entrance environment. The caves are also part of a long-standing human landscape, where some cavities have served as temporary shelters, pastoral refuges, storage spaces, and places associated with prayer, spiritual practices, local place-names, and oral traditions.

This chapter explores the Upper Sebou caves as components of a dynamic geological, hydrological, ecological, and cultural system. Rather than isolated cavities, they are presented as fragments of a larger landscape in which geology provides the architecture, water shapes the hidden pathways, life occupies the thresholds, and human memory gives meaning to the subterranean world.

Here, the stone remembers the sea,
the river remembers the mountains,
the caves remember the water,
and the people remember the caves

INTRODUCTION

The Living Caves of Oued Sebou

There is a Morocco we discover in daylight: mountains, valleys, plateaus, rivers, and open horizons. Yet beneath this familiar landscape lies another Morocco—quieter, darker, and shaped by water.

This is underground Morocco.

Across the country, carbonate rocks preserve a remarkable subterranean heritage extending from the Rif and Middle Atlas to the High Atlas and Anti-Atlas (Naouadir et al., 2025a). Much of this hidden world, however, remains poorly documented and only partially explored. Among Morocco's major karst regions, the Middle Atlas occupies a distinctive position, where carbonate plateaus, fractures, springs, rivers, and caves form a complex geological and hydrological heritage (Naouadir et al., 2025a; Naouadir et al., 2026a).

Here, the mountains do more than dominate the landscape.

They give birth to water.

Among the rivers emerging from this mountainous realm, the Sebou occupies a central position. Its basin covers approximately 40,000 km², and the river flows for more than 500 km before reaching the Atlantic Ocean. Yet the Sebou is more than a river. It is a geological and hydrological corridor, crossing plateaus, exploiting structural discontinuities, and progressively revealing the hidden architecture of the mountains.

This relationship between river, rock, and water becomes particularly striking in the El Menzel Causse. Here, the Sebou cuts across a broad, fractured dolomitic plateau, exposing a landscape of cliffs, springs, caves, and concealed groundwater pathways. More than 80 cave entrances have been identified across the El Menzel Causse, including numerous cavities along the Sebou corridor, while numerous karst springs and groundwater outlets testify to an extensive and still incompletely understood underground drainage system (Naouadir et al., 2025b; Naouadir et al., 2026b).

Among these springs, Aïn Sebou occupies a particularly emblematic position. With an average discharge of approximately 2,500 L s^{-1}, it provides a major surface expression of groundwater circulation within the Middle Atlas carbonate system. Water infiltrates the fractured dolomites, travels through concealed pathways, and eventually returns to the surface, linking the hidden hydrological network of the plateau with the river and valleys below (Akdim et al., 2012; Naouadir et al., 2026b).

Yet the Upper Sebou is not only a geological landscape.

It is a living one.

Along the river and its surrounding slopes, water, rock, vegetation, wildlife, and human communities have interacted for generations. The caves belong to this same continuum. They are geological structures shaped by dissolution and erosion, ecological thresholds between surface and subsurface environments, and places where human presence has become intertwined with the landscape.

Around cave entrances and along rocky dolomitic slopes, Mediterranean vegetation occupies a mosaic of microhabitats controlled by exposure, moisture, substrate, and the architecture of the rock. Among the conspicuous species observed in these rocky environments is Capparis spinosa L., whose ability to establish itself in fissures and crevices illustrates the close relationship between vegetation and the fractured karst landscape.

The cave entrance is therefore more than a doorway into darkness. It is a transition zone where light, air, moisture, organic matter, vegetation, and subterranean conditions meet. Beyond this threshold, the physical environment changes progressively, while the cave interior preserves traces of groundwater circulation, rock dissolution, and, in some cases, long-standing human use.

The caves of the Upper Sebou should therefore not be understood as isolated cavities scattered through the mountain. They are fragments of a larger geological and ecological system—interfaces between surface and subsurface, light and darkness, rock and water, geological time and living time.

This chapter approaches the Upper Sebou caves through these interconnected dimensions. From the dolomitic plateau to the river gorge, from springs to subterranean passages, and from geological history to human memory, it explores how geology provides the architecture, how water shapes and connects the hidden landscape, how life

occupies its thresholds and refuges, and how people have gradually given meaning to these spaces.
The deepest stories of the Upper Sebou are therefore not always written on the surface.

Some remain beneath our feet.
Here, the stone remembers the sea.
The river remembers the mountains.
The caves remember the water.
And the people remember the caves.

GEOGRAPHICAL, GEOLOGICAL AND ECOLOGICAL CONTEXT: A THEATRE OF ROCK, WATER, AND LIFE

Where the Middle Atlas meets the Sebou: the El Menzel Causse

To reach the living caves of Oued Sebou, one gradually leaves behind the urban landscapes of Fez and Sefrou and enters the rugged interior of the Middle Atlas. Located approximately 60 km southeast of Fez, the study area lies within the El Menzel Causse (Fig. 1), a broad, table-like dolomitic plateau marked by a strongly fractured surface, rocky escarpments, and a striking scarcity of surface runoff. At first sight, the landscape appears dry and austere.
Yet this impression is deceptive.
The apparent dryness of the Causse reflects, in large part, the efficiency of its karstic drainage. Rainwater readily infiltrates the fractured Jurassic dolomites through joints, faults, bedding discontinuities, and karstic openings, feeding subsurface flow pathways that remain largely invisible from the surface. Numerous karst springs and groundwater outlets occur across the plateau and along its margins, providing evidence of active groundwater circulation within the fractured carbonate massif (Akdim et al., 2012; Naouadir et al., 2026b).

Fig. 1: Location map showing the position of the El Menzel area in Morocco relative to major cities, including Fez.

Approximately 30 km from the cave-bearing sector, the historic city of Sefrou, often known as the “Garden of Morocco” and renowned for its cherry orchards, provides a natural gateway to the Middle Atlas highlands. From Sefrou, the RR402 regional road crosses the plateau toward El Menzel, where cultivated landscapes gradually give way to exposed dolomitic surfaces, rocky escarpments, valleys, and karstic depressions.
The Jurassic dolomites constitute the principal geological framework of the karst system and the main host rocks of the caves. Their bedding planes, joints, faults, and other structural discontinuities provide pathways for infiltration and groundwater circulation. Over geological time, the interaction between water and fractured carbonate rock has favoured the enlargement of selected discontinuities and the development of subterranean cavities and conduits (Naouadir et al., 2025a, 2025b).
The hidden waters re-emerge at Aïn Sebou. Emerging from the Middle Atlas carbonate system, the spring marks the hydrological origin of the Upper Sebou and provides a major surface expression of the region’s groundwater circulation. From here, the Oued Sebou crosses the Causse and, within the study sector, follows a broadly NW–SE course, progressively dissecting the dolomitic plateau and producing gorges, cliffs, steep valley sides, and natural geological sections (Fig. 2).
As the river has progressively incised its valley, it has exposed the internal architecture of the dolomitic plateau and altered the relationship between surface drainage and subsurface circulation. This evolving topography has

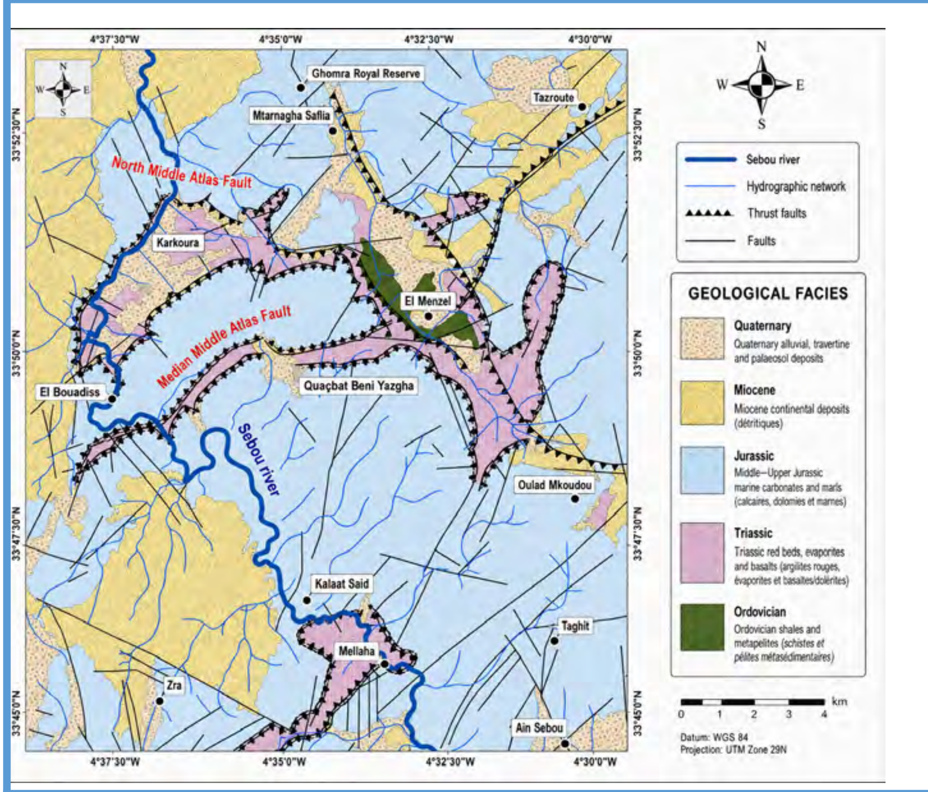

Fig. 2: Geological map of the El Menzel area showing the trajectory of the Sebou River and the settlements across the municipality.

contributed to the exposure of subterranean cavities within the fractured dolomites, including passages and chambers situated above the modern river level (Naouadir et al., 2025b).

Three elements define this landscape: the plateau, the water, and the river. The plateau provides the geological framework; fractures and other discontinuities influence infiltration and groundwater circulation; springs reveal the hidden hydrological network; and the Sebou continuously reshapes the terrain through fluvial incision.

The Upper Sebou is therefore a landscape in which surface and subsurface processes are inseparable. Rain enters the fractured plateau, travels through concealed pathways, re-emerges at springs, and is eventually gathered by the river as it continues through the mountains.

Within this setting, the caves are not isolated voids scattered through the dolomite. They are visible fragments of a larger geological and hydrological architecture extending from the surface of the Causse into the subsurface and, ultimately, toward the Sebou drainage system.

Above, the plateau appears dry.
Below, the water is already travelling.
At Aïn Sebou, it finds the light.
And from beneath the dolomite, the Sebou begins its journey.

Where Stone Remembers: The Geological and Tectonic Architecture of El Menzel

The El Menzel Causse is a geological archive in which hundreds of millions of years of Earth history are exposed along the Upper Sebou. From Palaeozoic basement rocks to Quaternary deposits, the valley brings together successive chapters in the geological evolution of the Middle Atlas. Among these formations, the Jurassic dolomites are particularly significant, forming the broad karstic plateau and constituting the principal host rocks of the caves along the Sebou corridor (Naouadir et al., 2025a, 2025b).

At the base of the exposed succession, Ordovician rocks (~450 Ma) record some of the oldest geological foundations exposed in the region. They are overlain by Triassic continental red beds and basaltic volcanic rocks, preserving evidence of extensional tectonics and magmatic activity associated with the progressive fragmentation of Pangaea and the opening of the Central Atlantic domain.

The geological landscape changed profoundly during the Early to Middle Jurassic (~201–163 Ma), when shallow-marine conditions prevailed across much of the region. Within the Tethyan realm, extensive carbonate platforms developed and accumulated thick carbonate successions, subsequently affected by dolomitization and diagenetic processes. These Jurassic dolomites now dominate the El Menzel landscape and form the principal geological framework of the karst system (Fig. 3a-b-c). Their bedding planes, joints, faults, and other structural discontinuities

Fig. 3. (a-b-c) Field photographs from the Sebou Gorges illustrating well-developed cave systems hosted within the Jurassic dolomitic formations

provided preferential pathways for fluid circulation and later played an important role in the development of subterranean cavities (Naouadir et al., 2025a, 2025b).

The mountains visible today, however, are the product of a much younger and more complex tectonic history. The Middle Atlas records the reactivation of inherited structural discontinuities and successive phases of deformation and uplift during the Late Cretaceous and Cenozoic, with landscape evolution continuing into the Quaternary. Former marine carbonate platforms were progressively elevated, fractured, dissected, and exposed by erosion. The present architecture of the El Menzel Causse therefore reflects the superposition of ancient geological inheritance and much younger tectonic and geomorphological processes.

As relief increased and drainage networks evolved, the Sebou progressively entrenched its valley through the carbonate massif. At the same time, groundwater continued to exploit the pre-existing structural fabric of the dolomites. Fractures and bedding discontinuities acted as preferential pathways for infiltration and subsurface flow, while the progressive development of the valley altered the hydraulic relationships between the karst system and the surface drainage network.

The geological record continues into the Miocene (~23–5.3 Ma), when tectonic deformation, sedimentation, erosion, and regional landscape reorganisation further modified the Atlas domain. During the Quaternary (<2.58 Ma), fluvial incision, slope processes, sediment redistribution, travertine formation, and climatic fluctuations contributed to the development of the landscape observed today.

The geological history of El Menzel can therefore be read as a succession of interconnected stages:

Palaeozoic foundations → Triassic extension and volcanism → Jurassic shallow-marine carbonate platforms and dolomitization → Late Cretaceous–Cenozoic tectonic reactivation and uplift → Miocene landscape reorganisation → Quaternary incision, erosion, and karst evolution.

This sequence is important because the caves cannot be understood independently of the geological architecture in which they developed. Their distribution, orientation, elevation, and morphology are influenced not only by the dissolution of carbonate rocks, but also by the structural framework inherited from earlier geological episodes and subsequently modified by tectonic deformation and valley incision (Naouadir et al., 2025b).

Across the Upper Sebou, the river cuts through this geological succession like a natural section, exposing rocks that record nearly half a billion years of Earth history. The cliffs are therefore more than dramatic landforms: they are three-dimensional windows into the geological evolution of the Middle Atlas.

And within this archive, the Jurassic dolomites occupy a special place.

They are the rocks in which the hidden landscape of the Sebou is written.

Every exposed formation is a chapter.
Every fracture is a clue.
Within the Jurassic dolomites, the caves are the hidden pages.
The river reveals the archive.
The dolomites preserve it.
Tectonics reshapes it.
Water writes within it.
And the caves are where the story disappears into darkness.

Where Rock Meets Life: The Hidden Ecology of the Upper Sebou

The geological richness of the Upper Sebou is accompanied by a remarkable ecological diversity. Along the river corridor, water availability, lithology, topography, exposure, and local microclimates interact to create a mosaic of habitats, ranging from humid riverbanks and springs to rocky cliffs, dolomitic slopes, Mediterranean shrublands, and forested hillsides.

Along the banks of the Sebou, where moisture and shade persist within the rugged valley, a variety of flowering

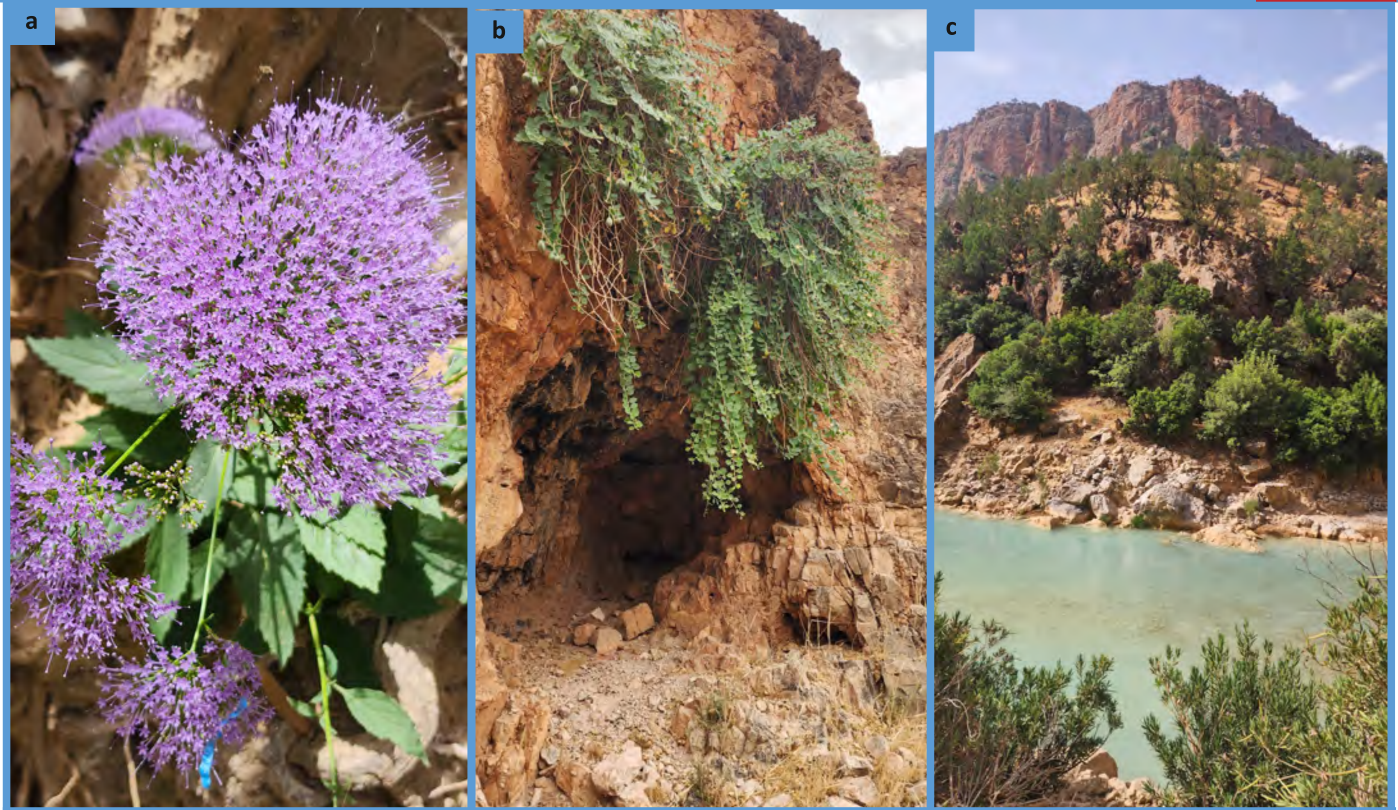

Fig. 4. Floristic assemblages and ecological zonation along the Sebou River gorges. (a) Trachelium caeruleum L. in humid riparian microhabitats. (b) Capparis spinosa L. colonizing fractures and rocky cave entrances. (c) Mediterranean vegetation on the upper slopes and cliff faces, including carob (Ceratonia siliqua), wild olive (Olea europaea subsp. europaea var. sylvestris), and juniper (Juniperus sp.).

plants find favourable conditions. Among the species observed along the river corridor are Trachelium caeruleum L. (Fig. 4a) and Nerium oleander L., which contribute to the distinctive botanical character of the river margins.

Around cave entrances and on the surrounding rocky slopes, Capparis spinosa L. (Fig. 4b), commonly known as the caper bush, is frequently associated with exposed rocky environments. This Mediterranean species is well adapted to dry conditions and can establish itself within narrow fissures, ledges, and cavities of the dolomitic walls. Its presence illustrates the close relationship between vegetation and the physical architecture of the karst landscape, where fractures and small rock niches can provide both anchorage and localized moisture.

Further upslope, vegetation becomes increasingly representative of the Mediterranean landscape, with wild olive, carob, fig, juniper, and diverse shrub communities adapted to rocky substrates, seasonal water stress, and strong exposure.

Along the Sebou corridor, the Ghomra Royal Reserve provides an additional refuge for biodiversity. Forested slopes and dense matorral contribute to a heterogeneous landscape supporting Mediterranean plant communities that include holm oak (Quercus ilex), wild olive (Olea europaea), lentisk (Pistacia lentiscus), and Phoenician juniper (Juniperus phoenicea) (Fig. 4c).

The ecological significance of the Upper Sebou is not restricted to the surface landscape. The caves and their entrances form part of a broader surface–subsurface continuum, in which water, temperature, humidity, organic matter, and shelter create environmental gradients between the open landscape and the underground environment. At cave entrances, these gradients are particularly pronounced: vegetation and organic material from the surface interact with increasingly shaded, humid, and thermally buffered conditions toward the interior.

The fractured dolomites play a role in both dimensions of this landscape. The same structural discontinuities that facilitate water infiltration and subsurface circulation can also create small niches for vegetation, while cliffs, rock shelters, and cave entrances provide protected microhabitats for terrestrial organisms.

The Upper Sebou therefore functions simultaneously as a geological and ecological corridor. Water connects habitats,

vegetation responds to gradients of moisture, exposure, and substrate, and the caves introduce a hidden dimension to this living landscape.
Rather than existing as isolated biological units, these environments are connected through the physical architecture of the mountain and the movement of water across and beneath it.

Here, biodiversity does not simply occupy the landscape—it follows the architecture of the rock and the pathways of water.
Where water finds a path, vegetation follows.
Where rock offers shelter, life takes root.
And where darkness provides refuge, another dimension of the landscape comes alive.

WHERE WATER WRITES IN DARKNESS: THE MAKING AND MEMORY OF THE SEBOU CAVES

When Water Entered the Stone

Before the caves existed, there were fractures.
Within the Jurassic dolomites of El Menzel, joints, bedding planes, faults, and other structural discontinuities created a hidden architecture through which meteoric water could penetrate the rock. What appeared at the surface as a dry and rugged plateau was therefore connected to an invisible system beneath it. Water followed pathways controlled by the geometry, connectivity, and permeability of the fractured dolomites.
Over geological time, repeated circulation progressively modified these pathways. Where conditions favoured dissolution, fractures widened and their intersections became enlarged. Elsewhere, openings remained narrow or became partly sealed. Gradually, a subterranean network emerged from the interaction between water and the pre-existing architecture of the rock.
The caves of the Upper Sebou are therefore not accidental holes in the mountain. They are negative landforms created through the progressive removal and dissolution of rock within the carbonate massif (Fig. 5a–b-c). Their passages and chambers reflect preferential pathways along which water was able to circulate, while their distribution is influenced by the structural and lithological organization of the Jurassic dolomites (Naouadir et al., 2025b).
Speleogenesis was therefore not a single event. It was a prolonged process in which structure created pathways, water exploited them, dissolution enlarged them, and time transformed them into caves.

Water entered the stone.
Fractures became pathways.
Pathways became passages.
And time turned them into caves.

The Slow Art of Darkness

A cave is not simply an empty space inside the mountain. It is a three-dimensional environment, with its own architecture, textures, volumes, and atmosphere.
Inside the caves of the Upper Sebou, the structure of the dolomites reveals itself in another form. Walls rise irregularly, ceilings follow bedding and fracture patterns, and narrow passages may open unexpectedly into larger chambers. Some spaces remain low and confined, while others expand where structural discontinuities intersect or where dissolution has preferentially removed the rock (Fig. 6a–b-c).
Every surface expresses a different aspect of the host rock. Rough walls, smoother dissolution surfaces, niches, small cavities, sharp edges, and fractured planes create a constantly changing underground architecture. The cave is therefore not a uniform corridor, but a succession of spaces whose dimensions and forms reflect the geological framework in which they developed.
This architecture also influences the underground climate.

Fig.5. (a-b-c) Exokarstic landscape along the Sebou River canyon, showing pronounced solutional landforms and cave entrances leading into the local subterranean system.

With increasing distance from the entrance, daylight weakens and the direct influence of the surface decreases. Temperature and humidity tend to become more stable, although their degree of stability depends on cave geometry, ventilation, depth, and connectivity with the exterior. Some passages remain influenced by air exchange, while more confined chambers may develop markedly different conditions.

Darkness is therefore not simply the absence of light. It is an environmental condition produced by the geometry of the cave and its relationship with the surface.

As one moves deeper inside, familiar visual references disappear and sounds become muted. The outside world—shaped by sunlight, wind, vegetation, and seasonal fluctuations—is gradually replaced by a more sheltered environment governed by space, moisture, airflow, and darkness.

The cave does not merely occupy the mountain.

It reveals another architecture of the mountain—one shaped by confinement, moisture, darkness, and time.

At the entrance, the outside world still speaks.
Deeper inside, the mountain becomes silent.
And in that silence, space takes another form.

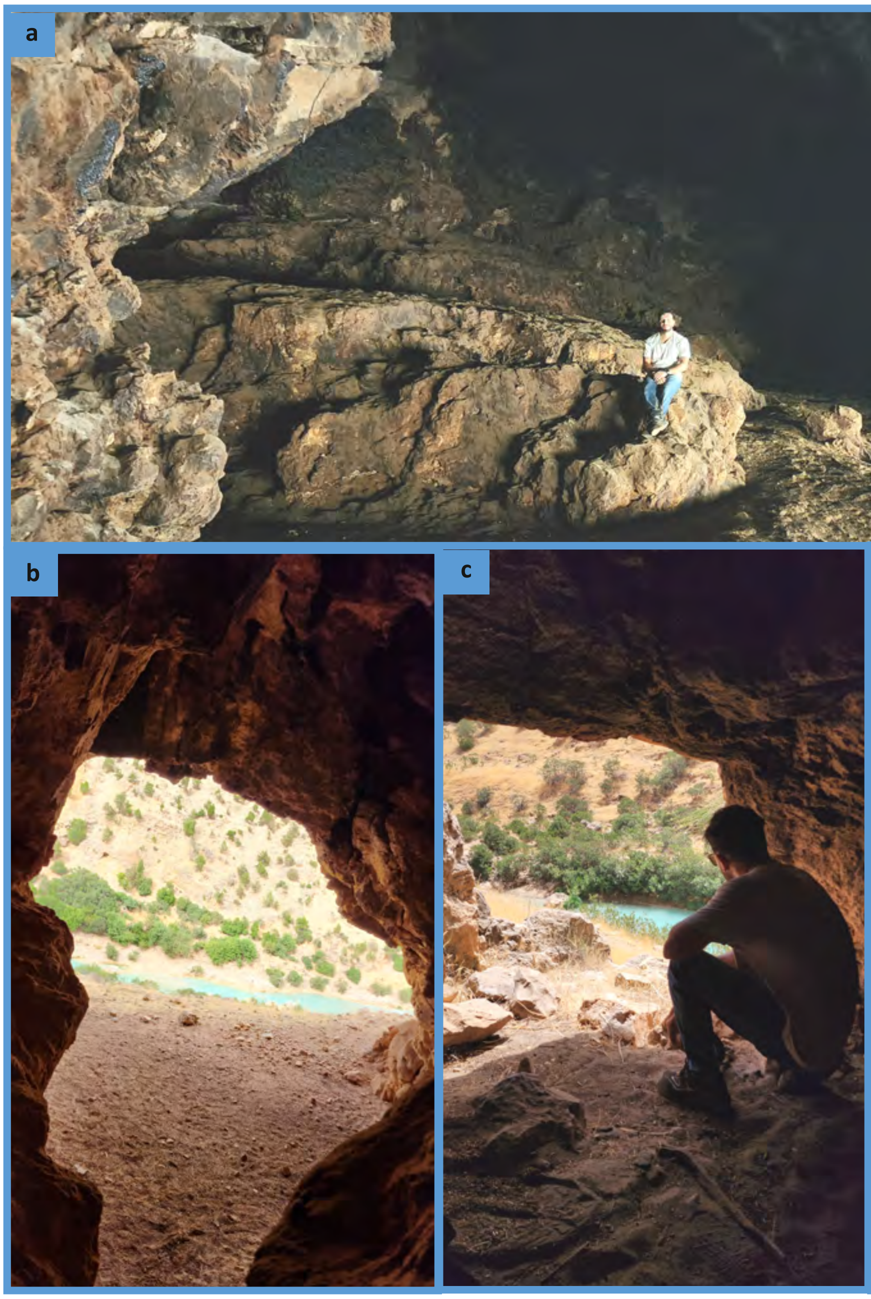

Fig.6. (a-b-c) Endokarstic diversity and cave morphology along the Sebou River canyon, showing varied conduit geometries, dissolution features, and subterranean speleothems.

Caves Above the River: The Hanging Memory of the Sebou

Some caves of the Upper Sebou now appear strangely detached from the river flowing beneath them. Their entrances open from dolomitic cliffs above the gorge, in places several metres above the modern channel. Their elevated position provides a remarkable record of the long-term evolution of the valley.

The position of these cavities can be understood in relation to changes in the regional drainage system. As the Middle Atlas underwent successive phases of uplift and deformation, the Sebou progressively incised its valley. This lowering of the fluvial base level modified the relationship between the surface drainage network and the karst system. Cave entrances occurring at different elevations may therefore preserve fragments of successive stages in the evolution of the underground drainage system (Naouadir et al., 2025b).

As the river deepened its course, the elevation of the active drainage network changed relative to the surrounding karst system. Former subterranean passages that had once been hydraulically connected to groundwater circulation could progressively become disconnected from the active drainage level. Some may have retained limited seasonal or local circulation, whereas others became relict components of an older underground network.

Their present elevation is therefore geomorphologically significant. Together with their morphology, orientation, and relationships with fractures and valley walls, it provides clues to successive stages in the evolution of the karst system and the incision history of the Sebou.

Seen from below, these cavities resemble silent balconies suspended above the river. Seen from inside, the perspective is reversed: the Sebou appears as a narrow ribbon at the bottom of the gorge, while the surrounding cliffs reveal the depth of the landscape that has developed around it.

The river descended.
The valley deepened.
The former passages remained above the water.
And the caves became windows onto an older landscape.

The Cave as a Geological Memory

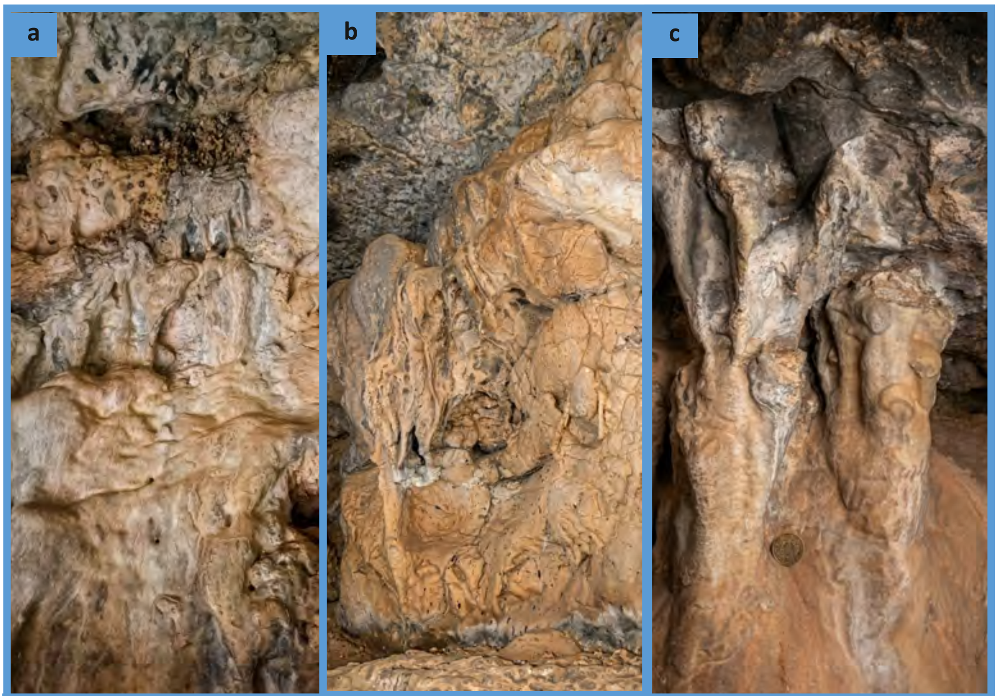

Fig.7: Internal speleothem morphology and wall encrustations in the Sebou caves: (a) massive flowstone and weathered parietal calcitic coatings; (b) corroded wall draperies and solutional crusts; (c) coalescent stalagmitic columns, with a coin for scale.

A cave is a geological archive written in negative.

Unlike an exposed rock outcrop, which records geological history in the material that remains, a cave also records history through the volume that has disappeared. Its walls, ceilings, passages, niches, deposits, and mineral forms therefore constitute a physical record of the processes that shaped the underground environment (Fig. 7a–b-c).

In the Upper Sebou, cave morphology reflects several interacting controls. The original architecture of the Jurassic dolomites provided the geological framework; structural discontinuities influenced the organization of underground pathways; and dissolution progressively modified the rock.

Sediments and secondary mineral deposits may preserve additional information. Where present and well preserved, they can provide clues about former hydrological conditions, phases of sediment transport, periods of reduced circulation, or episodes of mineral precipitation. Speleothems and other secondary mineral forms may likewise record changes in the chemistry and hydrology of the cave environment.

The geological record preserved within a cave is therefore not a single story. It is a succession of overlapping signals- structural, hydrological, mineralogical, and geomorphological- that must be interpreted together.

But this archive is fragile.

Caves exposed to stronger surface influence may undergo weathering, erosion, sediment redistribution, biological activity, and human disturbance. Delicate dissolution forms, mineral deposits, sediments, and speleothems can deteriorate or disappear, resulting in the irreversible loss of geological information.

Protecting the caves of the Upper Sebou therefore means preserving more than underground spaces. It means conserving fragments of a geological history in which rock, water, structure, and time interacted to produce the subterranean landscape.

The mountain records its history in stone.
The valley records it in relief.
The cave records it in the space where stone is no longer there.

Between Light and Darkness: The Living Threshold

A cave does not begin where daylight suddenly disappears. Its biological story begins at the threshold, where the surface environment gradually merges with the subterranean world.

At the entrances of the Upper Sebou caves, light, humidity, temperature, vegetation, air circulation, and organic matter interact to create distinctive microhabitats. Mosses and vascular plants may occupy shaded surfaces and fractures, while arthropods, reptiles, and other organisms can exploit sheltered ledges, crevices, and pockets where organic material accumulates.

The dolomitic architecture contributes to this ecological diversity. Fractures provide protected spaces for roots and small organisms, while irregular surfaces can retain moisture and organic particles. Even apparently barren rock may therefore contain small ecological niches that remain invisible from a distance.

The entrance zone is not a simple boundary between two environments. It is a gradient.

Light decreases progressively. Vegetation becomes less abundant. Humidity becomes increasingly important, while thermal fluctuations may diminish and the influence of airflow becomes more pronounced.

This transition creates an ecological interface where surface and subterranean processes meet. Organic matter enters from outside, water transports dissolved materials through the rock, air circulates between the cave and the atmosphere, and organisms exploit the different conditions available along the transition.

Deeper inside, ecological conditions become increasingly constrained by the scarcity of light and by the limited availability of energy from the surface. Yet life may persist wherever moisture, organic inputs, mineral resources, or suitable microhabitats remain available.

The entrance is therefore not merely the beginning of a cave.

It is a living threshold—a place where two environments overlap and where the geological architecture of the mountain becomes an ecological architecture as well.

At the entrance, light touches stone.
On the threshold, life takes root.
Beyond it, darkness begins.

THE HUMAN LANDSCAPE: WHEN PEOPLE ENTERED THE CAVES

The Sebou as a Corridor of Life

Long before roads crossed the Middle Atlas, the Sebou was already a natural pathway through the landscape. Water, fertile pockets, sheltered valleys, and accessible slopes created favourable conditions for movement, settlement, and pastoral activity. Along its course, people found not only water, but also routes, resources, shelter, and orientation.

For generations, communities living around the Upper Sebou have interacted closely with the river and the surrounding mountains. The landscape was never simply a physical setting. It was inhabited, crossed, cultivated, worked, remembered, and gradually transformed into a familiar human territory.

The caves formed part of this landscape. Their entrances offered naturally sheltered spaces, their elevated positions provided protection from the elements, and their proximity to the river and traditional routes made some of them accessible within a broader network of movement and subsistence.

Their use was not necessarily permanent. Depending on season, location, and circumstance, individual caves and rock shelters could serve different practical functions: temporary refuge, pastoral shelter, resting place, storage area, or shelter during adverse weather (Fig. 8a-b-c).

The significance of the caves therefore lies not only in their physical presence, but also in their position within a wider landscape of movement. The same valleys that guided water through the Middle Atlas also guided people, animals, and seasonal activities.

The Upper Sebou thus represents more than a geological corridor. It is also a corridor of human history, where the movement of water and the movement of people have followed the same landscape for generations.

The river carried water.
The mountains offered shelter.
And between them, people built their memories.

Between Shelter and Sanctuary: The Human Memory of the Caves

For communities that have lived around the Sebou for generations, a cave is rarely perceived as simply an empty space in the rock. Darkness, isolation, elevation, and proximity to water have given some cavities a particular place within the cultural landscape.

Along the Sebou, caves are not identified only by their geological characteristics. Some are known locally through names associated with families, clans, places, or particular events, linking individual cavities to the people who have lived, travelled, and worked around them.

Their practical value could extend beyond simple shelter. Some caves and rock shelters provided temporary refuge for shepherds and livestock, particularly during periods of heat, rain, or difficult weather. Others could be used as storage spaces, allowing food, agricultural products, or other provisions to be protected from the elements (Fig. 8a-b-c).

Yet the cultural significance of certain caves appears to extend beyond everyday use. Local oral traditions associate some cavities with prayer, retreat, or spiritual practices, reflecting the diverse layers of cultural memory preserved along the Sebou. In some places, oral traditions connect caves with Muslim religious practices, while others are locally associated with Jewish heritage and places of devotion.

Such traditions, transmitted largely through oral memory, are difficult to reconstruct systematically and should therefore be approached with care. Their precise historical details require further ethnographic and archival investigation. Even when their historical origins remain uncertain, however, they reveal an important fact: caves have been experienced not only as physical spaces, but also as places invested with meaning.

A cave may therefore be simultaneously a refuge for a shepherd, a shelter for livestock, a place for storing provisions, a landmark carrying a family name, or a site associated with spiritual memory.

This intimate relationship between people and caves gives the Upper Sebou a distinctive geo-cultural character. The significance of a cavity cannot be measured only by its dimensions, morphology, or geological history. Sometimes, its importance also lies in the story that people have attached to it.

Every cave has its stone, but some caves also have a name.
A name carried by families, by shepherds, by prayers, and by generations.
The rock remembers the water; the people remember the cave.

A HERITAGE UNDER SIEGE: THE FUTURE OF THE SEBOU CAVES

Fig.8: Anthropogenic and pastoral use of the Sebou karst caves, traditionally serving as overnight shelters and livestock pens for local herders.

A Hidden Heritage at Risk

The caves of the Upper Sebou have survived geological time, climatic fluctuations, river incision, and successive transformations of the Middle Atlas. Today, however, their vulnerability increasingly comes from a different source: pressures generated by human activity and environmental change.

A large part of this subterranean heritage remains insufficiently documented. The morphology of many cavities, their sedimentary records, biological communities, possible archaeological remains, and cultural histories are still poorly understood. This lack of knowledge is itself a form of vulnerability: what remains undocumented is difficult to monitor, interpret, and protect.

Potential pressures include soil erosion, vegetation degradation, wildfire, increasing human activity, and broader environmental change, all of which may affect cliff stability, cave entrances, and the ecological conditions surrounding subterranean habitats.

Inside the cavities, uncontrolled visits, littering, disturbance of sediments, and damage to natural or cultural features may cause irreversible losses. Fragile deposits and mineral forms can be particularly vulnerable because their destruction may erase information accumulated over thousands or even millions of years.

Climate change introduces another layer of uncertainty. Changes in rainfall patterns, prolonged droughts, and increasingly intense precipitation events may modify relationships between surface runoff, groundwater circulation, vegetation, springs, and subterranean environments.

Yet vulnerability should not lead to isolation.

It should encourage documentation, monitoring, conservation, and responsible discovery.

The numerous karst springs and groundwater outlets associated with the El Menzel landscape, together with the caves documented along the Sebou corridor, point to a subterranean heritage whose complexity is still only partly understood.

The challenge is therefore not simply to discover more caves.
It is to understand them before some of their stories disappear from memory.
A cave may survive for a million years,
yet lose its story in a single generation.
To protect the darkness,
we must first learn how to see it.

From Hidden Caves to Living Heritage

The future of the Upper Sebou caves should not be measured only by the number of cavities discovered, but by our ability to understand and protect the wider system of which they form a part.

The caves, dolomitic plateau, Sebou gorges, springs, vegetation, and cultural heritage of surrounding communities constitute an interconnected landscape. Their value lies precisely in these relationships.

This integrated heritage offers opportunities for scientific research, geotourism, ecotourism, environmental education, and responsible local development. Selected sites could support scientific and educational interpretation, while carefully designed trails could connect the plateau, river, springs, cliffs, villages, and other elements of the landscape.

Such development, however, should follow one essential principle:

Valorisation must never come before protection.

The objective should not be to transform every cave into a tourist attraction. Many cavities may be too fragile, scientifically sensitive, or culturally important for unrestricted access. Instead, sites should be evaluated individually, with controlled access and appropriate conservation measures wherever public interpretation is considered.

In this perspective, the concept of an El Menzel Geopark could provide an appropriate framework for bringing these dimensions together. Such an initiative could connect geological heritage with biodiversity, archaeological potential, agriculture, local traditions, and the cultural memory of communities living around the Sebou.

The caves would then cease to be isolated underground objects.

They would become part of a living heritage landscape, where scientific knowledge and local knowledge meet.

Perhaps this is the greatest opportunity offered by the Upper Sebou: not simply to reveal what lies beneath the mountain, but to recognise the value of everything that surrounds it.

A cave becomes heritage when we understand its story.
It becomes living heritage when that story is shared.
And it becomes a future when protecting it also protects the people and landscapes around it.

A Map Still Being Written: Exploring the Unknown

Despite the discoveries already made along the Upper Sebou, the subterranean landscape of El Menzel remains only partially known. Many cavities still require systematic surveying, mapping, and characterization. Their sediments, mineral deposits, biological communities, and possible archaeological or cultural traces may contain information that has yet to be recognised.

This incompleteness is not a weakness.

It is an invitation.

Every unexplored entrance represents a question. Every fracture disappearing into darkness may conceal a continuation. Every isolated chamber may preserve evidence of an earlier phase of subterranean development or a former environmental condition.

Future investigations should therefore combine speleology, structural geology, geomorphology, hydrogeology, palaeoclimatology, ecology, archaeology, and ethnography. No single discipline can fully explain a landscape in which rock, water, life, and human experience have interacted over such long periods.

Modern technologies offer new possibilities. High-resolution topographic surveys, three-dimensional cave mapping, remote sensing, photogrammetry, geochemical analyses, and environmental monitoring can progressively reveal the

hidden architecture of the karst while reducing physical disturbance to fragile environments.
Scientific exploration should nevertheless remain closely connected to the people who know these mountains. Local names, oral histories, traditional routes, and memories associated with caves constitute valuable forms of spatial and cultural knowledge. They can help researchers identify places that might otherwise remain absent from scientific maps.
The map of the Sebou caves is therefore not finished.
It is being written simultaneously by water, rock, science, and memory.
And perhaps the most fascinating part of this landscape is precisely what remains unknown.

Some maps end where the road ends.
Here, the map begins where the darkness begins.

CONCLUSION: THE LESSON OF THE DEPTHS

The caves of the Upper Sebou are far more than cavities hidden within the Jurassic dolomites of the El Menzel Causse. They are fragments of a much larger story, written over hundreds of millions of years by ancient seas, tectonics, water, erosion, climate, life, and human societies.
The rocks remember an ancient marine world.
The fractures bear witness to the forces that transformed the landscape.
The river carries the memory of the deepening valley.
The caves preserve the memory of waters that once travelled through darkness.
And the people of the Sebou have added another layer through names, shelters, practices, beliefs, and memories passed from one generation to another.
What makes this landscape exceptional is therefore not a single geological formation, species, or historical episode, but the continuity that connects them (Fig. 9).
The Jurassic dolomites provide the architecture.
The fractures open the pathways.
Water shapes the hidden spaces.
The Sebou reveals them.
Life inhabits them.
And people give them meaning.
No cave is identical to another. Each possesses its own architecture, history, scars, and silences. Some bear deep marks of dissolution and fracturing; others appear softer and more open. Some have been shaped by water for thousands of years, while others have become silent remnants of former landscapes. Some have sheltered animals, shepherds, travellers, or local communities whose memories became attached to their walls.
Like human beings, every cave has a life of its own.
Its fractures are its wounds.
Its walls carry its scars.
Its passages tell of its journeys.
Its chambers hold its memories.
Its darkness protects its intimacy.
And when light returns through its entrance, it reminds us that no story is ever completely separated from the world outside.
The caves should therefore not be regarded merely as geological objects, but as geological landscapes shaped by time.
To explore them is to learn their history; to study them is to listen to their traces; and to protect them is to respect what they have endured.
The Upper Sebou is thus not simply a karst landscape. It is a geo-ecological and cultural palimpsest, where geological,

ecological, and human histories overlap without ever completely disappearing.
They are not merely places we enter.
They are stories the mountain has chosen to keep.
And perhaps respecting a cave is much like respecting a living place: not erasing its scars, not violating its silence, but learning to understand what it has endured.

Fig.9. (a-b-c) Morphogenetic role of the Sebou River in landscape evolution and eco-geomorphological diversity.

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SISTEMA DE LA CUEVADE LOS CHORROS. SECTOR 2, 3 AND 4. RIÓPAR-VIANOS (ALBACETE-SPAIN)

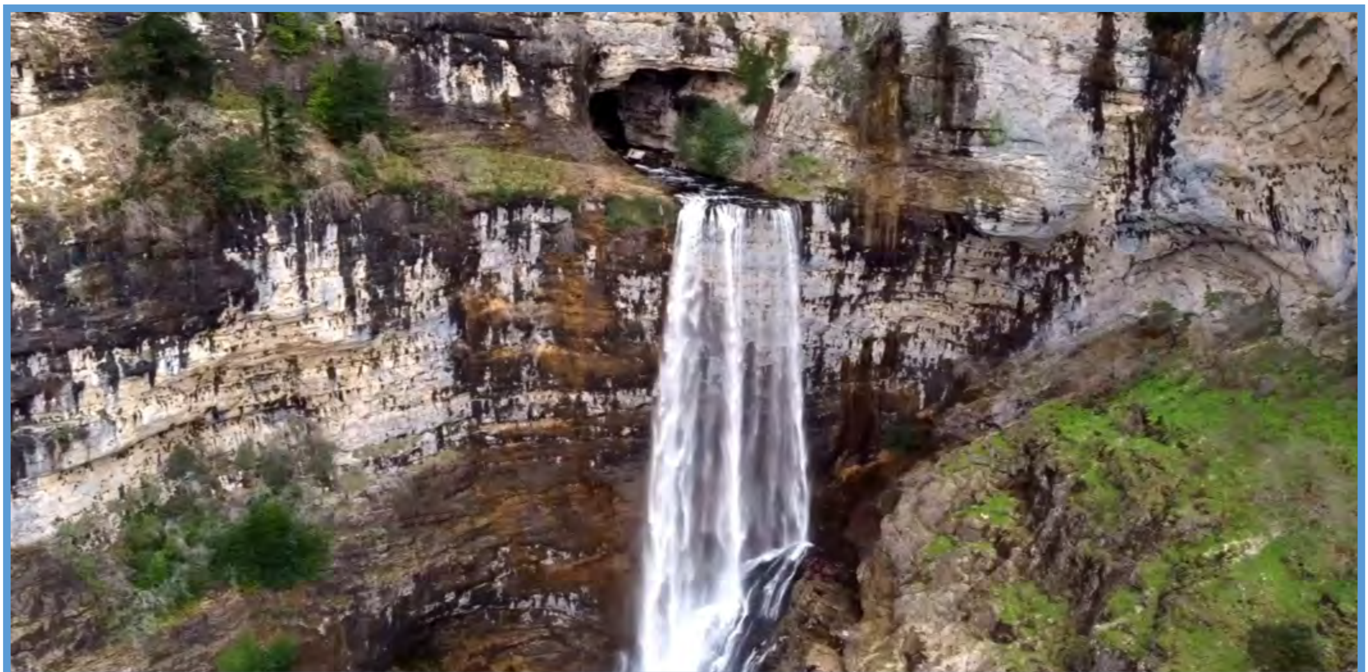
Victor Ferrer Rico & Extopocien

The Cueva de los Chorros (Cave of the Jets) is the spring where the Mundo River emerges. It is Sector 1 and forms part of the Cueva de los Chorros system. With almost 12 kilometers of passages, it is the most attractive, well-known, and most visited sector by speleologists.

However, few people know about the other sectors that are still being explored and that make up a network of more than 40 kilometers.

In this article, we will briefly describe the underground landscape of these sectors, unknown to most speleologists.

In the Hinneni shaft, a 400-meter-long siphon has been explored, and on the other side, extensive galleries have been found that will be explored and will yield significant surprises.



Entrance to the Cave Cueva de los Chorros. The waterfall plunges vertiginously into the middle of a cirque.

The Karst of the Calar del Mundo. The territory of Calar del Mundo is a karstic platform of 22 km long and 5 to 6 km wide. The carbonate rocks have conditioned the evolution of an important external karst that in depth feeds the Cueva de los Chorros System through coves, chasms, uvalas and sinkholes.

Aerial view of Calar del Mundo. In winter it usually snows at the highest levels.

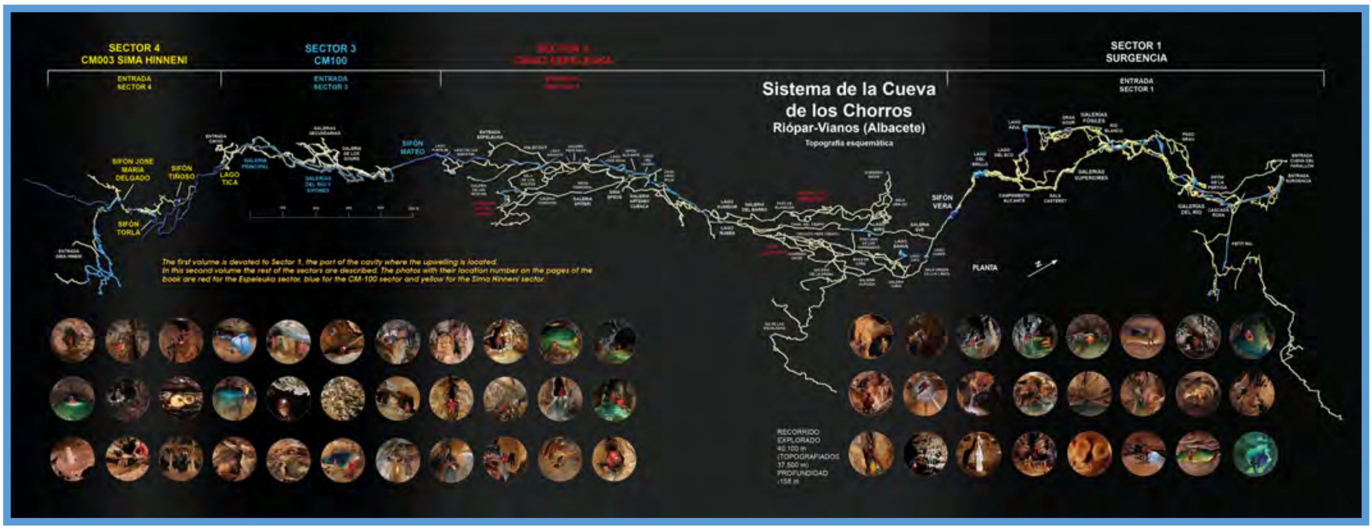
The cavity has more than 37 km of explored galleries. These are separated by siphons that divide them into 4 sectors. The first sector was described in the volume 1. This volume 2 include the remaining three sectors which form the majority of the system. Upstream, exploration continues to increase knowledge of the system by air or flooded galleries.

Various chasms communicate the sectors. The second sector, which is the largest up to now, is the Espeleuka chasm. The third sector is the CM100 chasm and the fourth is the Hinneni chasm. At the top of the mountain, there are chasms that could connect with the all system. Three cavities have already been connected to the first sector, Cueva del Farallón with the Cueva Tronchoni and the Sima del Mirador.

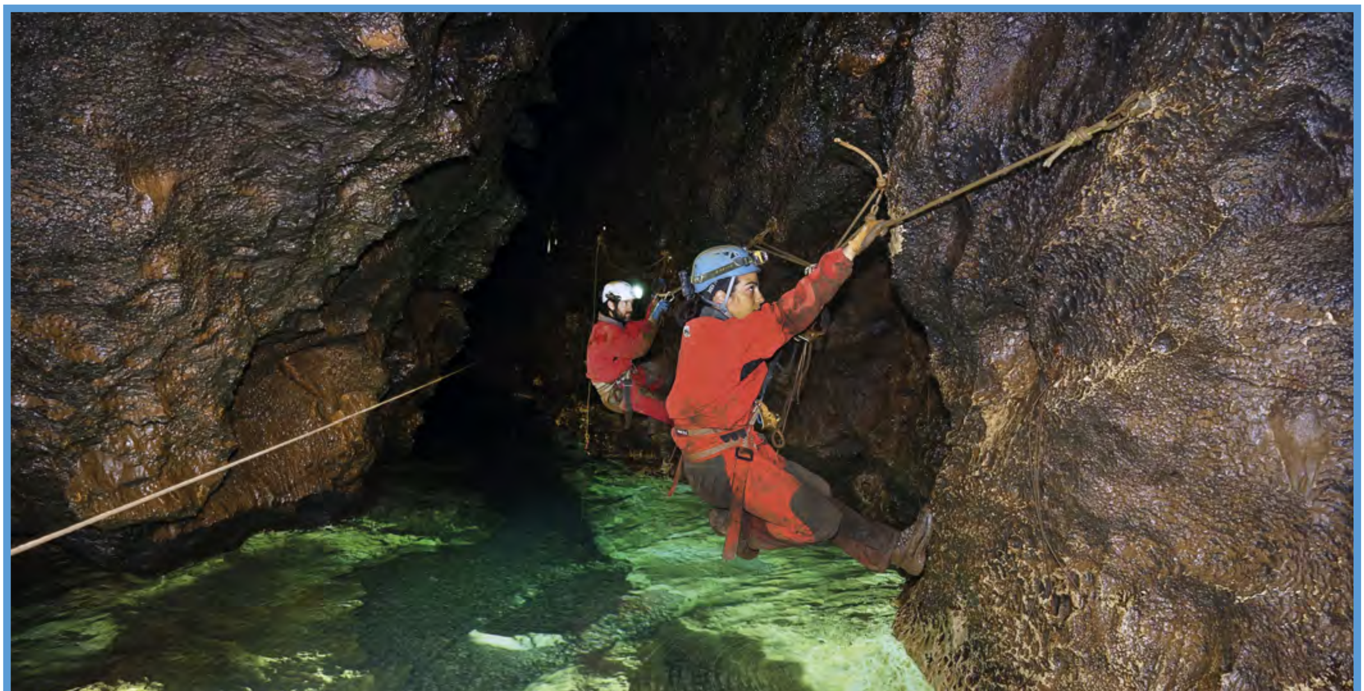
Calares del Mundo y de la Sima Natural Park. Cueva de los Chorros. Source of the Mundo River.

The geology-hydrology of the Cueva de los Chorros was developed in a Cretaceous period (Lower Senonense), formed by massive and white limestones with black bloulders (Rodríguez Estrella, 1999) with a thickness of 123 m. Under this formation appears another, also from the Lower Senonense, formed of yellowish clayey dolomites that acts as the base level of the cavity. It level present a notably lower permeability and greater resistance because is formed by dolomie and clays.

Calar del Mundo is roughly structured as a syncline hanging above the main base level, corresponding to Utrillas formation constituted by clay and sandstones. This is the largest of the calares, in an area known as "inverted relief" (Moral, 2005), due to the synclines are found at the highest levels and the nuclei of the anticlines have disappeared due to processes erosive. the proper name of the Park, Calares del Mundo y de la Sima, it refers to the permeability of the soil permeability, visible on the platforms that culminate the reliefs from 1,300 m. It is this permeability, with the erosive power of the water, which also originates underground karstic processes: chasms, caves and cavities of different sizes, forming important subsoil water networks.

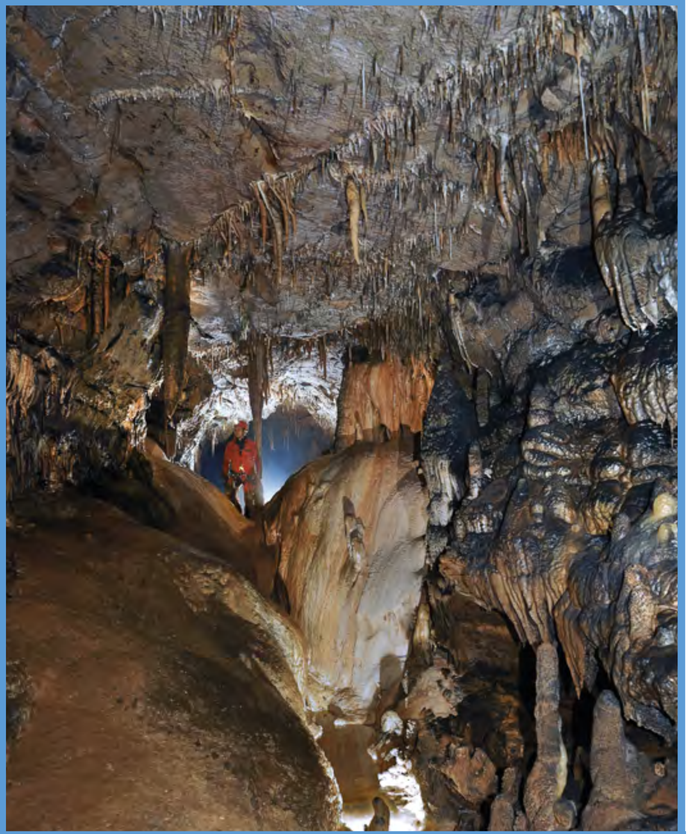


Espeleuka.The second sector. The Vera siphon gives way to a explored sector with more than 18 kilometers. After the Vera siphon upriver, the cave has differents amazing levels of galleries with big sizes and and a great variety of speleothems.The entrance pits and an upper network of galleries communicate with the collector.



Handrails in the Bathers Lake near the Mateo siphon that communicates with Sector Three.

After crossing the narrow vertical entrance, a 17 meter well leads to a gallery of comfortable dimensions.

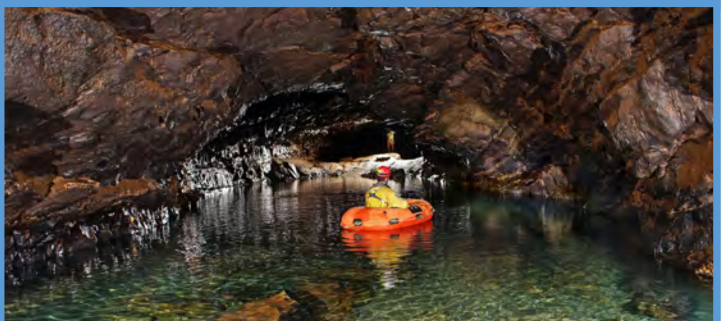


The Artemio Cuenca Gallery has the most quantity of espeleothems of the all sector.

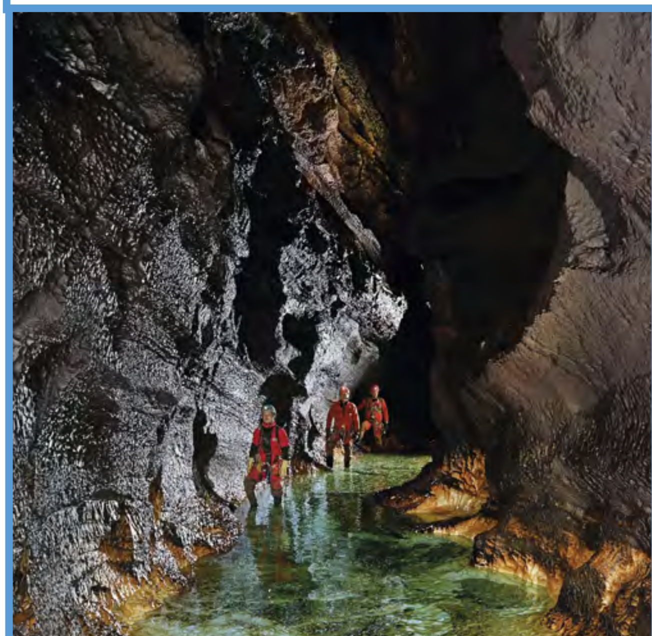
The Artemio Cuenca Gallery.

Some wells cut the gallery that goes up and down ocassionally. A small well leads through some lower galleries to the active course of the river. We find two lakes named Cruz Roja lake to the south and Olcina lake to the north are founded.

The morphology of this zone is very similar to the galleries of the river in the upwelling sector. The walls are black due to oxide of manganese precipitation.

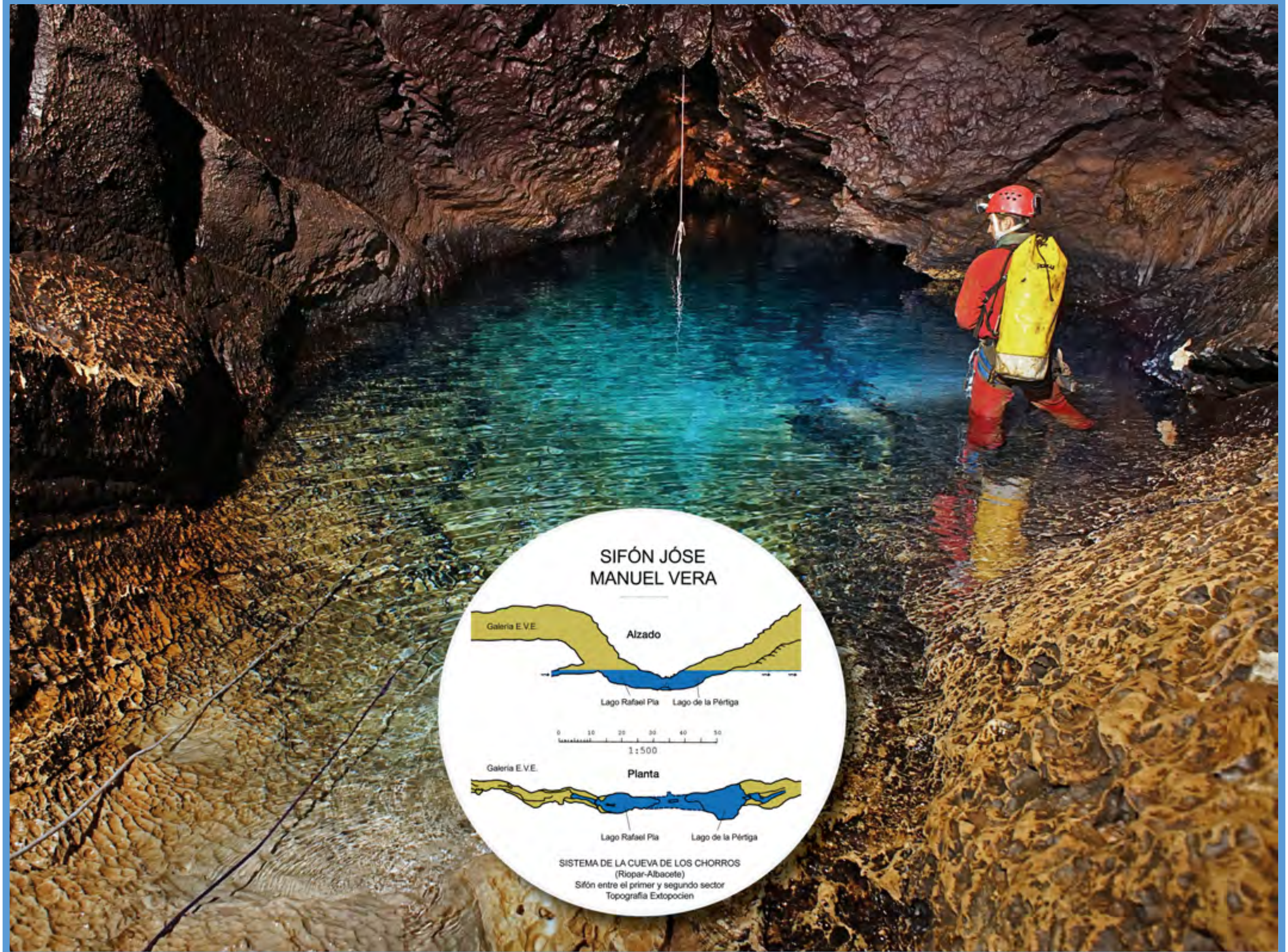


It is essential to cross the Ruben Lake to use a boat or Neoprene.



The canyon gains altitude. After a straight stretch it reaches the great Olcina lake.

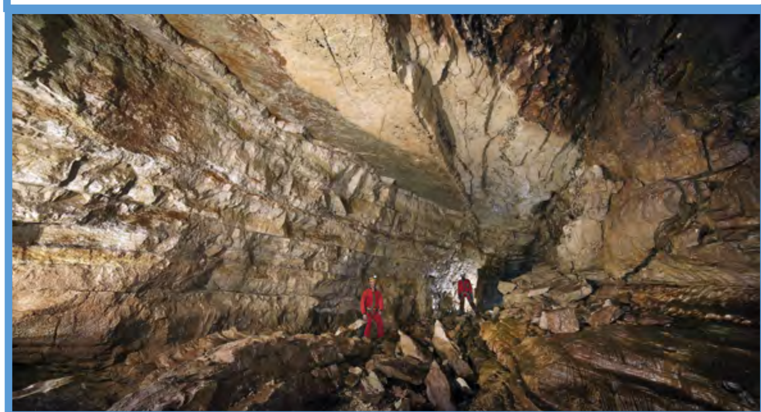
The EVE gallery, a continuation of Miro lake, leads directly to Lake Rafael Plá. On the wall you can see impressive gouge blows.



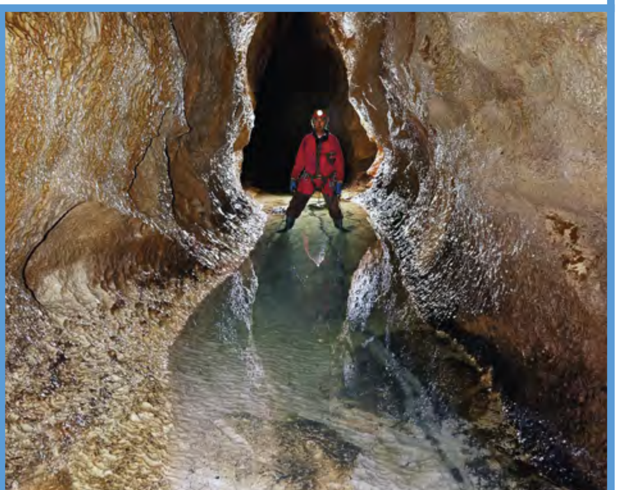
A projection leads to the Rafael Plá lake where the José Manuel Vera siphon is located. Through this siphon, the upstream Espeleuka sector

Garbanzos gallery (Chickpeas). Samples of special speleothems in the gallery.

The Arena gallery was used as the base camp for the CE Alicante expeditions. From here we return to the distant Speos chasm to continue to the other side of the cave upstream.

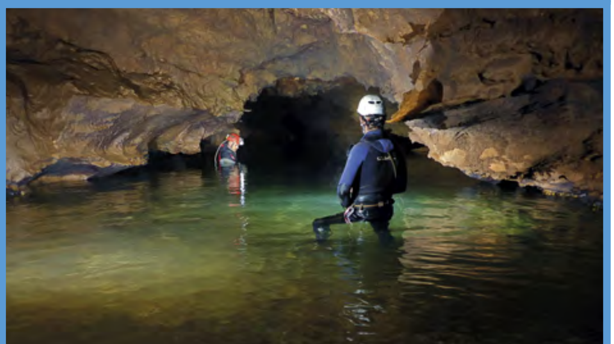


After going down the Speos chasm, a long gallery leads us to the Golpes Hall (Blows hall).Here, two rivers meet in lake Ariosto. One of them leads to the siphons of the Blanco River and the other to the Mateo siphon



Blanco River

Returning to the Golpes Hall (Blows hall), the confluence of the two rivers generates Ariosto lake. The lake ends with a siphon where the river continues.

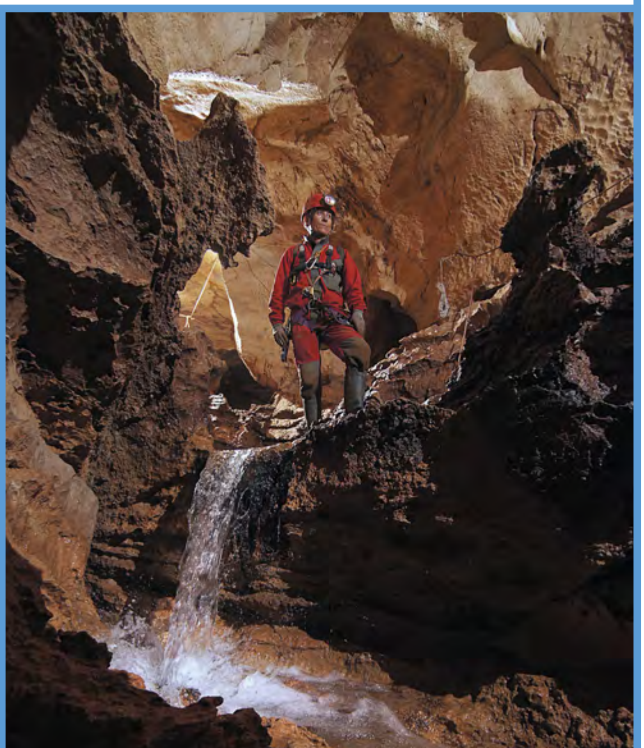


In Mateo Martín lake ends the sector Espeleuka ends in a siphon. It is deep and communicates with the CM100 chasm.

CM100. The third sector. This sector is also very interesting for several reasons. It is one of the most beautiful in the system and also has the largest underwater area of the cave with more than 900 meters of submerged galleries explored. At one end communicates through the José María Delgado siphon with the Hinneni chasm and on the other side with the Mateo Martín siphon of the Espeleuka sector.

A small well leads to a gallery that descends gradually in small projections. The gallery has many speleothems and it's easy to get around.

The well reaches the underground river.

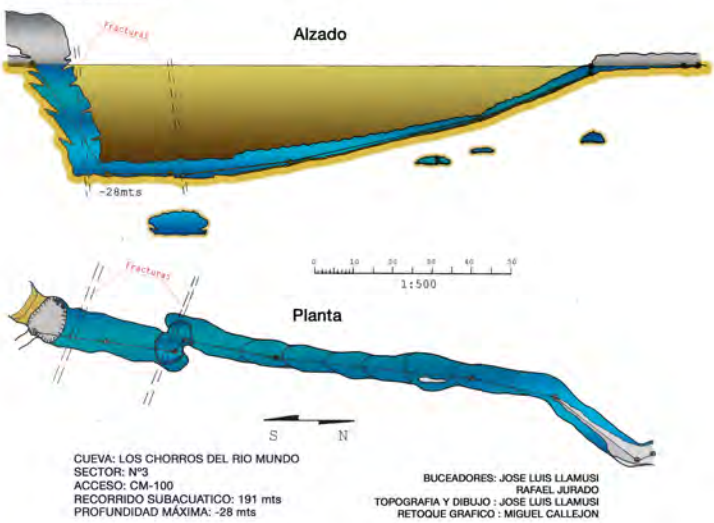


Going up the river, you quickly reach Tica lake, whose siphon communicates with Hinneni chasm through a network of submerged and aerial galleries that lead to the José María Delgado siphon.

Downriver, from the base of the wells, you can continue progressing through the gallery.

Small small pools, some flowstones and pool fingers decorate this part of the cave.

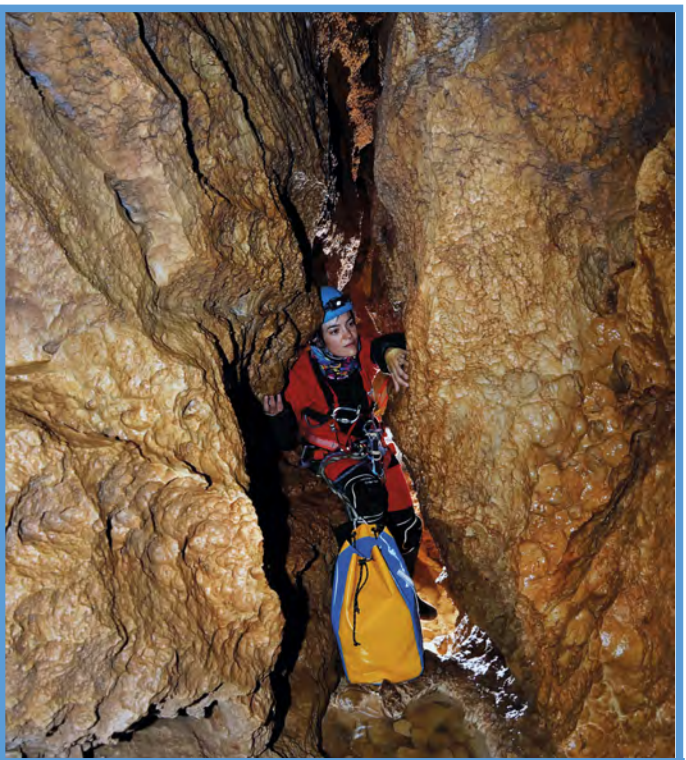
A series of gours lead to the siphon.



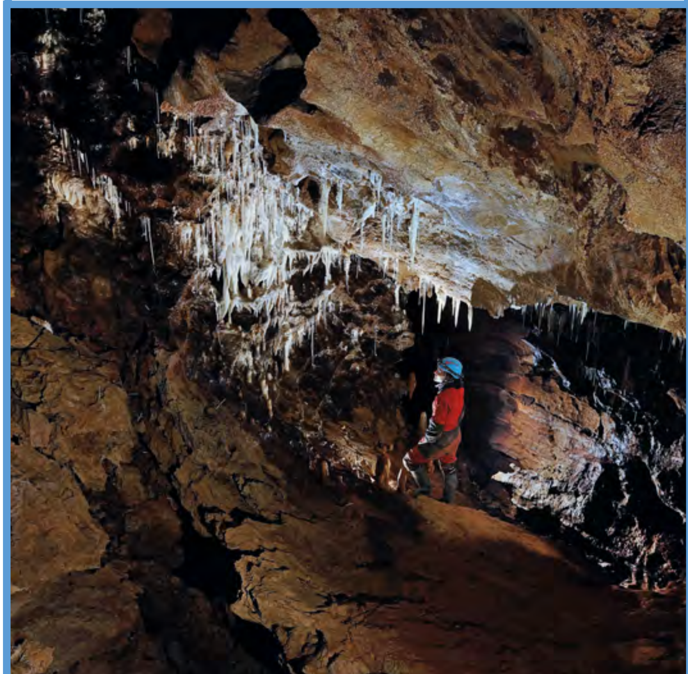
In the CM100 sector the Mateo Martín siphon communicates with the Espeleuka sector through a beautiful submerged gallery.

CM-003. Sima Hinneni. The fourth sector. The fourth sector is very interesting. The explorations are concentrated at the bottom of it. Wells and narrow meanders lead to a gallery that to the north communicates with the CM100 through a siphon. On the other side, the gallery continues through various points that are still being explored. Siphons and an upper gallery reveal a new network with new possibilities.

One of the wells is divided into two sections from a ledge. The cold and humid environment is of the alpine type.

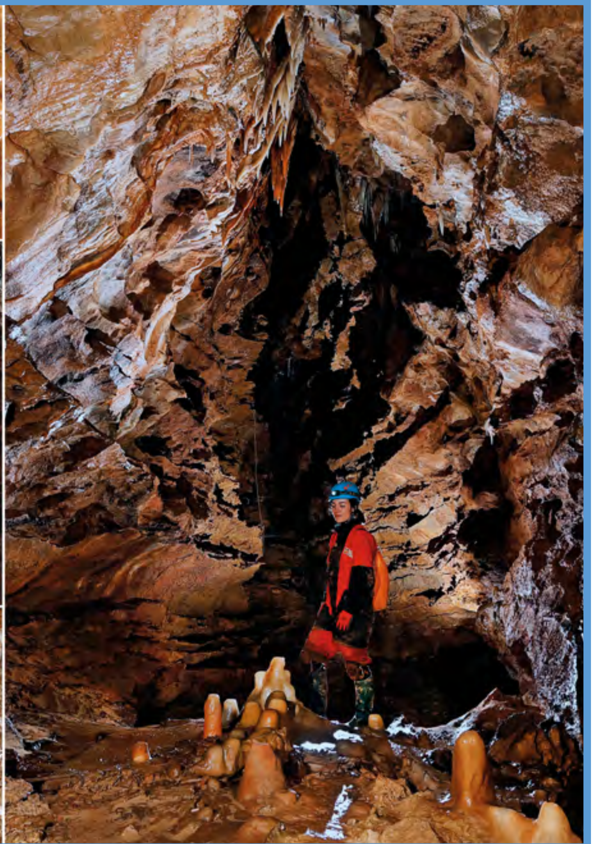


Some uncomfortable section for progression makes the route painful (crawling and narrow spaces).



The arrival to the gallery is special. The amplitude is the general view in the route that goes to the siphon

In this sector we can enjoy a spectacular concretion for its uniqueness.



Below, Bustamante lake is found which is connected to the CM100 through an extensive network of underwater and aerial galleries.

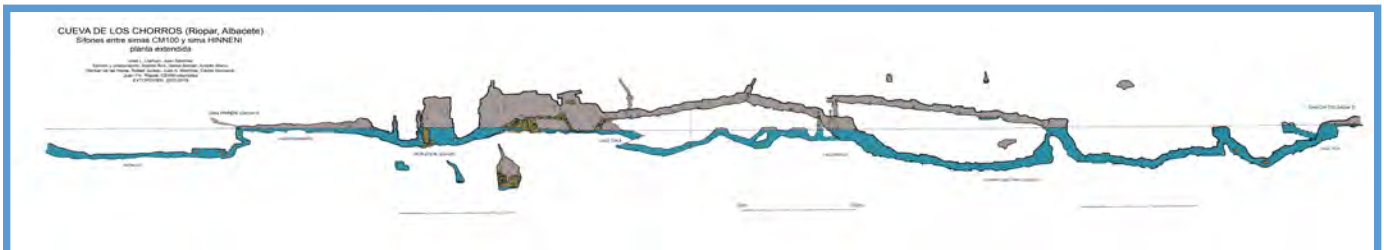
At the other end of the cave, the explorations continue through siphons and a gallery that goes up.

The underwater exploration of this great siphon was was developed between 2002 to 2004. It contributed 980 meters of submerged galleries and 420 meters of aerial zones between siphons.

Then, other siphons began to dive, opening up new possibilities in n the system exploration.

The named Ugly siphons and especially the Orange siphon are generating spectacular results.

Throughout all the sector af this huge cava, long underwater galleries have been discovered and explored.



Section between explored siphons.

Diving in the siphon of the Wine lake. Walls eroded by water. Photo J.L. Llamusí, model J. Sanchéz.

Sector of the upwelling. New explorations. The exploration of Sima del Mirador has been the key to the connection with Cueva de los Chorros and Cueva del Farallón.

The passage is developed by wide wells and small galleries with some rooms.

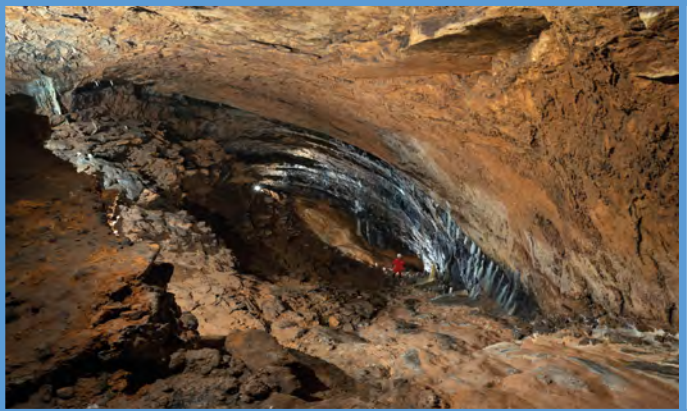
The Tronchoni Cave is also part of the system although it has not been physically connected.

The chasm begins with a well of 30 m deep. The gallery gaind deep and has some narrow passage.A decorated room appears before reaching the gatera of the union with the Cueva del Farallón.

After the union you reach the Espadas room (Swords room) of the Farallón cave.

In the rainy season the water has been circulated through the galleries of this part of the cave.

Below the Farallón cave is the Tronchoni cave. The small entrance gives way to three large rooms and a series of narrow tunnels that go outside.



The last room ends in a siphon, through which a small gallery is accessed.

Ph. Víctor Ferrer. Assistants: Aitor Dei Estal Fernández, Alberto Anton Barrera, Alvaro Herrero, Andeka Escolar, Andrea Serrano, Ariosto de Haro, Ester Martínez, Fermin Pastor, Fernando Guixot, Francisco Alarcón, Francisco Vidal,Guillermo Otero, Inmaculada Ayuso, Isabel Giménez, Ismael Lozano, Javier Ruberte Papaseit, Jessica Gallego, Jesús López, José Lorenzo Herrero, José Luis Madrigal, José María Calaforra, Juan Leandro Ronda, Juan Antonio Martínez, Juan Melero, L. Jover Peral, Laura Besoli, Laura Melero, Maria Inmaculada Sánchez, María Vicente López, Ramón Darío, Raquel Melero, Rober Ferrer, Salvador Inglés , Salvador Mateo, Segismundo Mendieta,Tomás David Carrasco y Vicente Guardiola.
Ph. Manolo Tremiño y Marisa Aldeguer.
Aerial photo : Mario Mondaray. Underwater Photos: Andrés Ros y José Luís Llamusi.

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KOCAIN CAVE – A HUGE CHAMBER

Ali Yamac
OBRUK Cave Research Group

Ancient cistern in Kocain Cave (Ph A.E. Keskin)

Following the Armistice of Mondros, signed between the Ottoman Empire and the Allied Powers on October 30, 1918, the Italians occupied Antalya and its surroundings. During the Italian occupation, which lasted from March 28, 1919, to June 1, 1921, intensive archaeological work was carried out in the region, and many ancient cities were discovered during these investigations. Moretti's discovery of Kocain also took place during these expeditions. While researching ancient cities in the vicinity of Camili Village, north of Antalya, Moretti learned that there were no ruins in the area when he reached this region. However, Ahmet Ağa, who lived alone in a valley northeast of Camili Village and worked as a woodcutter, told the team about a very large cave in the mountains that contained inscriptions. Based on this information, Moretti and his team, who spent the night in the area, set off towards Kocain on July 30, 1919, under the guidance of Ahmet Ağa.

In his article titled "In-Daghinda Qogia-In" (‘Kocain on Mount İndağı’ in Turkish) in the 6th issue of the journal "Annuario Della Scuola Archeologica di Atene" (1923-1924), he complained that the journey took 5.5 hours despite the guide saying; ‘We'll get there in two hours.’ Whether due to the guides' perception of time or the slow temperament of the travelers, we would experience the same difficulty years later, on our first trip in 1988.

Even a rough examination reveals that the research will be lengthy, and Moretti left Kocain on September 5, 1919, to return. Professor Azeglio Berretti from the Rome Museum also participated in this second expedition. The map of Kocain that Moretti drew during this research remains the oldest cave map drawn in Anatolia until an even older one is discovered. Although there are significant differences between the maps drawn later by Kocain and the map drawn by Moretti, the technique and precision applied in this drawing, made more than 100 years ago, are commendable.

Moretti, who took measurements in the cave, wrote in his article that the entrance was 60 meters wide and 15 meters high. He stated that the width varied between 50-60 meters along the gallery and that the ceiling height was around 25 meters. The error rate increases slightly in the measurements taken in the hall that begins to widen at the

First section of Kocain Cave from the entrance (Ph A.E. Keskin)

end of the gallery. From these points onwards, Moretti could not make a comment about the height because he could not see the ceiling, and he only wrote that it was "of very strange dimensions". Moreover, in these sections where lighting was very difficult, even today it requires skill to see any point, and even with modern devices, it is sometimes difficult to determine the lengths.

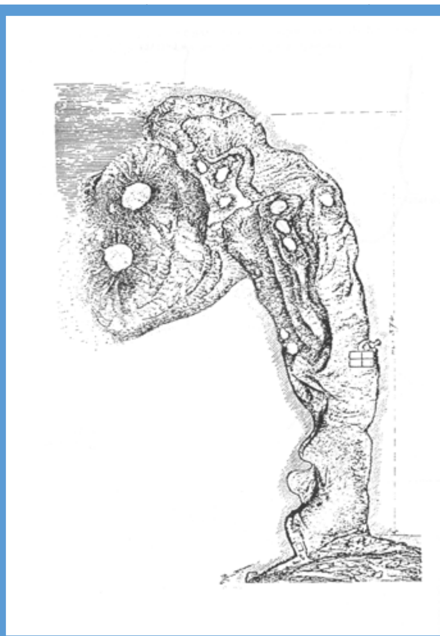
Moretti measured the diameter of the large column located about 150 meters from the point where the gallery turns to the south, behind the hill, as 12-13 meters. Kocain is important not only because of its dimensions, but also because of the inscriptions on its walls. During his brief research, Moretti identified 29 different inscriptions carved into the walls of Kocain and surveyed all of them. After so many years, most of the inscriptions are now illegible, and

Three huge stalactites in the middle part of Kocain Cave (Ph B. Langford) only 18 are still visible today. The section of Moretti's article, written years ago, concerning the archaeological finds at Kocain includes all 29 inscriptions and is the most comprehensive to date.

Moretti comments on the title Irenarkos, which appears in many of these inscriptions, arguing that this title belonged to the representatives of the Irenarkos who served in the region at various times and were sent to the cave for the sacred ceremonies. This sheds light on the religious function of the cave.

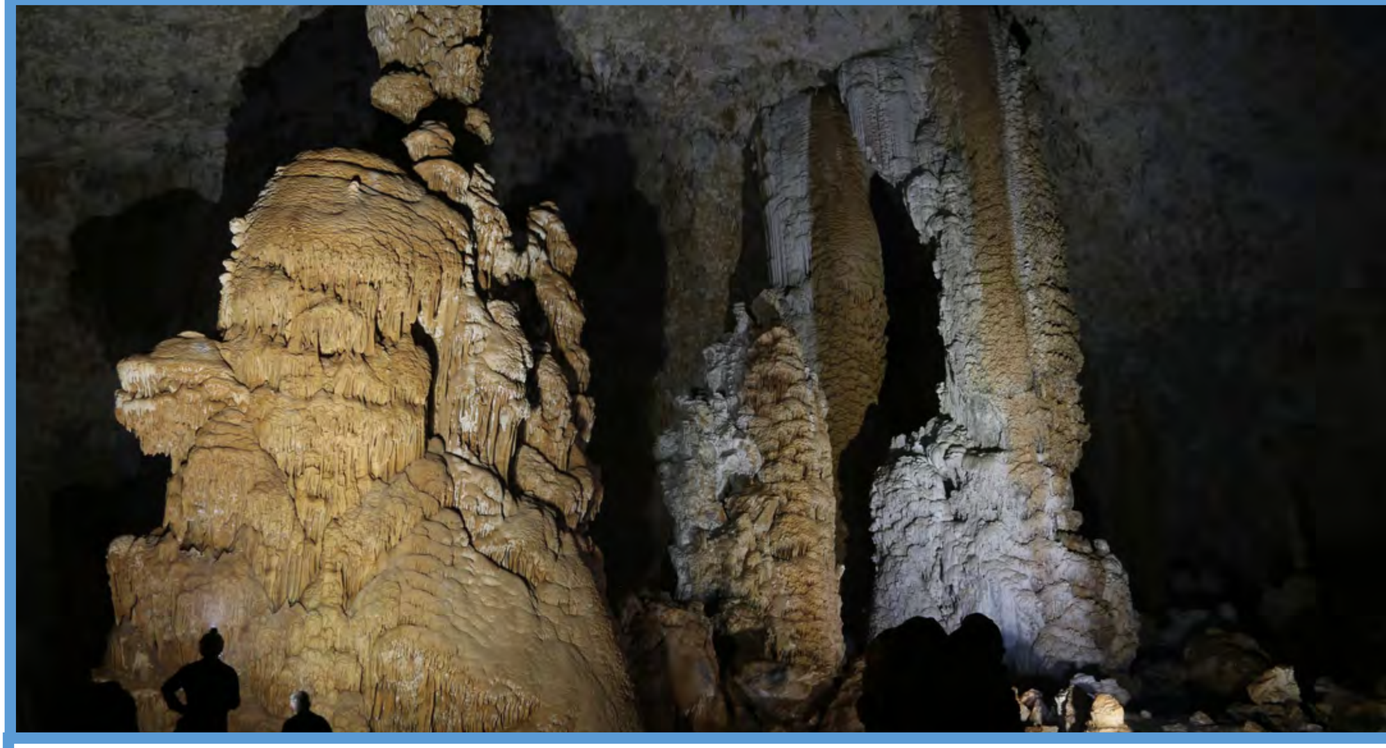
Sixty years later, in 1978, the Speleo Club de Paris became the second team to scientifically explore and survey the cave. Exactly 23 years later, Claude Chabert returned to Kocain Cave. To prepare a more detailed version of the first

This photograph of Kocain Cave, taken by Giuseppe Moretti, is the oldest known photograph taken in a cave in Turkey.

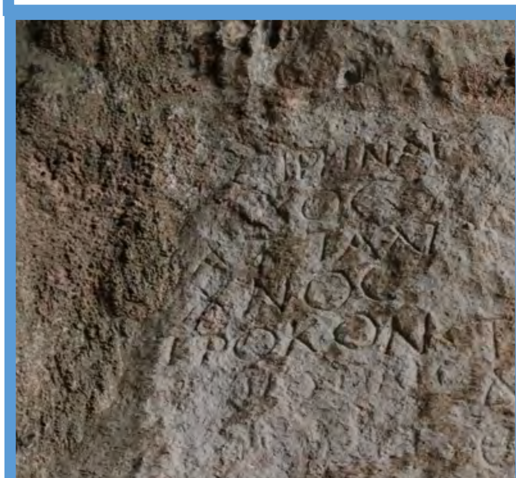


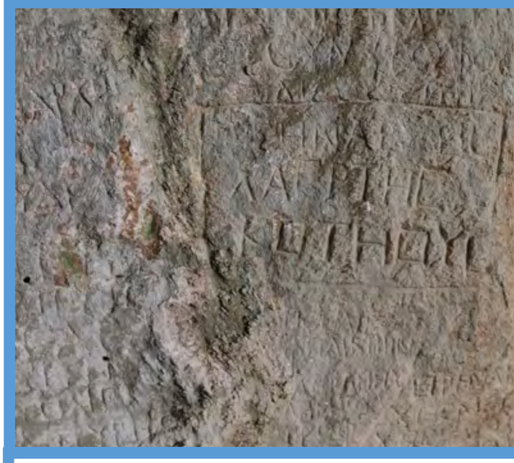
The plan of Kocain Cave, drawn by Giuseppe Moretti, is the oldest known cave plan of Turkey

The enormous columns of Kocain Cave (Photo A.E. Keskin)



The columns at the far end of the Kocain Cave (Ph B. Langford)

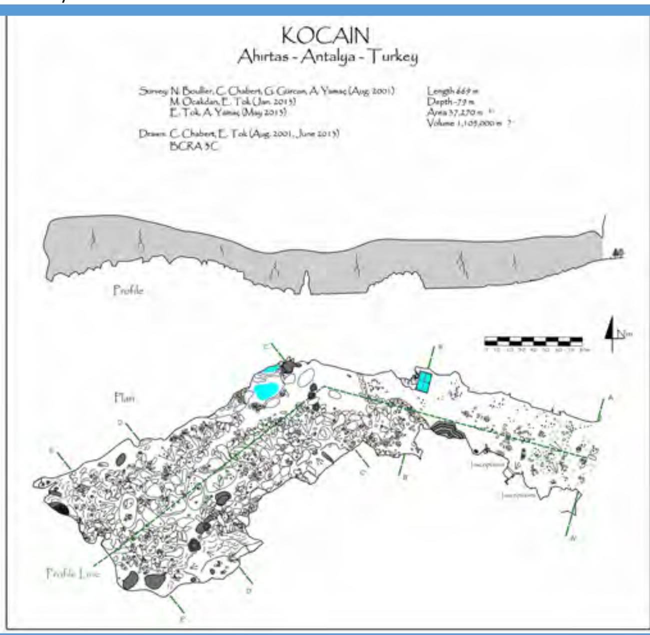




Inscriptions on the walls of Kocain Cave (Ph A. Yamaç)

occupation and whose research, due to long interruptions, was completed in a record time of 94 years, finally received the map it deserved. In light of the latest measurements, it was confirmed that Kocain is 669 meters long and covers a total area of 37.200 square meters.

With the discovery of the vast underground rooms throughout the years, today Kocain has been ranked 27th in the world for the largest cave chambers, On the other hand we are passionately committed to Kocain, believing that such records are of little consequence and that what counts is the beauty of the cave.



Final plan of Kocain Cave (Drawn C. Chabert, E. Tok)

UNDERGROUND VISION

international **contest** - ***3rd*** *ed.*

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Víctor Ferrer Rico

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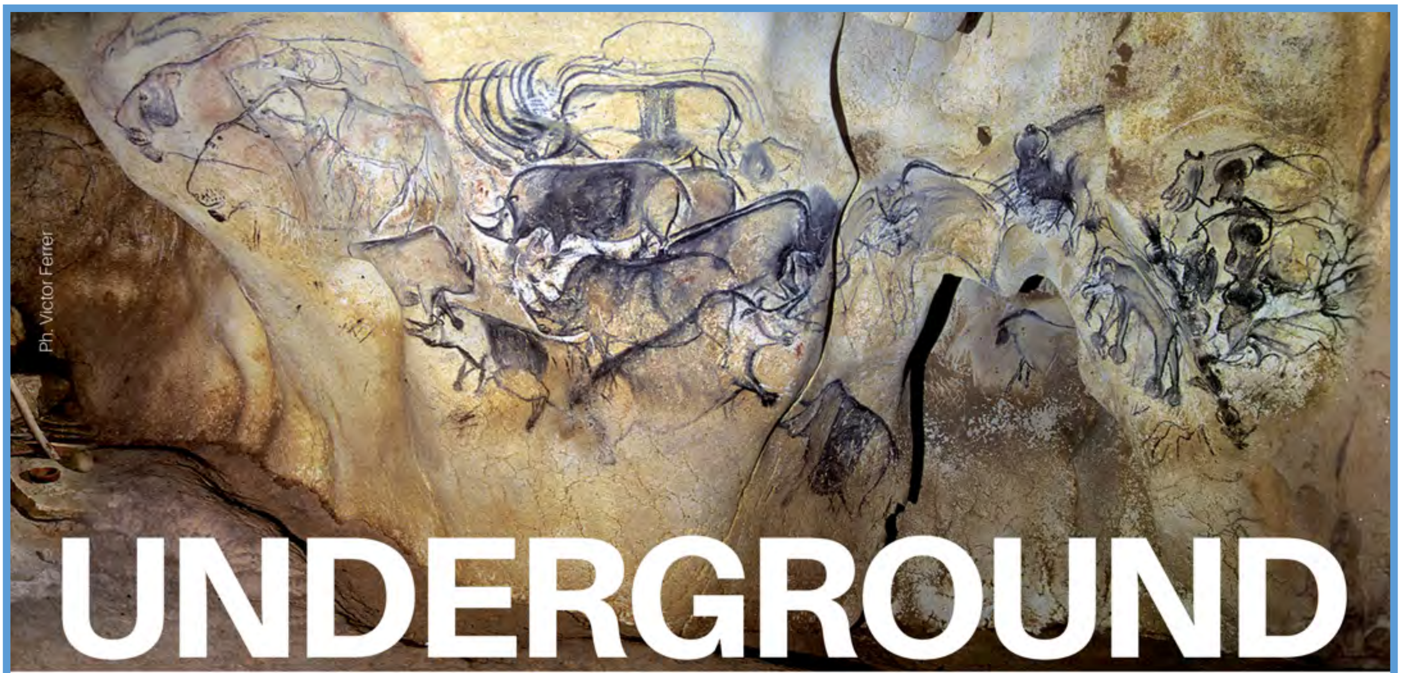
COSTACCIARO 26
Raduno Internazionale di Speleologia

The deadline for submission is October 15, 2026

for more information and complete regulations



UNDERGROUND VISION

eurospeleo **youth contest** - ***2nd*** *ed.*

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The deadline for submission is October 30, 2026

for more information and complete regulations

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