Hypogene caves Atmos and Sulfur and the largest underground thermal lake in the world

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Abstract

In southern Albania, in the valley of the Sarandaporo River, members of the Czech Speleological Society discovered a hydrothermal karst connected to the sulphurous mineral waters of the Vromoner Valley. The area is defined by a massive limestone anticline that rises above the surrounding flysch. Here, thermal waters rich in hydrogen sulphide have created a series of massive hypogene caves with large domes, lakes and active streams.

In recent years, Czech speleologists have been carrying out speleological and hydrogeological research in the area, culminating in Lidar scanning and the creation of a 3D model of the subsurface and surface, including hydrology, in 2024. The largest caves in the area are Sulfur Cave, Shpella Breshkë (Turtle Cave) and Atmos Cave. A lake in the Atmos Cave was discovered, mapped and named Neuron Lake. This lake is the largest underground thermal lake in the world (known to date). All the springs in the valley have the same temperature and composition. The total yield of springs is 200 litres per second. Tracer tests have shown that the water from Lake Neuron polyfurcates into all the springs in the valley except the Old Spa Spring. Multidisciplinary international research of the hypogene area and biological research of the unique underground biotope continue.

1. Introduction

The South-Albanian fault, with rising warm waters and other fluids, follows the line Tomor–Qeshibesh–Bodar–Lëngaricë–Postenan–Melesin–Vromoner (Eftimi, Frashëri 2016).

Hypogene caves are located where this fault crosses the limestone outcrop at the surface. There are several such areas in southern Albania (fig.1)

Several hydrothermal areas are known in the Sarandaporo River valley between the Gramos and Pindos mountains. As early as the 14th century AD, the Pixaria Baths were built here (Audy et al., 2024).

The nearby Vromoner hydrothermal area, 1 km downstream of Sarandaporo, has been known since the 16th century. The Greek baths of Xomos were also built here.

The politically dark period of the second half of the 20th century prevented speleological research. The Vromoner area was a border zone with restricted access.

The geological setting of the Sarandaporo River is fairly straightforward, although the local tectonic setting, complicated by younger tectonics, tends to be quite complex. As a literal cross-section of the Albanides thrust belt (the Ionian Unit), it comprises a series of tectonic slices formed by a Jurassic to Eocene limestone sequence overlain by an Oligocene flysch sequence. These slices are separated by thrust faults/zones associated with steeply dipping bedding planes, representing the overturned limbs of SW-vergent asymmetric anticlines. These steeply dipping zones are usually associated with the presence of deep, narrow canyons separating sections of the mostly wide Sarandaporo River valley.

At the turn of the millennium, Albanian scientists described a cave from which a thermal stream flows (Eftimi, Frashëri, 2016).

Speleogenesis of caves in Vromoner was predominantly caused by hydrogen sulfide (H_2S). H_2S is derived from sulfates, which are common in groundwater, especially where evaporates occur at depth. When sulfate meets migrating oil and gas (mainly methane), the sulfates are reduced to H_2S. H_2S, together with residual sulfates, migrates with deep groundwater toward the ground surface. Here, it meets O_2 in shallow groundwater and, especially from the air (in fractures above the water table), and after its oxidation, sulfuric acid is produced. Sulfuric acid reacts with limestone and converts limestone to gypsum. Gypsum periodically falls from cave walls, exposing fresh limestone in a repetitive process. Part of H_2S is oxidized to native sulfur.

In 2021, Czech speleologists began exploring the Vromoner area and its sulphuric acid cave systems (SAS).
The first documented cave was the horizontal Sulfur Cave. The entrance to Sulfur Cave is located near the level of the Sarandaporo River on the Greek side of the border. Most of the area of this horizontal cave is already under Albanian territory. A 26°C warm thermal river flows from the base of the Universe dome (fig. 2) (Audy et al., 2022 and Audy, 2022). The presence of massive underground spaces is indicated by large dolines at the surface.

Fig. 1: The main tectonic faults in Albania with an indicated position of the Vromoner thermal springs.

Entrances to other SAS caves have been found in these sinkholes. The Paleohypogene Horse Cave is filled with calcite and gypsum deposits.
Shpella Breshke (Turtle Cave) is particularly interesting. At the bottom of the cave, at a depth of 68 m, is an elliptical thermal lake with an 85 m circumference and a temperature of 26°C.
The most recent discovery was the Atmos sinkhole cave. The entrance, 150 metres from the hillside entrance, periodically emits clouds of steam that can be seen from a distance of 1 kilometre in winter. At the bottom of Atmos Cave, at a depth of 127 m, a large thermal lake was discovered and named "Lake Neuron" (Audy et al., 2023).
The Atmos and Sulfur Caves are located on the gently sloping limb of one of the above tectonic blocks. The whole sedimentary sequence generally dips gently SW but is folded into open folds with large wavelengths that dip gently SSE. A cleavage system has been detected that is genetically unrelated to the main folds. It is a subvertical, practically N-S striking cleavage, dipping steeply to the W. Four fracture systems can be distinguished. NE-SW and NNW-SSE striking fractures are the most dominant systems, accompanied by two minor systems: NNE-SSW and ENE-WSW striking systems.

Fig. 2: Mineral springs on the bottom of the giant dome Vesmír (Universe) in the Sulfur Cave. The Vesmír Dome was named after a Czech journal at the occasion of its 150th anniversary. (Photo by M. Audy & R. Bouda)

2. Materials and methods

The SAS survey of the Vromoner Caves initially focused on mapping and hydrogeology. Various gas detectors were used to measure H_2S concentrations, which ranged from 2 to 22 ppm in open areas. The air temperature in hydrothermally active caves ranges from 15° to 29°C, while inactive caves in the area maintain a temperature of 12° to 14°C.
DistoX and BRIC were initially used to map the caves. When researchers measured the massive lake dome in Atmos Cave, they could not fix points in the middle of the lake. A mobile lidar scanner, the Geoslam ZEB Horizon, was purchased in 2024 with a grant from the Neuron Foundation for Science Support. This device, capable of recording 300,000 points per second, This allowed us to create a 3D model of the entire hydrothermal area and obtain precise data on the dimensions of individual caves and thermal lake areas.
To obtain bathymetric data for the lakes in Turtle and Atmos Caves, we used the River Surveyor M9 sonar.
The yield and physico-chemical parameters of all springs in the area were measured. In order to detect the connection between the springs and the underground flows in the cave, a tracer test was performed using sodium fluorescein dye injected into the outlet of Neuron Lake in Atmos Cave.

3. Results

Lake Neuron at the bottom of the Atmos Abyss is currently the largest thermal cave lake in the world (Fig. 3). We used the most advanced measurement techniques to obtain dimensional data (Table 1, Fig. 4). These measurements will allow us to compare changes in the cave interior in the future.

The largest spring is the stream flowing from the Sulfur Cave, which reaches a discharge of up to 60 L/s. The total yield of the springs in the Vromoner area is 200 L/s. All the springs in the area have the same physicochemical parameters, which means that they originate from the same source. The water temperature is 26 °C, and the total dissolved solids are 1 g/L.

The tracer test has shown that water from Lake Neuron flows into all the springs in the area, indicating extensive polyfurcation. (Fig. 5) The only exception, where the tracer did not reach, is the Old Spa spring, which is probably fed by borehole.

	NEURON LAKE	ATMOS DOME
Perimeter	344,9 m	490,4 m
Area	3 200,6 m^2	5 268,6 m^2
Volume	8 335,0 m^3	138 544,6 m^3
Length	138,3	174,5 m
Width	42,0 m	42,6 m
Lake depth	-7,46 m	–

Tab. 1 Dimensions of Atmos Cave obtained by lidar scanning.

Fig. 3: The southern quarter of the gigantic thermal lake Neuron on the bottom of the Atmos Cave. Neuron Lake has a temperature of 26 °C. With a volume of 8335 m^3 is the largest subterranean thermal lake in the world. (Photo by M. Audy and R. Bouda).

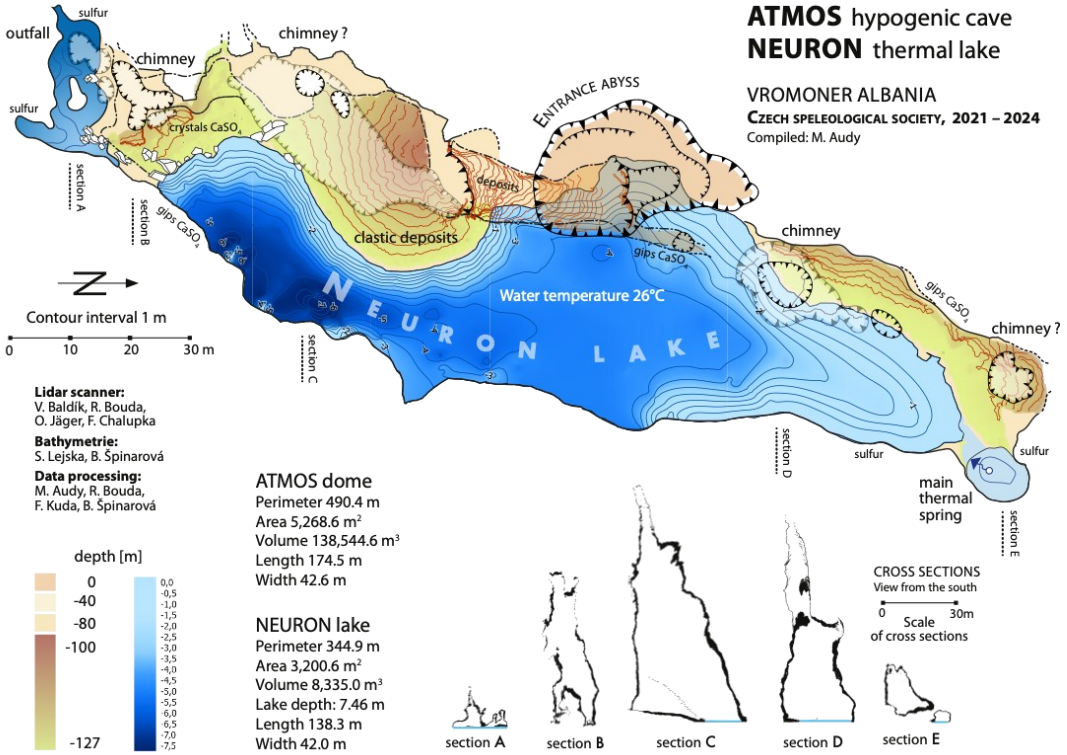

Fig. 4: A map of the Atmos Cave generated from the point cloud obtained by a lidar scanner and sonar bathymetry.

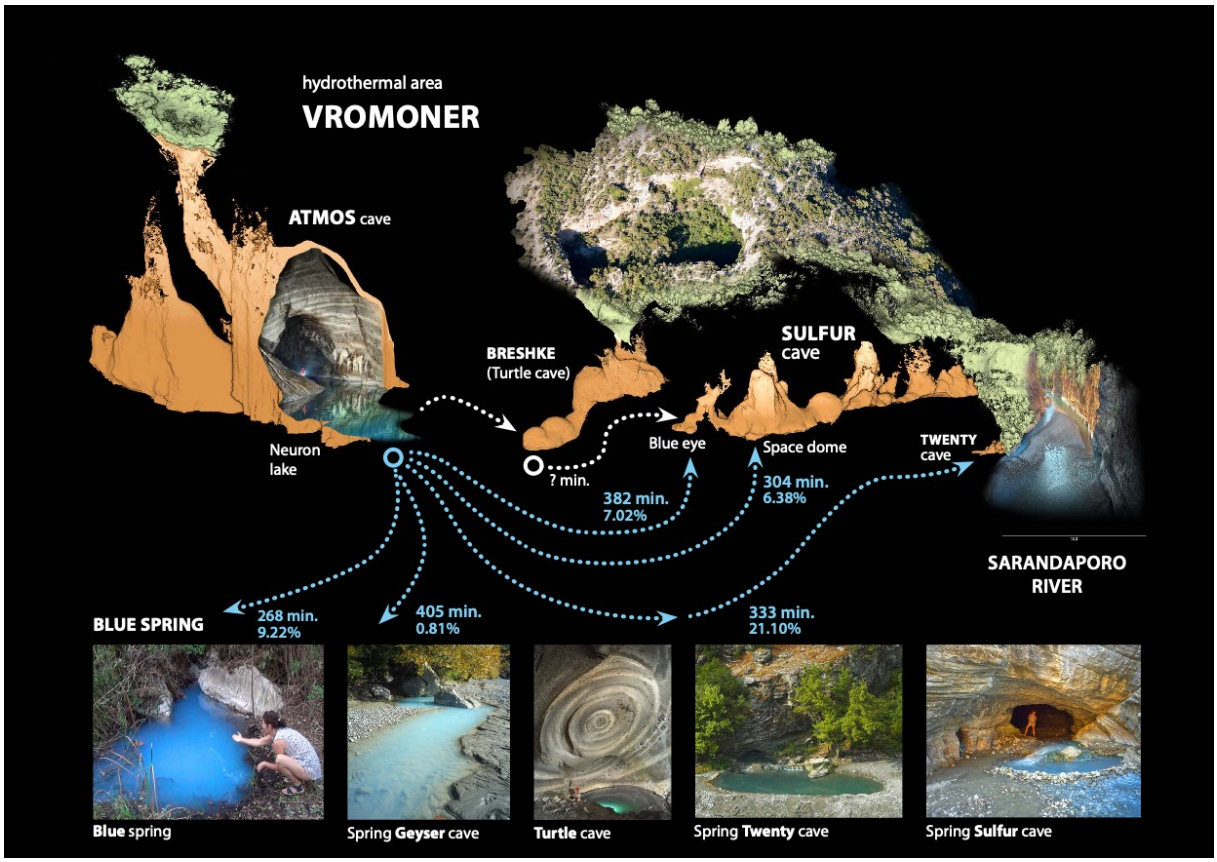

Fig. 5: Situation of hypogene caves in the Vromoner area. Water from Lake Neuron (Atmos) flows into all springs in the valley (blue arrows), except for the outlets at the Xomos spa complex. Values indicate the time of first arrival in minutes. The percentage recovery of the tracer (fluorescein) is given.

4. Discussion

In the future, we hope to work in other SAS caves in nearby areas of Albania and Greece. The nearby thermal springs of Pixaria and Kavasila are related to the hydrothermal area of Vromoner. The Amarantos and Postemani hot steam vents, originating from limestone fissures high in the mountains, are of particular interest. The extensive SAS cave system, which has yet to be documented, is located on the Langarica River (alb. Lëngarica) near the town of Petran. One of the local caves, which has been listed as a cultural heritage site in Albania since 1983, is of significant importance. However, the extensive SAS cave system, with its active thermal flow, was only recently explored by Italian speleologists.

5. Conclusion

Intensive multidisciplinary research continues in the Vromoner area. We are also collaborating with local authorities. We are working towards having the hypogene caves included in the Vjosa National Park. Previously, Albanian hydrogeologists and historians succeeded in preserving the Bënjës geothermal area on the Langarica River by publishing information on the high heat flow of the vents and highlighting their potential for energy use (Frashëri 2013). Similarly, we aim to prevent the construction of a dam on the Greek side of the Sarandaporo River, as it could negatively impact the Sulfur Cave's habitat.

6. Acknowledgments

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7. References

AUDY M. (2022) Sulphur Cave. Une cavité thermale hypogénique exceptionelle en Albanie. Spelunca 165:6-13.

AUDY M., BOUDA R., BRUTHANS J., RUZICKA V. (2022) Hypogenní kras jižní Albánie. Speleofórum 41:42-51.

AUDY M., BRUTHANS J., KASTOVSKY J., BOUDA R. (2023) Atmos – nová hypogenní jeskyně (Shpella Avulit), Albánie. Speleofórum 42:72-78.

AUDY M., BRUTHANS J., MARES J., SARBU S., GALDENZI S., BOUDA R. (2024) Sulfur 2023, hypogenní jeskyně Albánie a Řecka – Kavasila, Vromoner, Langarica. Speleofórum 43:4-13.

Benassi A. (2023): Lengarices 2023 – Inseguendo il Respiro del Drago. https://www.scintilena.com/lengarices-2023-inseguendo-il-respiro-del-drago/05/13/

Eftimi R., Frashëri A. (2016): Ujërat Termale dhe minerale të Shqipërisë. SHBLB E RE: 1–224. (in Albanian) https://www.researchgate.net/publication/302914492

Frashëri A. (2013) Shpella prehistorike Bënjës, Tema. (in Albanian) https://www.gazetatema.net/2013/08/01/mos-shkaterroni-monumentet-e-natyres-dhe-te-historise

SARBU S. M., BRAD T., BANCILA R.I., STEFAN A. (2024) Exploring Biodiversity and Food Webs in Sulfur Cave in the Vromoner Canyon on the Greek–Albanian Border. Diversity 16:477