NORTHERN VELEBIT DEEP CAVES

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Research of Northern Velebit started in the early 90s by Slovak cavers. From then on, each year at least one caving expedition is carried out in the Northern Velebit. In 22 years in the Northern Velebit area a total of 348 caves were explored of which three caves are deeper than 1000 m, five caves are deeper than 500 m, nine caves deeper than 200 m, and 27 caves deeper than 100 meters. Other explored caves do not reach 100 m of depth. Most of cave entrances are located at an altitude between 1400 to 1600 m.

Basic morphological features of Velebit caves are verticality and the incidence of major verticals. The biggest discovered verticals are located in Patkov gušt (P553), Cave system Velebita (P513), Meduza (P333) and in Cave system Lukina jama (P329). Five verticals are deeper than 200 m and 100 m verticals are quite common.

The majority of Croatian caving associations participated in the cave research but the most of those expeditions were organized by the Speleological Committee of Croatian Mountaineering Association. During all these years of research an excellent international cooperation was formed with cavers from Slovakia, Hungary, Belgium, Polish, Lithuania, France, Italy, Switzerland, Great Britain, Slovenia, Spain, Bulgaria, USA and Serbia.

In the last four years, there were four expeditions. In the summer of 2009 Lubuška jama was resurveyed and some new parts was explored. During summers of 2010 and 2011 Cave system Lukina jama was resurveyed and also some new parts was explored and in the summer 2012 in Cave system Velebita exploration were continued. Expedition leaders were Luka Mudronja and Ronald Zeleznjak. Results of these expeditions are presented in this article.

1. Introduction

Mount Velebit, with its 145 km in length, is the longest Croatian mountain (Figure 1). Its strike is NW-SE direction, and it spreads over three Croatian regions: Lika, Dalmacija and Hrvatsko primorje.

Northern Velebit is a mountainous region between the Adriatic Sea and the Ličko-Gacko Polje. It begins at the saddle of Oltari in the north and spreads over to the saddle of Veliki Alan in the south with a length of 17 km and a maximum width of the massif of 30 km. The middle part of the massif reaches a height of almost 1700 m (Mali Rajinac, 1699 m). Despite being only several kilometres away from the sea, the area of Mount Velebit is influenced by the mountain climate. The mean annual precipitation in Northern Velebit is around 2000 mm. In the highest parts of the massif, the snow cover remains on the ground for over 100 days in a year. The mean annual temperature is about 4 °C.

Velebit has always attracted people, not only with its valuable flora and fauna, but also with its natural beauty on the border between the mountains and the sea. Ever since the beginning of systematic speleological surveys in 1990, Velebit has constantly surprised cavers.
2. Geology of Northern Velebit

Figure 2. General groundwater flow directions tested by tracing and according geological structure (Prelogović 1989, Prelogović et. al., 1998, Blašković, 1998, Velić & Velić, 2009, Stroj, 2010)
The area of Northern Velebit is composed of lithostratigraphic units ranging from Middle Triassic to Paleogene Age (Mamuzic et al., 1969, Sokač, 1973, Velić et al., 1974). The Middle Triassic deposits are predominantly composed of limestone. Tuff and tuffite occur laterally in the uppermost part. The lower part of Upper Triassic is characterized by the sequence of clastic rocks up to 200 m thick represented by shale and sandstones. Carbonate sedimentation proceeded with 250 m thick dolomite deposits. Due to a lower permeability as the consequence of lithological composition (clastic and dolomites), and structural position in the central part of an anticline structure, the Triassic sediments form the complex hydrogeological barrier of Mt. Velebit. The largest part of Northern Velebit is composed of Jurassic sediments, which have deposited continuously under almost identical conditions and which contain carbonate rocks only. Limestone prevails in the composition of deposits, but dolomites are also present. Generally, Jurassic sediments are very permeable units, but in some locations dolomite inhibits groundwater flows and acts as a relative barrier (the Apatišan area) (Pavicevic, 1997). The thickness of Jurassic deposits is approximately 2850 m. However, speleological explorations have revealed a more complex geology of Northern Velebit. For example, Lukina Jama contains deposits of carbonate breccias from –450 to –700 m and from –750 to -950 m. A similar situation occurs in Slovacka Jama as well. This poses a number of questions related to their stratigraphy and tectonic movements (Lackovic, 1994, Šmida 1999).

In the investigated area, the well permeable Cretaceous sediments have not greater importance. At a narrow belt along Adriatic coast they are represented by limstone-dolomite alteration. In the Lika region on the side of Mt. Velebit (Lipovo polje) deposits are composed of limestones intercalated by dolomite and calcareous breccias. The significant part of the area concerned is covered by Jelar formation of Upper Paleogene age. Its origin is closely related on strong tectonic movements, which affected the area during that time (Bahun, 1974). In the hinterland (Lika) they are partially permeable but in the higher positions on Northern Velebit calcareous breccias are highly permeable. This can best be seen in the spectacular landscape of Hajdučki and Rožanski kukovi area (Figure 3), as well as the numerous karstic phenomena and the deepest caves of Croatia among them. The thickness of calcareous breccias is up to 300 m (Kuhta & Bakić, 2001).

The geological structure is the consequence of two main periods of tectonic activity. During the Tertiary tectonic cycle, which lasted from Eocene to the end of Miocene, compressive movements oriented NE-SW reached their cumulative maximum with orogenesis of the Dinarides. As the consequence of mentioned regional tangential stress, the deep nappa structures, folds and regional faults of Dinaric strike (NW-SI) have been formed. During the later, Neotectonic period, the main stress changed to N-S, resulting in further uplift and transpressive deformation of older structures, which were broken in the smaller structural units and tectonic blocks.

On the basis of geology of the studied area and the basic tectonics involved, distinctive areas, structural units and faults that influence the hydrogeology of the terrain and karstification processes development presented on Figure 2. Numbers mark the most important faults that affected the development of numerous deep caves in the investigated area.

The regional longitudinal reversal Velebit fault (1) located in the coastal area, on the surface manifested as 4-6 km wide faulting zone, represents the boundary between Dinaricum and Adriaticum megastructural units. The tangential movement is estimated on 6-8 km.

The Bakovac fault (2) is very strong normal fault. The horizontal movements along it are not observed but the vertical displacement is estimated on about 1500 m (Prelogović, 1989). After Blašković (1998) this fault is reversal which means different hydrogeology interpretation. The fault interrupted extension of the Velebit complex barrier and significantly affected the hydrogeological relations in the area. In geomorphologic sense, the Bakovac fault represents the boundary between Middle and North Velebit.

The Lomska Duliba fault (3) is located on the northern boundary of the investigated area. The vertical displacement is estimated on 150 m. All mentioned faults have been very active during Neotectonic period. The vertical neotectonic movements were estimated on the basis of deformations of the Jelar formation, position of the Pliocene and Quaternary deposits, comparison with neighbouring areas and disposition and deformation of geomorphologic elements. In the area concerned, the summary amplitudes of these movements reach 1600 m.

Speleological exploration of deep caves on the Northern Velebit show a deep vadose zone within the central part of the carbonate massif. Considerably higher underground water level in the sinking areas indicates a sudden fall of the water level in the east part of the massif.

Figure 3 Rožanski kukovi on Northern Velebit
One of the reasons for this can be the hydrogeological function of active fault zones which might act as partial barriers for underground water flows. The active faults partially direct underground water flows parallel to their own strike (toward NNW) in the upstream area, but also dispersing and allowing the restrained flows to pass directly toward the Velebit channel at the same time (Figure 2). Another reason is sought in the process of retrograde karstification caused by uplifting of mountain massif, i.e. lowering of the erosion basis. Influence of active fault zones and advancement of the karstification process are not mutually exclusive, but probably act together. The karst areas upstream (Lika hinterland) and downstream (Velebit Mountain Massif) from the zone of sudden water level fall are hydraulically mutually separated, and can be analyzed as separate parts of the cascade system. This enables significantly different directions of underground flow within different parts of the system (Stroj, 2010).

Mentioned tectonic activity, the emergence of concentrated flows of water which descend to the bottom of deep sinkholes in times of climate change and melting of glaciers. Tertiary carbonate breccia resistance to mechanical erosion enabled remarkable development and preservation of corrosion landforms (ledges), inside of which the entrances of the important caves are situated. Smaller glaciers of the peak segments of the relief did not have enough ice mass and pronounced horizontal movement that would destroy karst morphology of the terrain below. Finally an important factor and is a very deep vadose zone within the carbonate massif.

3. Northern Velebit pits

Research of Northern Velebit started in the early 90s by Slovak cavers, members of the Speleology Club of Comenius University. From then on, each year at least one caving expedition is carried out in the Northern Velebit.

In 22 years in the Northern Velebit area a total of 348 caves were explored of which three caves are deeper than 1000 m, five caves are deeper than 500 m, nine caves deeper than 200 m, and 27 caves deeper than 100 meters. Other explored caves do not reach 100 m of depth. Most of cave entrances are located at an altitude between 1400 to 1600 m.

Basic morphological features of Velebit caves are verticality and the incidence of major verticals (Figure 4). The biggest discovered verticals are located in caves: Patkov gušt (P553), Cave system Velebita (P513), Meduza (P333) and in Cave system Lukina jama - Trojama (P329) (Bakšić, 2006). Five verticals are deeper than 200 m and 100 m verticals are quite common. Vertical morphology of the pits is most distinct in the parts built of massive tertiary breccia that is why after entering the older stratified deposits, probably of Jurassic age, this morphology is partly alleviated.

The reason is unbedded breccia, for which the karstification relates solely to systems of steep to vertical cracks. Great persistence and low incidence of cracks in the breccia favors the development of extremely deep and spacious verticals, which typically occur at the intersections of cracks. Concentrating of flows towards the most permeable parts of the rock mass mechanisms of epikarstic zone is the most important factor in the development of large underground vertical dimensions. Verticals formed that way are beneath the surface, without an external entrance (example is the large vertical in Cave system Velebita) and due to denudation of the surface ground external entrance for some pits was subsequently opened (Patkov gušt).

Figure 4. Cross section of Northern Velebit massif with profiles of deep pits. Big Halls are shown with numbers: 1 - in Cave System Velebita - 253 260 m³; 2 - in Ledena jama - 192 000 m³; 3 - in Cave System Lukina jama - 118 750 m³; 4 - in Slovačka jama - 72 000 m³.
In older carbonate beds, under the influence of higher density discontinuity and slightly inclined layer surfaces, canals are generally somewhat less steep, with smaller pits and narrower meanders. It must be noted that the lower parts of these caves are also very vertical.

Vertical morphology of caves in vadose zone of Northern Velebit massif indicates the abrupt rise of this terrain, whereby there was probably not enough time for the formation of significant horizontal phreatic and epiphreatic channel systems at different altitudes in the massif. Interesting phenomena are large halls (Figure 4 - Velebita 253 260 m$^3$, Ledena jama 192 000 m$^3$, Lukina jama 118 750 m$^3$) and smaller halls and fragments of the horizontal channels (Slovačka jama - hall 72 000 m$^3$), whose formation is associated with vadose flows within the massif, and are in the range from 494 to 563 m above the sea level, high above the present phreatic zone, but 13 to 82 m above Lika river sinkhole.

Only the hall in Ledena jama is at slightly higher altitude between 924 and 957 m. These subterranean spaces are traces of the earlier stages of karstification, which were largely disintegrated and fragmented in more recent tectonic movements.

Figure 5 shows plans and dominant direction of channels of most significant caves in the Northern Velebit. According to the directions of channels dominant orientation discontinuity by which the karstification occurred can be well observed.

Lukina jama and Lubuška jama channels (both located in Hajdučki kukovi partially overlapping in plan) are dominantly oriented in NW-SE direction, and subordinately in NNW-SSE and SSE-NNW. Slovačka jama (Rožanski kukovi) formed to an equal extent by orientation systems NW-SE and NNE-SSW and is less pronounced in NE-SW Cave system Velebita (located in the westernmost part of Rožanski kukovi) predominantly oriented in NNE-SSW direction and subordinately in WNW-ESE and NE-SW. In Meduza cave, also located in the western part of Rožanski kukovi orientation of the channels are very similar to those in Velebita, with even more pronounced dominance of channel oriented in NNE-SSW direction.

Directions of the channels are largely in line with structural features. From directions of channels increasing importance of discontinuity of orientation NNE-SSW is noticeable in the Northern Velebit in a westerly direction, probably as a consequence of approaching the zone of Velebit fault. At the direction of east, the greatest influence on the direction of development of karst channels are gradually taken over by discontinuities oriented in NW-SE.

In caves occurrence of snow and ice is relatively common. In 118 pits (34%) snow and ice was recorded. Usually if forms at the depth of 50 m and goes even up to a depth of over 500 m. The deepest recorded occurrence of snow and ice was in Patkov gušť cave at a depth of -553 m and it was the snow and ice that fell mainly in the higher parts of the pit. Increased melting of snow and ice over the past 20-odd years was observed (opening passages in the depth).

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4. Results of new caving expeditions

In the last four years, during summers, there were four expeditions: "Lubuška jama 2009", "Lukina jama 2010", "Lukina jama 2011" and "Velebita 2012". Expedition leaders were Luka Mudronja and Ronald Železnjak.

Entrance to Lubuška jama was found on 11/09/2000 by Polish cavers from Bobry Žagan ans Gawra Grozow associations accompanied by cavers from SO PDS Velebit from Zagreb. During two expeditions they explored Lubuška jama to a depth of -521 m. Possibility of further progress and connection to the Cave system Lukina jama encouraged the organization of expedition 2009 to try to find a passage to the Cave system Lukina jama.

Expedition in the Cave system Lukina jama was made for resurveying and because of the dive into a siphon at the bottom of the cave, while the expedition at Cave system Velebita was made to explore promising parts of the cave.

4.1. Expedition "Lubuška jama 2009"

During expedition to Lubuška jama in 2009 a new map of the cave was drafted M 1:500. According to the newly created map, depth of the pit is smaller and amounts to -508 m and the length increased to 2164 m.

The most important finding of this expedition was, most likely, a new species of stigobiontne leech currently on DNA analysis.

4.2. Expeditions "Lukina jama 2010" and "Lukina jama 2011"

A new map of Cave system Lukina jama" from the entrance Trojama (Manual II) to the bottom of the cave was made. However, drawing of the Cave system Lukina jama from the entrance Lukina jama to the junction of Trojama could not be repeated because at 60 m of depth in Lukina jama an ice- snow cap prevented the passage.

Newly determined depth of the Cave system Lukina jama is -1421 m (poligon was made to a depth of -1409 m). Length is 3730 m and the volume is about 313 000 m³.

By comparing the map of Lukin jama made in 1993 and 1994 with the one made in 2010 (Figure 6) it was concluded that the maps differ for 0.94 %. According to UIS Mapping Grades (Häuselmann, 2012) the mark would be UISv2 5.4-BF.

Junction of "Vjetrotviti channel" with the bottom of the pit was proven.

During 2010 expedition two dives were made in Congeria siphon at the bottom of Lukina jama. The first dive in the length of 135 m and depth 20 m were made by Ivica Čukušić and Robert Erhardt, and the second dive in length from 135 to 40 m depth was performed by Branko Jalić.

On this occasion living specimens of cave bivalves (Congeria kusceri) were found in the siphon, which determined the second known populations of shellfish in Lika, and fourth in Croatia. Unexpected finding was so far the only known underground cave sponge Eunapius subterraneus (Bilandžija et. al. 2012, Bedek, J. et. al.,

Figure 6 Comparison of two surveys of Cave system Lukina jama from 1994 and 2010. There is significant biospeleological finding of one new springtails species Disparrhopalites sp. nov, provisionaly assigned to genus Parisotoma (Čuković & Lukić, 2012).

During expeditions 2010 and 2011 scientific research of Cave system Lukina jama was conducted on 20 measuring points from the entrance to the bottom. Cave geology, microclimate parameters, radon concentration, water quality and dynamics were investigated.

4.3. Expedition "Cave system Velebita 2011"

The main goal of this expedition was to continue previous scientific research (Paar, 2008) of geological, physical, chemical and biological properties of the cave (scientific project “Investigation of deep pits of North Velebit National park”). There is significant biospeleological finding of one new springtails species of the genera Tritomuras (Čuković & Lukić, 2012).

Cavers was continued in promising and open channels in Velebita vertical shafts, but they failed to go further. During the expedition, 43 new caves were found. Their exploration will continue in 2013.

5. Conclusion

Cave research of Croatian deep caves spurred the development of the Croatian caving, scientific research, development of cave rescue and enabled international cooperation.
Acknowledgments

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References