PHYSICAL RESEARCH IN CROATIA’S DEEPEST CAVE SYSTEM: LUKINA JAMA-TROJAMA, MT. VELEBIT

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The objective of this study is to present the first results of research conducted in the 1421 m deep cave system Lukina Jama during 2010 and 2011. The cave is situated in the area of Hajdučki kukovi in Northern Velebit National Park (Croatia) and is the deepest cave system in the Dinaric karst. In situ measurements of microclimate parameters and radon concentrations were performed at 20 measuring points. Two temperature gradients were detected: dT/dh = -3.65 ± 0.3°C/100 m from the entrance to a depth of 200 m and dT/dh = +0.39 ± 0.04°C/100 m to the bottom of the cave. Ice and snow dynamics influenced microclimate parameters to a depth of 200 m. Mean radon concentrations changed with distance, from 200–600 Bq/m³ in the upper cave sections, to 1139 Bq/m³ in the lower sections. This increase is in correlation with the partial pressure of carbon dioxide, which is an important factor in a variety of geochemical processes occurring in caves. Speleothems occur rarely in the deep caves of Mt. Velebit, and therefore the microclimate and geological conditions at the locations where they occur. As reported here, microclimate conditions below a depth of 220 m to the bottom are very stable, so speleothems are good candidates for further paleoclimate investigation.

1. Introduction

Mt. Velebit is a 145 km long mountain in the Croatian Dinaric Karst area, lying between the Adriatic Sea and the Ličko Polje and Gacko Polje fields. It is characterized by deep karst developed in thick carbonate beds (Velić & Velić 2009). Its deep aquifers are the result of complex geological structures and hydrogeological conditions influenced by the presence of clastites deep in the anticlines cores (Stroj 2011). Owing to its position between the Adriatic Sea and the continental Lika region and altitudes up to 1757 m, the mountain also serves as an important climatological border. The consequence is climate diversity, changing from a dominant temperate humid climate (Cfb) towards a humid boreal climate (Df) in the highest parts, and a submediterranean climate (Cfa) along the Adriatic coast. Such a border position, in addition to temperature diversity, also results in high precipitation (>3500 mm/y). Both factors are important for geomorphological and physical processes observed in caves.

The northern Velebit region is important because of a significant number of extremely vertical and deep caves discovered and explored in the last 20 years (Bakić 2006) (Table 1).

These caves provide an excellent means of gathering new insights on the geology and geomorphology of Mt. Velebit (Lacković 1999; Kuhta 2001; Bočić 2006), karst hydrology (Stroj 2010) and subterranean fauna (Bedek et al. 2012). Therefore, the aim of scientific research is to gather as much information on the properties and characteristics of these caves during speleological expeditions.

Table 1. Deep caves of Northern Velebit

<table>
<thead>
<tr>
<th>Cave name</th>
<th>Depth (m)</th>
<th>Length (m)</th>
<th>Explorations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovačka Jama</td>
<td>-1320</td>
<td>5677</td>
<td>1998–2002</td>
</tr>
<tr>
<td>Cave system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patkov Gušt</td>
<td>-553</td>
<td>601</td>
<td>1997</td>
</tr>
<tr>
<td>Lomska dubila</td>
<td>-536</td>
<td>629</td>
<td></td>
</tr>
</tbody>
</table>

The aim of the present study is to present the preliminary results of research conducted in the 1421 m deep cave system Lukina Jama-Trojama during 2010 and 2011. This system is situated in the area of Hajdučki kukovi in Northern Velebit National Park and it is the deepest Croatian cave investigated since 1993. Although the widely accepted name is Lukina Jama, this is actually a cave system Lukina Jama-Trojama because of the two entrances and shafts that are connected at a depth of 558 m. During 2010 and 2011, the Lukina Jama entrance (altitude 1438 m) was choked with snow and ice at a depth of around 70 m. This condition, not consistent with the trends of global warming, has been ongoing for years, unlike in the 1990s when the entrance was passable. The
second entrance, Trojama, at an elevation 37 m higher (1475 m) was passable, and therefore the scientific research was conducted through this entrance.

These entrances experience differing ice and snow conditions. During previous expeditions, ice and snow were recorded at the Lukina Jama entrance down to a depth of 556 m (Buzjak et al. 2010). In the Trojama entrance, ice and snow are only present at depths between 25 and 200 m.

Figure 1. Ice in the cave system Lukina Jama at -50 m (photo by D. Paar). The deepest ice location is at -556 m (Buzjak et al. 2010).

2. Methods

In situ measurements of microclimate parameters and radon concentrations were performed at 20 measuring points (Fig. 2).

Microclimatic parameters (T, RH and dew point) were measured using Onset Hobo Temp/RH, Oakton RH/Temp data loggers and Telaire 7001 Carbon Dioxide Monitor. The logging intervals were 1 and 2 hours.

Integrated measurements of radon and its short-lived progenies in the air were performed by means of the passive track etching method with type II LR-115 SSNT detectors (Kodak-Pathé, France). The cylindrical detector cup, with a diameter and length of 11 cm and 7 cm respectively, was either covered with a paper filter with a 0.078 kg/m² surface density (diffusion detector), or was open. Radon concentration in the air was determined as a product of the sensitivity coefficient and track density of the diffusion detector. The measurement method with two detectors (diffusion and open) enables determination of the equilibrium factor for radon and its progenies in the air (Planinić et al. 1997).

Figure 2. Cave system Lukina Jama (profile) with measuring points L1-L20. Cave map edited by D. Bakšić and L. Mudronja.

3. Results and Discussion

In order to obtain a complete overview of the microclimatic parameters, monitoring should be undertaken over an extended period of time (Cigna 2002; Buzjak 2012). However, deep pits do not allow this due to
the very complex access to measuring points. Consequently, at most points, the cave microclimatic parameters were monitored during speleological exploration, though monitoring over a one-year period was conducted at a few selected points.

Changes of microclimate parameters are minimised and cease to exist. A comparison of the one-year microclimate measurements on the ground surface (Fig. 4) showing high daily and seasonal amplitudes, with the one-year records in the cave at depths of 180 m and 1225 m shows T and RH disturbances at a smaller scale (Figs. 5 and 6). On the other hand, values at greater depths are very stable. At 180 m there is substantial ice and snow throughout the year and there are likely strong dynamics during winter or periods with high percolation and low temperatures.
Deep in the cave, T is very stable, under the instrumental error of 0.2°C and RH approaches 100%. From these measurements, it can be concluded that at depths greater than 220 m, even short time measurements give relevant results.

According to the parameter trends, two temperature gradients can be determined (Fig. 8): one from the entrance to a depth of 200 m, and a second from 200 m to the bottom of the cave. At 200 m there is a change in the cave morphology with a narrow passage in a meander (with air circulation). Below this point there is no snow and ice, so it is expected that there will be some small influence of the geothermal gradient and temperature gradient will change a sign and value (from -3.65 to +0.39°C/100m).

![Figure 7. Two temperature gradients in the cave system Lukina Jama.](image)

If the presented temperature gradients are compared with previously obtained values (Paar et al. 2008) from the 1026 m deep cave system Velebita, virtually the same gradients are evident in the upper parts of the caves (Table 3). However, differences occur in the lower cave sections. There is likely a less significant external influence than the influences due to cave geomorphology, hydrology and other properties. One substantial difference is that there is no ice and snow in the cave system Velebita, as both entrances are horizontal (as opposed to both entrances of the cave system Lukina Jama which are vertical). This is also likely the reason why the change from a negative to a positive temperature gradient occurs at different depths.

![Figure 8. Measurements of radon concentration c at various depths in the cave system Lukina Jama.](image)

| Table 3. Comparison of temperature gradients in the Lukina Jama and Velebita cave systems (Paar et al. 2008). |
|-------------------------------------------------|-------------------------------------------------|
| | Lukina Jama | Velebita |
| dT/dh₁ | -3.65 ± 0.3 °C/100 m | -3.5 ± 0.2 °C/100 m |
| dT/dh₂ | +0.39 ± 0.04 °C/100 m | +0.25 ± 0.03 °C/100 m |
| Gradient change at | - 200 m | -100 m |

As shown previously, in the cave system Velebita there is an entrance to a 513 m long shaft at a depth of 100 m, and this change can be attributed to cave morphology and detected air circulation in the upper part of the pit where air circulation changes the temperature gradient by condensation or evaporation which releases or absorbs heat (Paar et al. 2008). In the lower part, the temperature increases with depth because of the Earth’s geothermal gradient. It is also shown that small water masses flowing into a mountain are able to perturb the rock temperature (Badino 2005).

In the Trojama entrance of the Lukina Jama system, the temperature gradient change occurs at a depth of 200 m, around the lower level of ice and snow. There is a narrow entrance to a meander that continues down to a depth of 520 m where the entrances are connected.

In analysing speleothems to obtain paleoclimate information, it is important to know the stability of cave environment so as to estimate if speleothems are formed under conditions of isotopic equilibrium of carbon and oxygen (Fairchild & Baker 2012). Speleothems rarely occur in the deep caves of Mt. Velebit, and therefore it is important to know the microclimate and geological conditions at the location where they occur. In Lukina Jama, speleothem samples were collected at depths between 900 and 987 m. As shown in the present study, at those depths, the microclimate conditions are very stable, and therefore speleothems are good candidates for further paleoclimate investigation. In deep caves, temperature dependence with depth is additional factor that must be considered in the analysis.

The average radon concentrations varied with location from 200–600 Bq/m³ in the upper part of the cave, up to 1139 Bq/m³ in the lower section (Fig. 8). These values are much lower than in other Croatian caves, where concentrations of up to 25,000 Bq/m³ were measured (Radolić 2009; Paar et al. 2005). The highest value in caves on Mt. Velebit was measured in Lubuška Jama, c = 3800 Bq/m³ (Radolić 2011). This cave is very close to Lukina Jama, but in comparison with Lukina Jama, it has very narrow meanders, which likely results in much lower air circulation.

In 2011, the slope of the radon concentration change with depth was twice that in 2010. The preliminary measurements indicated an increase of the carbon dioxide partial pressure in Lukina Jama from 380 ppm at the entrance to 1005 ± 50 ppm at a depth of 1368 m (siphon at the bottom of the cave).
4. Conclusions

This paper presents new data on the microclimate parameters and radon concentrations in the cave system Lukina Jama, the deepest cave in the Dinaric karst. Microclimate dependence with cave depth was discussed. Two temperature gradients were detected in the Lukina Jama and Velebita systems: T drop in vertical passages at depths of 100–200 m and T rise below those depths. Such T distribution is influenced by the permanent ice and snow distribution. At depths below 220 m, the microclimate conditions are very stable, and speleothems samples collected below a depth of 900 m are good candidates for paleoclimatic investigations.

The measurements showed an increase of radon concentrations with depth. Further analysis of radon concentrations as a natural tracer can help us to understand transport processes at the interfaces of the lithosphere, hydrosphere and cave atmosphere. This may provide a large amount of information on the development and changes of the cave microclimate, particularly in correlation with carbon dioxide, which is an important factor in a variety of geochemical processes occurring in caves.

Acknowledgments

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References


