

# SOME NEW POTENTIAL SUBTERRANEAN GLACIATION RESEARCH SITES FROM VELEBIT MT. (CROATIA)

## **Neven Bočić**

University of Zagreb  
Marulićev trg 19/II  
Zagreb, 10000, Croatia, nbocic@geog.pmf.hr

## **Nenad Buzjak**

University of Zagreb  
Marulićev trg 19/II  
Zagreb, 10000, Croatia, nbuzjak@geog.pmf.hr

## **Zoltán Kern**

Institute for Geological and Geochemical Research,  
Budaörsi ut 45.  
Budapest, H-1112, Hungary, kern@geochem.hu

## **Abstract**

Despite the frequent reports about their shrinkage, detailed survey of the major subterranean ice deposits is still lacking in Croatia. Here we present cave maps and detailed description of cave ice accumulation from five caves of the Velebit Mt. Morphological constraints allowed ice volume estimation for four of them. Ice volumes were estimated as ~1500 m<sup>3</sup> at the Gavranova Pit in 1999, 100 m<sup>3</sup> at Štirovača ice cave in 1987, 150 m<sup>3</sup> at Japagina 3 in 2000, 1500 m<sup>3</sup> at Kugina ice cave in 2004. These new records provide reference data for future studies to evaluate glaciological changes/processes taking place in the corresponding cave environments. As a common topographical characteristic of these caves and the previous ones, it seems that the present elevational limit of permanent cave ice occurrence in the Velebit Mt is ~1000 m a.s.l. Regarding the climatic parameters it corresponds to the January isotherm of -2° C and 14° C in July, annual sum of precipitation of 1750 mm and 90 days with snow per year.

## **Introduction**

Cryospheric processes in the karst systems remains heavily under-researched, though a pervasive ice loss trend has been documented for the glacierized caves worldwide (Kern and Perşoiu, 2013).

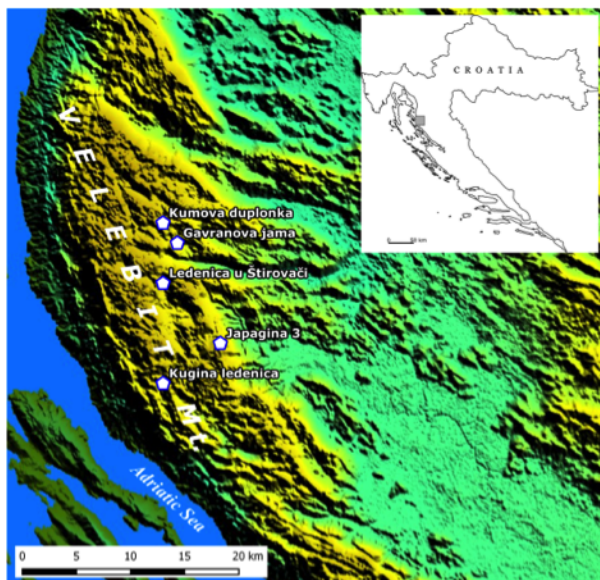
A prominent region of the karstic world is the Dinarides, where numerous cavities host perennial ice and snow accumulation. The exact or approximate number of Croatian caves with permanently glaciated parts is unknown but the data collection is in progress (Buzjak et al., 2011). The first scientific report about Croatian ice caves has been published surprisingly late (Božičević, 1971). Relatively modest research efforts have been focused on them (Jelinić et al., 2001; Horvatinčić, 1996) although recently mass ice loss (Bočić et al., 2008; Kern

et al., 2008, 2011) or complete deglaciation (Bočić et al., 2012) have been reported from caves. Therefore the detailed documentation of the major subterranean ice deposits is an urgent task.

Present paper will provide speleoglaciological description of five localities from Croatian part of the Dinaric system, where major perennial cave ice accumulation exists. The provided cave maps and the estimated ice volumes will provide valuable reference data for evaluating glaciological changes/processes taking place in the corresponding cave environments during future times.

## **Physical geography settings**

Mt. Velebit is part of the Dinaric Karst and it is located in Croatia. It stretches between the eastern coast of the Adriatic Sea and continental Lika region in length of 145 km. The highest altitude is 1757 m a.s.l. Because of carbonate rocks Velebit area is highly karstified with numerous and dense surface karst forms, and many vertical caves (Bočić et al., 2012; Bakšić and Paar, 2006). The deepest cave system is Lukina jama -Trojama (-1431 m), and the longest one is Kita Gačešina-Draženova puhaljka system (length 26 km). The studied area includes the northern and central part of the Velebit mountain range (Fig. 1) with the highest altitude 1699 m a.s.l. (Mali Rajinac peak). The zone above 1500 m a.s.l. has a humid boreal climate (Köppen's type *Df*) and the lower parts have a temperate humid climate (*Cfb*) mainly determined by the relief (Zaninović, 2008). Mean annual air temperature in the area up to 1000 m a.s.l. is about 5.5°C and in the highest region drops to 3.5°C. The coldest months are January and February (between -2 and -5°C) and the warmest one is July (12-16°C). Due to proximity of the Adriatic Sea, there are important climate modifications. The most important one is high



**Figure 1.** Location of the presented ice caves.

amount of precipitation that varies from 2000 to 3900 mm/year. In combination with higher altitude and larger depressions with intense temperature inversion there are good conditions for the accumulation of ice and snow in karst depressions like deep mountain dolines and caves and pits (Buzjak et al., 2010, 2011).

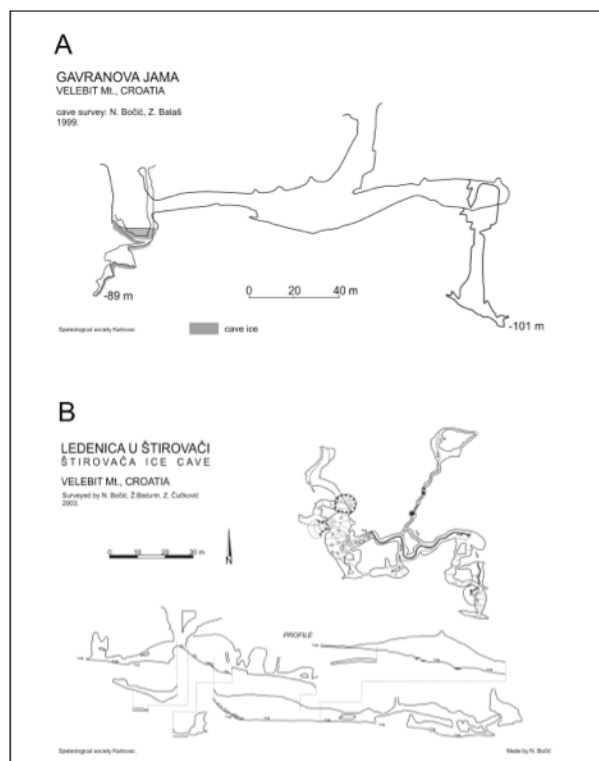
## Methods

Maps of visible ice fillings have been sketched using speleological mapping methods (e.g., Kovačić & Čepelak, 2000). Basic speleoglaciological characteristics, such as observed/assumed ventilation regime and type of ice occurrence were provided following the classification schemes of Luetscher and Jeannin (2004) and Citterio et al. (2004). Although ice thickness estimates suffered from major uncertainties, in line with other similar studies (e.g. Luetscher et al., 2005), ice volumes were estimated where morphological criteria supported the estimation.

## Results

### **Gavranova jama (Gavranova pit; Fig. 2a)**

Gavranova pit is located in the area Begovača (eastern part of the north Velebit) at 1100 m a.s.l. It has two main entrances (the higher and the lower) with 20 m of the vertical, and 95 m of horizontal distance. There is also small third entrance very near the lower one and on the same elevation. The cave has been explored in 1999 (Bočić, 2001). Below larger entrance is vertical channel, which continues to depth of 25 m. On the bottom there



**Figure 2.** Cave survey of Gavranova jama (A) and Ledenica u Štirovači (B).

is a greater accumulation of firn with congelation ice deposits. The diameter of this ice plug is about 15 meters. Between the ice and the bedrock is a narrow passage up to 89 m depth, but due to the re-deposition of ice it is not possible to determine the exact thickness of the ice plug. The estimated volume of the ice was at least about 1500 m<sup>3</sup>. During the subsequent visit in 2005, it was found that the level of ice in this period decreased by about 1 m. Specific cave morphology probably influences the complex ventilation of the cave and this has influence on cave ice dynamic. So, it is necessary to undertake a detailed microclimatological measuring to determine airflow regime.

### **Ledenica u Štirovači (Štirovača ice cave; Fig.2b)**

Štirovača Ice Cave is situated in the large Štirovača karst depression, at 1110 m a.s.l. It is a 351 m long cave with two vertical entrances. Its entrances are only 6 m apart one from another, with an altitudinal difference of 5 m. Under the entrances there is a chamber (dimensions 22 x 8 x 14 m). It extends to the south and has inclined bottom (about 30°). It was formed by a collapse of the ceiling in the main channel section. During the first exploration of this cave in August 1987 a substantial mass of snow and congelation ice was noticed in the entrance part,

estimated at a volume of approx. 100 m<sup>3</sup>. Therefore the cave was named “ledenica” or “snježnica”, which means icy or snowy cave, i.e. “ice cave” or “snow cave”. In the next investigation, in the summer of 2003, and afterwards, snow and ice were no longer noticed (Bočić et al, 2012a) actually meaning that Štirovača ice cave has already lost the perennial ice deposit during the last decade of the 20<sup>th</sup> century.

### **Japagina 3 (Japagina 3; Fig.3a)**

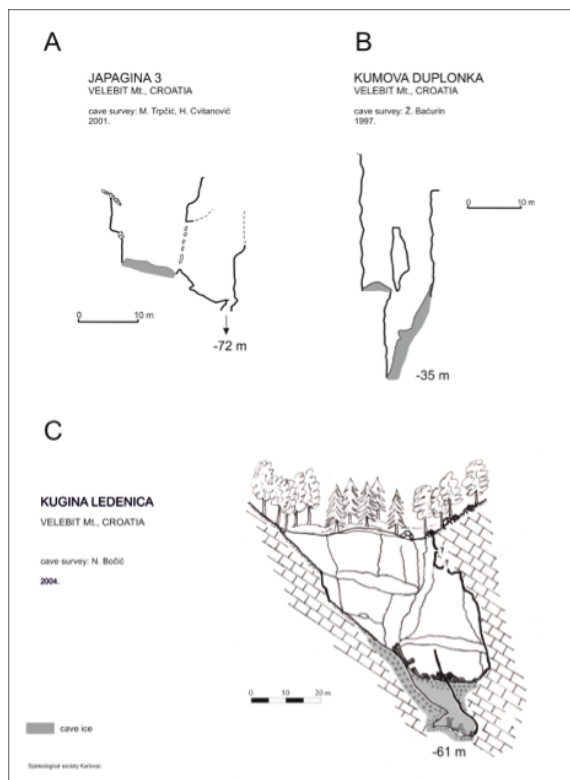
Japagina 3 is located in the area Japaga on the eastern slopes of the central Velebit (Bačurin & Stopić, 2002). There are a significant number of caves in this area of which a part contains more or less amount of ice. Japagina 3 is located at about 1300 m a.s.l., and its depth is -72 m. It was found in June 2000, and was investigated in July 2001. Its ice deposit consists of accumulated snow and firn. Estimated volume of the ice was approx. 150 m<sup>3</sup>. The relatively fresh snow surface suggests that the deposition is active. Regarding the morphology of the entrance zone it is likely that the deposit is fed primarily by wind-blown snow.

### **Kumova duplonka (Godfathers double-barreled gun cave; Fig.3b)**

This cave is located at the foot of Begovački kukovi (Northern Velebit) at 1205 m a.s.l. It has one common entrance for two vertical shafts that connect to a depth of -19 m. Morphological characteristics suggest statodynamic ventilation regime. The first Croatian exploration descending to a depth of -35m took place in 1997 (Bočić, 1997), although notes from a latter report suggest a visit by a group of Slovakian cavers in the previous year (1996) to the depth of -31 m (Šmida et al, 1999).

### **Kugina ledenica (Kugina ice cave; Fig.3c)**

The cave has been explored in late July of 2004 (Bočić, 2005). It is a simple cave but with large entrance (43 x 27 m) and one large chamber. At the bottom there is a 15 m wide ice plug. The known depth of the ice profile is about 20 m. Ice plug (profile) extends from the depth of -40 m to -61 m. The estimated volume of the ice was approx. 1500 m<sup>3</sup>. Regarding the morphological characteristics it is a typical static cave with firn. A peculiar character of this deposit is the significant number of wood trunks embedded in the ice layers.



**Figure 3.** Cave survey of Japagina 3 (A), Kumova duplonka (B) and Kugina ledenica (C).

## **Summary and Outlook**

Here are shown some ice caves as potential sites for further detailed speleoglaciological research. Some common characteristics of these caves, as well as previously-explored caves can be classified into climatic, morphological and climatic-morphological criteria. Climatic characteristics are these: they are in the area within the January isotherm of -2° C and 14° C in July, they are in precipitation isoline of 1750 mm and the number of days with snow is over 90 (Zaninović, 2008). Morphological characteristics are mainly related to the characteristics of the entrances. They are generally larger (usually over 10 m) and shaft-like type, which are oriented upward. From the climatic-morphological point of view it is important that all caves are located at an altitude of over 1000 m a.s.l., and most caves are located in larger or smaller karst depressions under the influence of temperature inversions and can function as cold air traps. The above examples, as well as most other observations (Kern et al., 2008; Bočić et al., 2008; Buzjak et al., 2012) during the explorations indicate a negative trend in the ice level of the caves. It is mainly noted lowering levels, i.e. reducing the amount of accumulated ice and open space between the ice and the bedrock. However,

it is important to note that there are caves with different trends. According to previous experiences their number is relatively small, but they have a very interesting ice dynamic. For example, in Lukina jama-Trojama system (the deepest pit of the Dinaric karst), below the main entrance (Lukina jama) the level of accumulated ice has increased and closed the passage, and now for descending into the system entrance Trojama must be used exclusively. In the pit Patkov gušt (the second largest vertical shaft in the Dinarides, 553 m) passage through the ice plug repeatedly closed and opened from the year 1997 when pit was discovered. However, this dynamic is not only or mainly a result of changes in the volume of ice accumulation, but a number of different processes (microclimate variations, the collapse of the accumulation of ice and ice “flowstones”, re-freezing of the meltwater, etc.). It should be stressed that there are caves and pits that do not have permanent cave deposits of snow and ice (e.g. Slovačka jama, Meduza, Lubuška jama, Olimp). They are located in the same climatic conditions and same altitude as well as those with the ice but they differ in characteristics of the entrances (Buzjak et al., 2011). Their entrances are usually small (at most a few meters), horizontally oriented (look like a horizontal cave, but not a shaft entrance), and some are partially covered by collapsed blocks.

This brief overview shows that area of the Velebit Mt., especially northern part, has high importance and research potential in speleoglaciology. With the former already known sites, there are many new sites with permanent ice.

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