SELECTED CHARACTERISTICS OF THE MICROCLIMATE OF THE DEMÄNOVSKÁ ICE CAVE (SLOVAKIA)

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Abstract: The article contains a summary of the microclimate research in the Demänovská Ice Cave. The current measurements results and measurements of the elements of the microclimate were used in the analaysis. They were presented against the background of the former research initiated in the second half of the 20th century. The profile of the cave's microclimate contains the data on the course and distribution of the parameters; microclimatic-ice zones were isolated; moreover, it contains the analysis of the determinants of the occurence of ice phenomena and their correlation with the microclimate.

Key words: Slovakia, Demänovská Ice Cave, microclimate, ice monolith

INTRODUCTION

Demänovská Ice Cave is located on the north slope of the Low Tatra Mountains and it is a part of the biggest cave system in Slovakia – the Demänová Caves system (Fig. 1). The cave is located on the right slope of the Demänovská valley, 90 meters above its bottom, 840 meters above sea level. The corridors are 1750 meters long, and the differences in height are 57 meters altogether. The cave communicates with the surrounding area through three main openings (the entrance hole, the old entrance hole and the exit hole; Fig 2, 3). Morphology of the Demänovská Ice Cave and the localization of the openings is conductive to the constant occurrence of ice monolith in its interior (Fig. 2, 3). A. Droppa (1957) estimated the age of the monolith to be around 400 – 500 years. According to the latest research (May 2005, Strug K. et al., 2006) the bulk of the bottom ice is 1042 m^3, its surface area is 1407 m^2, and the average thickness 0.74 m, the maximum thickness being 3.03 m.

In the second half of the 20th century, changes in the morphology of the caves were made. They were the result of the exploration of the cave and making it accessible for the tourists. A passage from the *Kmeťov dóm*, through *Dóm trosiek*, and leading out of the cave was opened (Fig. 3). The newly created hole/opening (the so-called Old Exit) was situated somewhere around the low level of the cave, much lower than its two natural openings (in the *Štrkový dóm* hall and at the end of the corridor leading to the Entrance). In 1952, a siphon was dug at the end of the *Jazerná chodba* corridor, resulting in opening the connection between the Demänovská Ice Cave and Peace Cave (Benický V., 1957, Droppa A., 1957, Otruba J., 1957). A consequence of this actions was a change of natural temperature and circulation system in the cave, resulting in diminishing of ice bulk inside the cave. The remedial actions undertaken in the middle of 1950s restored the climatic conditions to the quasi-natural state, yet the range of the ice monolith did not revert to the pre-1950 state (Benický V., 1957, Boček A., 1954, Droppa A., 1957, Otruba J., 1957, 1971, Halaš J., 1984). Making the cave accessible for tourism as well as natural climatic changes in the surroundings made the potential evolutionary changes of its microclimate possible.

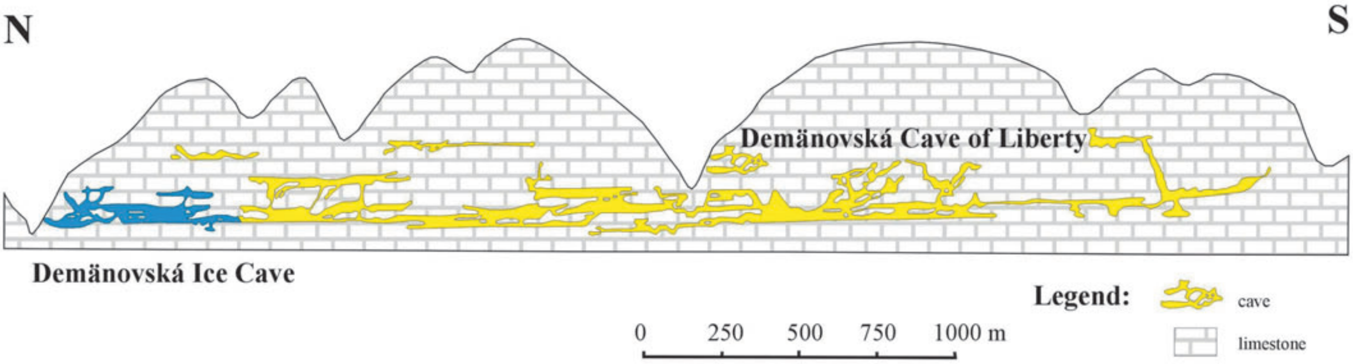

Fig. 1. System of the Demänová Caves – longitudinal section

It has been almost 20 years since the last climatic and ice research in the Demänovská Ice Cave was made. In the period, the aforementioned phenomena were under the influence of tourism. Thus, the main aim of the speleo-

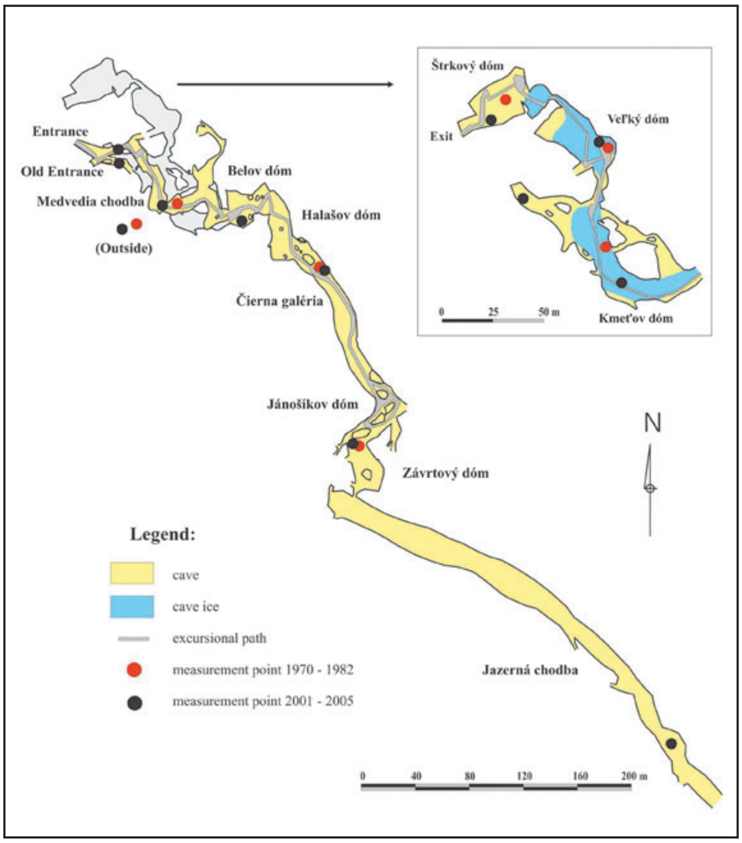

Fig. 2. The location of measurement points in the Demänovská Ice Cave in 1970 – 1982 period and since 2001

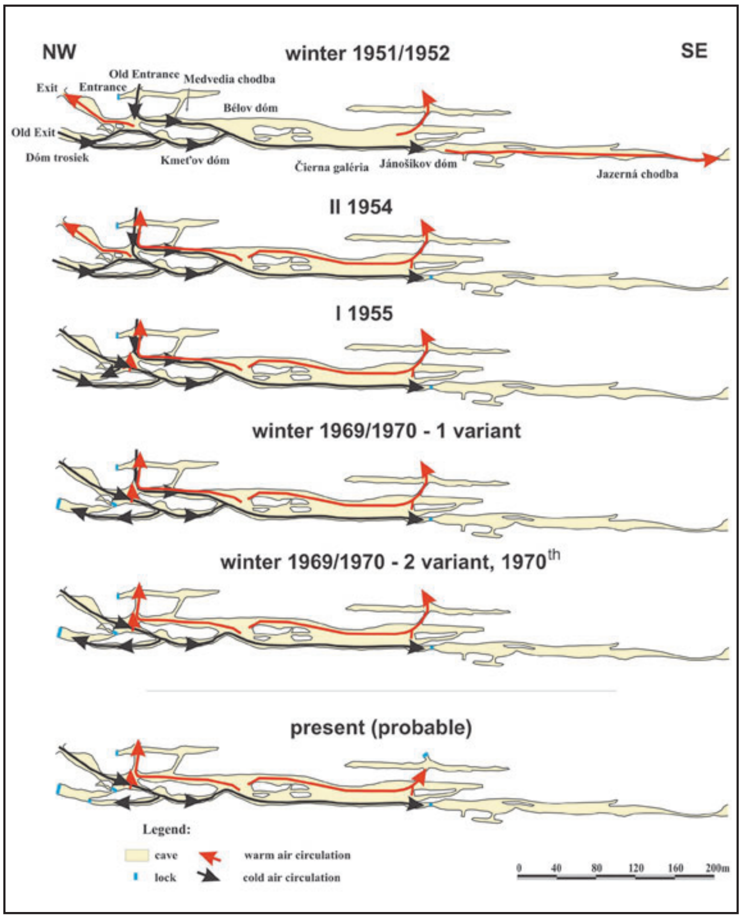

Fig. 3. The schemes illustrating changes in air circulation in the Demänovská Ice Cave in 1951 – 2005 (according to Droppa A., 1957; Otruba J., 1957, 1971)

logical and climatic research initiated in 2001 was to gather data on the current state of the cave's microclimate and possible changes in its ice range (Zelinka J., 2002). The data and observations from the last four years refer to, and are an important complement of the outcome of the researches from the past. It was assumed that the latest data and observations were to help carry out a comparative analysis as well as to create a survey of changes in the selected elements of Demänovská Ice Cave microclimate beginning from the second half of the 20th century.

HISTORY OF RESEARCH

The most notable researchers of the cave's microclimate in the second half of the 20th century were: A. Droppa (1957), J. Otruba (1957, 1971), F. Šiška, V. Sedlatý, M. Búgel, F. Vrabec (1977) and J. Halaš (1984). Currently, the research is carried out by J. Zelinka (2002) and the authors of the paper.

In 1952, A. Droppa (1957) was the first one to make periodical temperature and relative air humidity measurements. He also presented the pattern of the summer and winter circulation in the cave and characterized the main features of ice in the cave. He estimated the bulk and surface area of ice monolith.

J. Otruba (1957, 1971) made periodical temperature, relative air humidity and air circulation measurements twice (in the 1954 – 1956 and 1969 – 1970 period), and in 1955 – 1957 period, he made periodical measurements of rock temperature. He also presented the overall patterns of air circulation in the cave for winters: 1953 – 1954, 1954 – 1955 and 1969 – 1970. The objective of his considerations was also to explain the reasons for ice occurrence and to come up with a prognosis of the ice phenomena development.

In the 1975 – 1976 period, a team led by F. Šiška (1977) made first trial measurements of the directions and velocity of air flow in the cave, and from 1975 to 1977 they carried out periodical temperature, relative air humidity and air pressure measurements.

In the 1970 – 1982 period, J. Halaš (1984) carried out an ongoing monitoring of air temperature, thus providing the longest series of climatic observations for the Demänovská Ice Cave. The measurements were treated only as a documentation and were not further processed. The gathered documentation was supplemented with the outcome of rock temperature measurements from the 1977 – 1978 period (J. Halaš, 1983). The data gathered by J. Halaš contains also an overall characteristics of the ice in the cave from his observation period.

RESEARCH METHODS

In the analysis the entire available documentation was used from the so far measurements in the cave. The basis for the analyses and graphic representations are the mean monthly temperatures and air humidity from the 1970 – 1982 period, collected by J. Halaš (1984) as well as from the 2001 – 2005 period, collected by J. Zelinka (2002) and his team.

The methods of measurements changed during the speleologic and climatic research. In the existing literature on the subject, there is a lack of precise information on the used instruments and the frequency of the measurements in the past (whether they were made every 24 hours, several times a month, etc). It made the comparisons of microclimate in various periods difficult. Given the lack of homogenous measurements series, the authors pointed out only the differences that were highly probable.

From the data gathered by J. Halaš in the 1970 – 1982 period, it seems that he used the standard sets of meteorological thermometers (psychrometric set) and external thermometers that were placed on stable plinths, some 1.5 meters above the ground.

Currently, since 2001 the temperature and air humidity is monitored by automatic registers of the „Black box" type by COMET SYSTEM LTD. The parameters are measured every hour. Periodically (every 2 – 3 months) the scope and duration of the ice phenomena observations are made. Ice phenomena are one of the factors influencing the microclimate of the cave.

The localization of measurements points differed in both main research periods (Halaš J., Slíva L., 1979, Halaš J., 1984, Fig. 2). However, as the comparisons showed, these differences are of no great importance for delimiting the microclimate zones when the mean monthly and yearly data is considered. Yet, they can, to a certain extent, influence the scope of the zones.

Bearing in mind the cycle of development of ice and microclimatic phenomena, the hydrological year (starting in November and ending in October) was considered a basis for analysis and comparisons. The gathered data was processed by a spatial interpolation method of „inverse distance power" in the SURFER 8 software. According to the authors, the aforementioned method is the most suitable one for estimating the spatial distribution of relative air humidity, temperature and its amplitude, given not too many measurements points in the cave. All of the maps illustrating the course and distribution of meteorological elements and the delimitated zones were made for the bottom layer of air up to around 2 meters above the ground. The measurement points were placed within this height. Also, within this layer of air majority of the constant and seasonal ice forms appear.

AIR CIRCULATION

Air circulation measurements carried out in the Demänovská Ice Cave in the first half of the 1950s (Droppa A., 1957, Otruba J., 1957, 1971) allowed for the recognition of air circulation pattern within the cave and between the cave and its surroundings (Fig. 3).

In winter the inflow of cold air was through the Old Exit located on the level of lower corridors and through the much higher located Old Entrance and the Štrkový dóm hall. Such a pattern caused significant cooling of the air in the following profiles:

- Old Exit – Kmeťov dóm – Belov dóm;
- Štrkový dóm – Veľký dóm – Kmeťov dóm;
- Old Entrance – Medvedia chodba – Belov dóm.

The penetration of cool air into the cave reached maximally to Jánošíkov dóm (Fig. 3, Tab. 1). Jazerná chodba which is located deeper into the cave was not visibly influenced by the air from the outside. This was affirmed by the results of air temperature measurements in this

Tab. 1. The results of periodical measurements of air temperature in the Demänovská Ice Cave (in 1952 – 1956 period; according to Droppa A., 1957, Otruba J., 1957).

	22 I 1952 (Droppa A., 1957)	6 VIII 1952 (Droppa A., 1957)	6 II 1954 (Otruba J., 1957)	10 II 1954 (Otruba J., 1957)	21 I 1955 (Otruba J., 1957)	26 VII - 4 VIII 1955 (Otruba J., 1957)	25 II 1956 (Otruba J., 1957)
Outside	-3.0	27.2	-15.8	-10.9	-10.8	12.9 to 16.9	-14.8
Štrkový dóm	-	-	-	-1.5	-6.5	1.5 to 1.8	-
Veľký dóm	0.0	1.1	-3.3	-4.4	-4.4	0.2 to 0.5	-3.8
Kmeťov dóm	0.3	0.4	-4.1	-3.0	-1.7	0.2 to 0.4	-3.1
Entrance	-1.3	12.6	-12.0	-8.0	-2.0	8.2 to 9.0	
Medvedia chodba	-1.2	3.6	-6.0	-3.7	-2.5	1.8 to 2.2	-12.8
Belov dóm	0.9	1.9	-4.5	-2.9	-1.0	1.1 to 1.4	-
Čierna galéria	-	-	-2.5	-1.6	-0.4	1.0 to 1.2	-
Jánošíkov dóm	1.3	2.1	-1.5	-1.1	0.0	1.4 to 1.5	-
Jazerná chodba	5.5	5.8	-	-	-	-	-

period (Tab. 1). The transformed, relatively warm cave air flew outside through the system of chimneys inside the caves, in the ceiling of the Jánošíkov dóm corridor. Štrkový dóm and the Old Entrance could also play a role here as an outlet for the relatively warm cave air (Fig. 3).

The authors do not have enough data on the summer circulation between the cave and its surroundings, but according to the acknowledged patterns of air circulation for multi-opening caves (Cigna, A. A., 1967, Mavlyudov, B. R., 1997, Wigley, T. M. L., Brown, M. C., 1976) they tried to re-create the summer circulation pattern.

In summer, the lowest opening of the cave (Old Exit), is probably the way for the flow of cool, heavy cave air outside. This air, upon leaving the cave "sucks" air from the further corridors, initiating the constant flow from the inside of the cave, through its icy parts (Kmeťov dóm) and further outside.

The presented patterns of air circulation for winter and summer were conductive for intensive formation of seasonal ice forms in the winter months and their disappearance in the summer months. The scope of ice forms that were formed in winter took all the area close to the openings and reached probably up to Jánošíkov dóm. However, as a result of the summer circulation in the first half of the 1950s, a loss of ice was noticed (including the bulk of ice monolith) in these parts of the cave that are constantly covered with ice (Kmeťov dóm, Veľký dóm).

Because a justified fear of the total disappearance of the cave's ice filling (Boček A., 1954), actions that were meant to prevent the process and restoring the former air circulation were undertaken in the mid-1950s. First of all, the lower opening leading to the cave (Old Exit) was filled and the siphon joining Demänovská Ice Cave and Peace Cave was secured. The observations carried out in the 1970s (Otruba J., 1971, F. Šiška et al. 1977) showed, that as a result of these actions, air circulation in the parts of the cave that were close to the openings was changed (Fig. 3). The blocking of the Old Exit caused that the winter supply of cold air into the cave was only through the area of Štrkový dóm. According to F. Šiška et al. (1977) around 330 million m^3 of air flew into the cave through the opening yearly. Simultaneously, the series of corridors from the Belov dóm hall, through Medvedia chodba to the Old Entrance began to function only as a way of outflow of the relatively warm, transformed cave air. Such a winter circulation caused:

- Increased freezing of Veľký dóm, Štrkový dóm halls, compared to the situation in former years;
- The supply of cool air to the parts that are below Štrkový dóm (Dóm trosiek) decreased, as well as the

Tab. 2. A long-term typical quantity of air temperature in the Demänovská Ice Cave (according to mean monthly from periods: 1971 – 1982 and 2001 – 2005).

Parameters		Air temperature – mean long-term: yearly air temperature (TY), summer season air temperature (T(XI-IV)), winter season air temperature (T(V-X)) and amplitude of air temperature (AT)				Months – the coldest (C) the warmest (W) mean monthly (Tm)		Number of months with T ≤ 0°C
Cave chambers	Period of measurements	TY	AT	T(XI-IV)	T(V-X)	C, Tm	W, Tm	
Outside	1970 – 1982	5.8	21.7	-0.6	11.9	Jan. -4.7	Aug. 15.5	3
	2001 – 2005	6.2	21.0	-0.1	12.2	Jan. -3.6	Jul. 15.7	4
Štrkový dóm	1970 – 1982	0.5	8.9	-1.9	2.5	Jan. -3.2	Sep. 3.5	4
	2001 – 2005	0.7	9.2	-1.6	3.0	Jan. -3.8	Sep. 4.1	4
Veľký dóm	1970 – 1982	0.0	4.1	-1.0	1.0	Jan. -2.3	Sep. 1.2	5
	2001 – 2005	-0.4	4.3	-1.4	0.3	Feb. -2.5	Sep. 1.3	7
Kmeťov dóm (centre)	1970 – 1982	-0.1	1.9	-0.5	0.3	Jan. -1.0	Aug. 0.5	5
	2001 – 2005	-0.2	1.6	-0.5	0.1	Jan. -1.1	Nov. 0.2	6
Kmeťov dóm – NW	2001 – 2005	0.2	1.7	-0.1	0.4	Feb. -0.6	Nov. 0.8	4
Entrance – lake	2001 – 2005	4.9	8.0	7.6	2.4	Feb. 1.5	Aug. 9.6	0
Entrance – stairs	2001 – 2005	4.5	6.8	6.7	2.5	Feb. 1.7	Aug. 8.5	0
Medvedia chodba	1970 – 1982	1.7	1.6	1.3	2.1	Feb. 1.0	Aug. 2.4	0
Belov dóm	2001 – 2005	1.0	2.6	0.3	1.6	Jan. -0.2	Aug. 2.1	3
Čierna galéria	1970 – 1982	1.1	2.2	0.5	1.7	Jan. 0.0	Aug. 2.0	2
Jánošíkov dóm	1970 – 1982	1.4	1.7	1.0	1.8	Feb. 0.5	Sep. 2.1	0
	2001 – 2005	1.7	1.8	1.3	2.2	Feb. 0.7	Aug. 2.5	0
Jazerná chodba	2001 – 2005	5.8	0.1	5.8	5.8	Mar. 5.8	Nov. 5.8	0

supply of the air to the halls deep inside the cave (Belov dóm, Čierna galéria and Jánošíkov dóm);
- The increase of air temperature above 0 °C (with the exception of extremely cold years) in the profile from hall Medvedia chodba to the Old Entrance (compare the Tab. 1 and Tab. 2, 3) and the disappearance of ice forms in the area.

was a flow channel of warmer cave air outside. In these places the temperature did not fall below 0.0 °C (with the exception of extremely cold years), thus, no seasonal ice forms were observed. The same amount and area of ice inside the cave as it was presented by J. Halaš (1984), can be also observed currently (Strug K. et al., 2006) and we assume that it is close to the pre-1950 state.

Tab. 3. The typical quantity of air temperature (T) and relative humidity (H) (according to 24-hour mean in 2001 – 2005 period).

Parameters	Air temperature [°C]					Relative humidity [%]		
Cave chambers	Mean long-term	Absolute extremum			Number of days with T ≤ 0°C [%]	Mean long-term	Absolute extremum	
	TY	T max	T min	AT		HY	H max	H min
Outside	6.2	23.1	-14.2	37.3	26	77	100	41
Štrkový dóm	0.7	4.7	-13.0	17.7	31	94	100	49.8
Veľký dóm	-0.4	2.0	-6.7	8.7	65	-	-	-
Kmeťov dóm	-0.2	0.4	-3.7	4.1	43	98	100	70.5
Kmeťov dóm (NW)	0.2	1.0	-2.3	3.3	28	97	100	74.3
Entrance – lake	4.9	11.2	1.0	10.2	0	-	-	-
Entrance – stairs	4.5	9.3	1.0	8.3	0	-	-	-
Medvedia chodba	1.9	3.0	0.0	3.0	0	-	100	93.7
Belov dóm	1.0	2.4	-2.1	4.5	19	-	100	77.7
Čierna galéria	1.2	2.5	-1.3	3.8	18	95	100	77.6
Jánošíkov dóm	1.7	2.7	0.3	2.4	0	98	100	85.6
Jazerná chodba	5.8	6.0	5.6	0.4	0	100	100	97.4

The blocking of the Old Exit probably influenced also the air circulation between the cave and its surroundings in the summer. The blocking of the lowest opening which was the outlet for cool, relatively heavy cave air made it possible for the air to stagnate and the "conservation" of cool air inside the Kmeťov dóm. In comparison to the situation observed in the first half of the 1950s this created better conditions for the forming of ice and its all-year-long existence within this zone. This conclusion is reaffirmed by the observation of the phases of growth and disappearance of ice in the cave (Halaš J., 1984, Strug K. et al., 2006).

Because since the last air circulation measurements there were no major interventions in the morphology of the cave, one can assume that currently the air circulation between the cave and its surroundings follows a similar, already described pattern. This assumption may be indirectly affirmed by comparing the historical data on air temperature measurements (from the 1970 – 1982 period) and the data acquired currently (in the 2001 – 2005 period), as well as the information about ice in the cave supplied by J. Halaš (1984). In the 1970 – 1982 period the observed constant ice in two halls: Veľký dóm and Kmeťov dóm, as well as seasonal ice forms in the Štrkový dóm, Belov dóm, Čierna galéria. At the same time, the Medvedia chodba corridor with the Old Entrance opening

THE INFLUENCE OF SURROUNDINGS ON THE TEMPERATURE INSIDE THE CAVE

The influence of temperature outside the cave on the temperature inside was analyzed basing on data on air temperature gathered by J. Halaš in the 1970 – 1982 period (mean monthly temperatures) and basing on data from the last few years (24-hour mean temperatures). The correlation of temperature in the measurement points inside the cave with the air temperature outside gave similar results for both series (Tab. 4, 5). These results can indicate that the processes of energy exchange between the cave and its surroundings are currently similar to those from the 1970s.

Seasonal and yearly air temperature changes, observed in the profile from the entrance to the Jánošíkov dóm hall strictly correlate with the temperature changes outside (Fig. 4, 5). There are visibly cooler and warmer periods in the entire profile. The duration of these episodes, as well as the degree of cooling/warming up of the individual halls and corridors is connected with:
- the temperatures outside;
- the distance from the cave openings;
- the role of the corridor in air exchange.

The analysis of air temperature inside and outside the cave, done separately for winter and summer periods

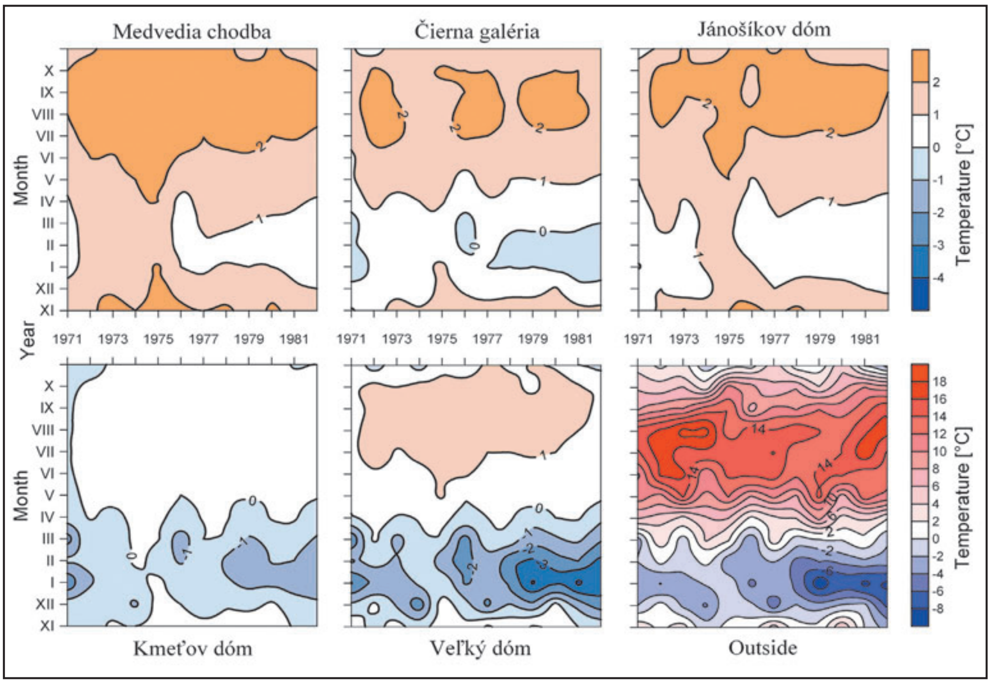

Fig. 4. The yearly course of air temperature outside and inside the Demänovská Ice Cave (chosen measurement points) in 1970 – 1982, according to mean monthly

showed that the influence of the surroundings is the strongest in winter period (Tab. 4, 5). This influence is most notable in the Exit – Štrkový dóm – Belov dóm – Čierna galéria profile (correlation coefficient R2 from 0.9 to 0.3; Tab. 4, 5), and it is less evident in the Entrance – Medvedia chodba (correlation coefficient 0.2 – 0.3; Tab. 4, 5). The diversification of the correlation coefficient in these two profiles indirectly hints at the direction of cool valley air penetration inside the cave and at the way of the outflow of the transformed cave air outside. It also shows that Medvedia chodba (which

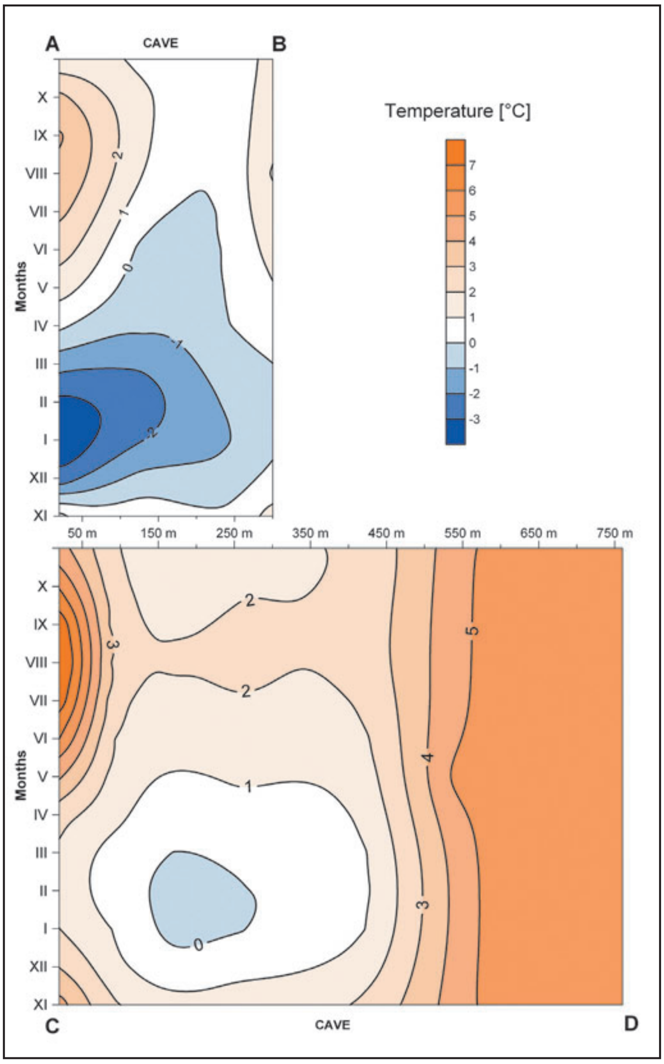

Fig. 5. The mean long-term course of air circulation in longitudinal sections A – B (Exit – Kmeťov dóm) i C – D (Entrance – Jazerná chodba) in the Demänovská Ice Cave

Tab. 4. The Pearson's correlation coefficient (R2) of mean monthly air temperature between chosen chambers of the Demänovská Ice Cave and its surroundings for year, summer season and winter season in 1970 – 1982 period.

Cave chambers	Period		
	Year (XI – X)	Summer season (V – X)	Winter season (XI – IV)
Veľký dóm	0.8104	0.0137	0.7305
Kmeťov dóm	0.585	0.0537	0.4171
Medvedia chodba	0.429	0.0393	0.2386
Čierna galéria	0.6163	0.0317	0.3846
Jánošíkov dóm	0.4609	0.0122	0.2165

Tab. 5. The Pearson's correlation coefficient (R2) of mean daily air temperature between chosen chambers of the Demänovská Ice Cave and its surroundings for year, summer season and winter season in XI. 2001 – X. 2005.

Cave chambers	Period		
	Year (XI – X)	Summer season (V – X)	Winter season (XI – IV)
Štrkový dóm	0.9055	0.0991	0.9226
Veľký dóm	0.8504	0.015	0.8493
Kmeťov dóm (centre)	0.7719	0.0272	0.7865
Kmeťov dóm (NW)	0.5479	0.0779	0.4802
Entrance	0.6914	0.3142	0.2016
Medvedia chodba	0.5661	0.0882	0.2998
Belov dóm	0.6952	0.121	0.5046
Čierna galéria	0.5059	0.0252	0.3403
Jánošíkov dóm	0.4748	0.0059	0.2183
Jazerná chodba	0.0052	0.0202	0.0037

is close to openings) is thermally „privileged" in comparison to other halls which are also located closely to the openings (Veľký dóm, Kmeťov dóm) and the halls located further into the cave (Belov dóm, Čierna galéria; Fig. 4, 5).

In the summer period the influence of temperature of the surroundings on the air inside the cave is visibly smaller (Fig. 4, Tab. 2, 3). It is connected to the fact that the air exchange between the cave and its surroundings is coming to a stop (or that is weakened). In this period, the air in the cave stagnates, and the natural supply of warmth from the outside is minimal, in comparison to winter. The energy flow is mainly through the rocks and with the infiltrating rain water. In the halls with ice, the presence of ice monolith has an additional influence on the air temperature changes; the ice works as a buffer and keeps the temperature around 0 °C (Fig. 4, 5).

The presented analysis shows that the character of winter period is of great importance for the energy in the cave. The length and low temperatures of winters directly influence the degree of freezing of the cave. Thermal conditions in the summer period are of less importance. These statements are positively verified by the observations in the 2001 – 2006. The greatest amounts of ice were noted in the years in which the mean monthly air temperature in winter was below -1.0 °C. In the years in which the mean monthly air temperature in winter was higher than 0.4 °C, the growth of the ice bulk was negligible (Halaš J., 1984). Higher than usual mean monthly air temperature in summer was, however, not important for the amount of ice that survived until the next winter period.

MICROCLIMATIC ZONES IN THE DEMÄNOVSKÁ ICE CAVE

Delimitation of the microclimatic zones in the cave was carried out according to the classification of ice-filled caves presented below (Tab. 6). The following data were taken into consideration: mean yearly air temperature (TY), mean temperature of the warmest and the coldest month (Tmax, Tmin) as well as the yearly amplitude of temperature (AT) between the warmest and the coldest month, as an indicator of stability and dynamism of the climate (Pulina M., 1999):

Tab. 6. The criterions of delimitation of temperature climatic zones in the ice caves.

Climatic zones	TY [°C]	T_{max} [°C]	T_{min} [°C]	AT [°C]
I climatic zone	≤ 0.0	≤ 0.0	≤ 0.0	> 0.5
II climatic zone	≤ 0.0	≤ 0.0	> 0.0	> 0.5
III climatic zone	> 0.0	≤ 0.0	> 0.0	> 0.5
IV climatic zone	> 0.0	> 0.0	> 0.0	> 0.5
V climatic zone	> 0.0	> 0.0	> 0.0	≤ 0.5

In the proposed delimitation, specific data that characterize its temperature regime have been attributed to every zone. Spatial diversity of the mean long-term air temperature, its amplitude, and the temperature of the warmest and the coldest month were shown on figures 6 – 9.

As far as the dynamism of the climate is considered, the delimitation distinguishes only two zones: dynamic, with AT > 0.5 °C and static, with AT ≤ 0.5 °C. As a rule, the range of amplitude of air temperature in the

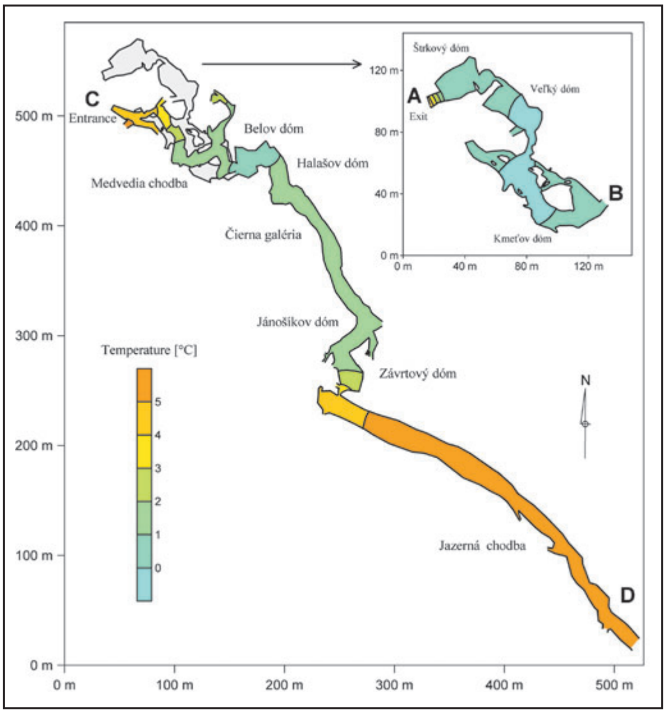

Fig. 6. The distribution of mean long-term air temperature (TY) in the Demänovská Ice Cave

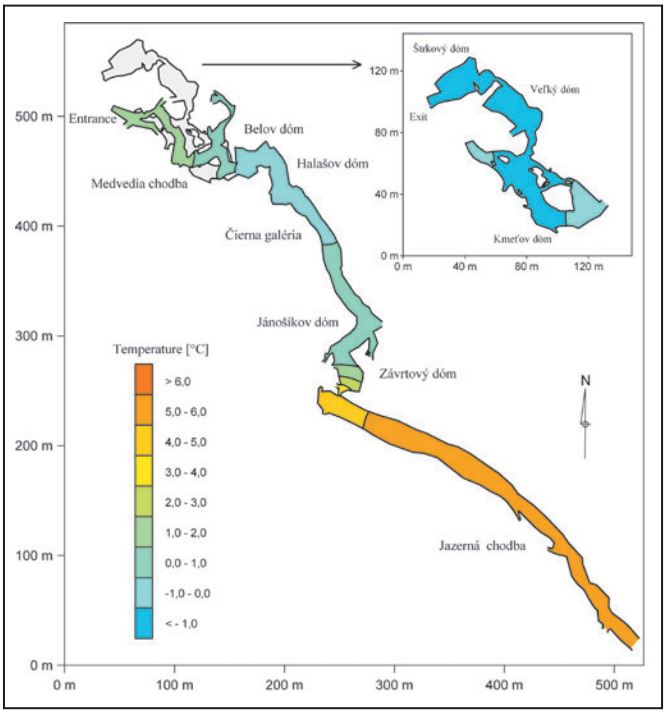

Fig. 7. The distribution of mean long-term air temperature in January (AI) in the Demänovská Ice Cave

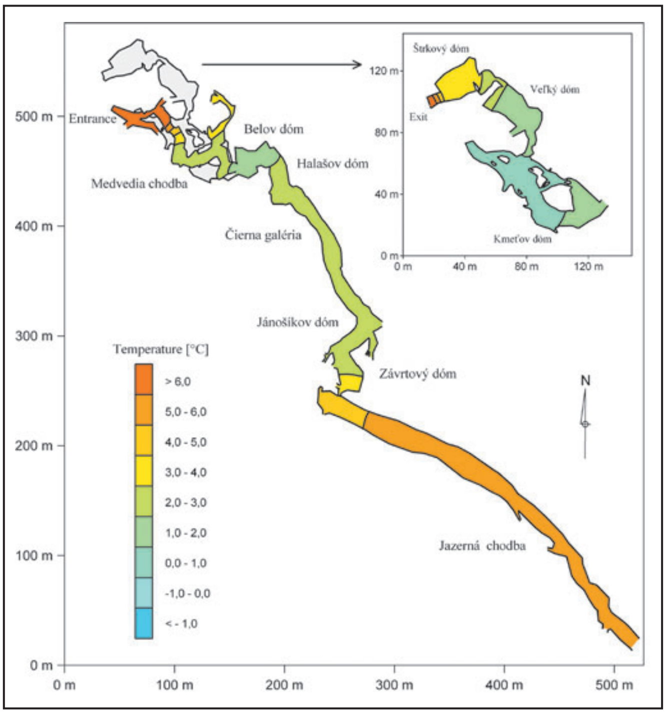

Fig. 8. The distribution of mean long-term air temperature in August (AVIII) in the Demänovská Ice Cave

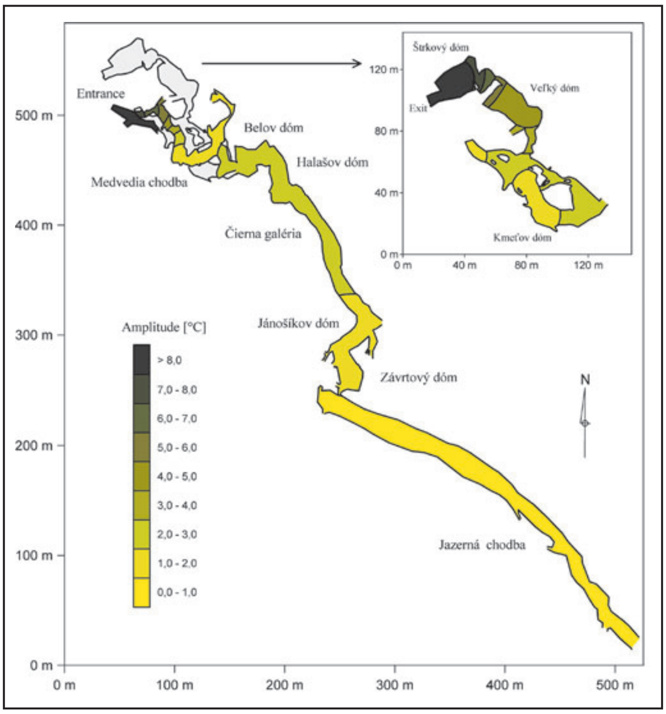

Fig. 9. The distribution of mean long-term amplitude of air temperature (AT) in the Demänovská Ice Cave (a difference between the warmest and the coldest month in year)

dynamic zone is very large. That is why for practical purposes further division of the zone is used into the dynamic-close-to-the-opening zone and the dynamic-transitory zone. The dynamic-close-to-the-opening-zone has a big changeability of the amplitude in the longitudinal profile of karst void. In the dynamic-transitory zone, the amplitude gradually decreases towards the borders with the static zone (Piasecki J., 1996).

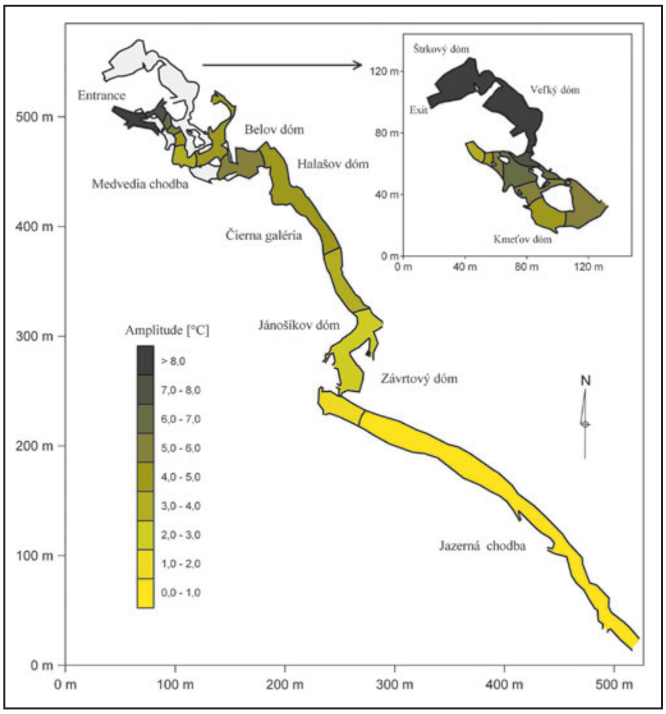

Fig. 10. The yearly amplitude distribution of air temperature (AT) in the Demänovská Ice Cave in 2002 (a difference between the extreme air temperatures in year – hourly quantity)

In the Demänovská Ice Cave the static climate zone is limited to the Jazerná chodba corridor, whereas all the rest of the cave is within the dynamic climate zone. The variability of the amplitude of temperature within the dynamic climate zone is between > 1 °C in the corridors deeper into the cave and > 8 °C in the close-to-the-openings areas (Fig. 9). The variability increases from > 2 °C to > 17 °C, when we take extreme temperatures (absolute minimum and maximum temperature in a year; Fig. 10) as a basis for yearly amplitude.

The mean long-term amplitude of air temperature along the longitudinal profile of the cave (the growth of amplitude per unit of length from the border of the static climate zone), was used to delimit the approximate border of sub-zones: dynamic-close-to-the-opening and the dynamic-transitory. For the entire cave, the mean amplitude was 3.5 °C. For the profiles done independently of both of the openings it was different. In the "Exit"–Kmeťov dóm – inner corridors profile, the approximate border of the sub-zones is marked out by 4 °C amplitude, while in the "Entrance"– inner corridors, by the amplitude of 3 °C. The difference between these values is determined by the morphology of the corridors. Their shape and development co-influence the transformation of the air that flows into the cave from the outside.

THE CHARACTERISTICS OF THE MICROCLIMATIC ZONES OF DEMÄNOVSKÁ ICE CAVE

In the Demänovská Ice Cave, the **I climatic zone** does not exist. The coldest **II zone** stretches through the cen-

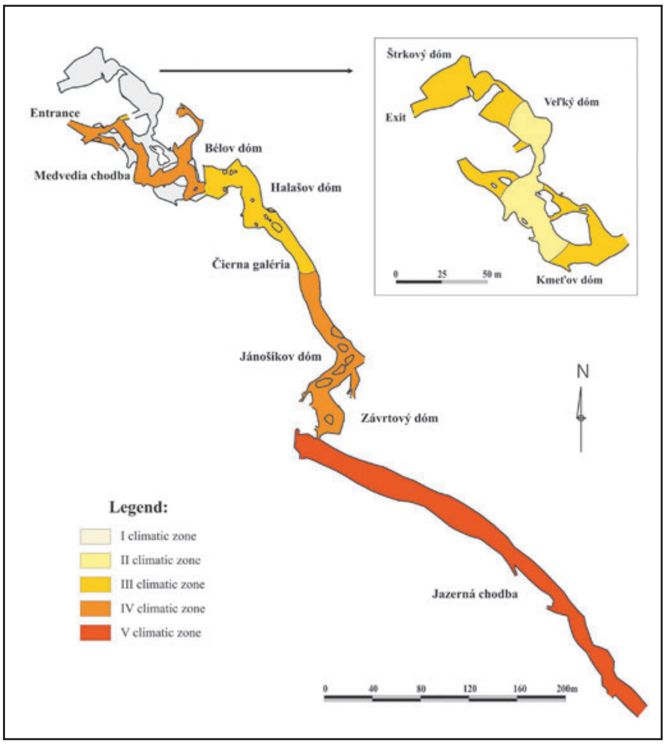

Fig. 11. The mean long-term range of climatic zones in the Demänovská Ice Cave.

tral part of the hall which is permanently iced Kmeťov dóm and the SE part of the Veľký dóm, which is also iced (Fig. 11). This zone is called microclimatic dynamic--transitory sub-zone. The mean long-term air temperature here is ≤ 0 °C. The yearly amplitude of air temperature varies between 1.6 °C in the central part of Kmeťov dóm to > 4.0 °C on the border with neighboring zone in Veľký dóm. The coldest month is January or February, while the warmest period begins in August and finishes in October. For 5 to 7 months the mean monthly temperature is lower than 0 °C. In the area of the cave where the zone stretches, the number of days with the mean 24-hour temperature that is ≤ 0 °C is between 43 % and 65 % of days in a year (Tab. 2, 3). In the summer season a very slow air temperature increase is notable here, caused by absorbance of the heat (delivered by air circulation) by the rocks and ice filling (Fig. 4).

III climatic zone – divided in two parts by the II ice zone. The first part of the zone stretches from Štrkový dóm (Exit) to the central and NW part of the Veľký dóm. The second part is from NW and E part of the Kmeťov dóm together with the neighboring corridors, through Belov dóm to the central part of Čierna galéria corridor (Fig. 11, Tab. 2, 3). Together with the II climatic zone, it is the coolest part of the cave. In the entire zone, the mean yearly temperature is > 0 °C, while the temperature amplitude changes from > 1.5 °C to > 8 °C, depending on the layout of the corridors in relation to the exit opening. In Štrkový dóm the number of days with the mean 24-hour temperature ≤ 0 °C is about 30 % of the year. In the Čierna galéria corridor it is up to around 20 %. The coldest months are January or February, and the warmest is August (deep into the cave) or September (in the area that is close to the opening of the cave). With regards to the dynamics of the microclimatic conditions, this zone divides into: dynamic-transitory sub-zone (the corridors adjacent to Kmeťov dóm and Belov dóm as well as the part of Čierna galéria corridor) and dynamic--close-to-the-opening-zone (the area of the cave from Veľký dóm to the Exit from the cave and part of the corridors below the Entrance).

IV climatic zone, it's much warmer than the preceding two zones and covers area (Fig. 11); it stretches from the corridors below the entrance through Medvedia chodba corridor in NW part of the cave and S part of Čierna galéria until Závrtový dóm deep in the cave. It is much less influenced by the cold valley air that reaches into the cave. During the flow of this air from Kmeťov dóm to deeper corridors it is gradually transformed upon contact with the warmer rocks and upon meeting with the autochthonic air. All over the zone, the mean yearly air temperature is higher than 1.0 °C. In the central halls of the cave, the mean yearly amplitude of temperature changes within around 1.5 °C to 3.0 °C, and it reaches up to > 8 °C near the cave opening. As the distance from the corridors and halls covered by the III climatic zone grows, the number of days with mean 24-hour temperature ≤ 0 °C diminishes (Tab. 2, 3). The period of appearance of lowest mean 24-hour air temperature is also delayed (February). Microclimate of this zone is classified as dynamic-transitory.

V climatic zone stretches across Jazerná chodba corridor. This corridor is isolated by a sluice from the rest of the cave (Fig. 11, Tab. 3). There are static microclimatic conditions in this zone. November is the warmest month; March is the coolest. Thermal conditions are formed mainly by the energy exchange between the rocks and autochthonic cave air.

The maximal ranges of climatic zones were shown in the coldest (1971) and the warmest (1975) year in the 1971 – 1982 period (Fig. 12, 13). The comparison of the changes of the climatic zones range in the two extreme years allowed us to prove that the occurrence of several relatively cold winters in a row can cause a significant increase of the area of the II and III climatic zone. In such conditions the enlargement of the reach of seasonal and periodical ice forms occurrence will probably take place. In case of the occurrence of several warm winters, the area of the aforementioned zones will probably become smaller and the development of ice forms and their range will be limited, too.

In reference to the division of the cave into climatic zones, a division into ice zones was made (Fig. 14). In order to do so, the results of the measurements and observations made by the authors in the 2003 – 2006 period were used. The information found the literature on the subject and oral stories were also of help. 3 ice zones as well as 1 zone that is free of ice forms were distinguished (Tab. 7). These are:

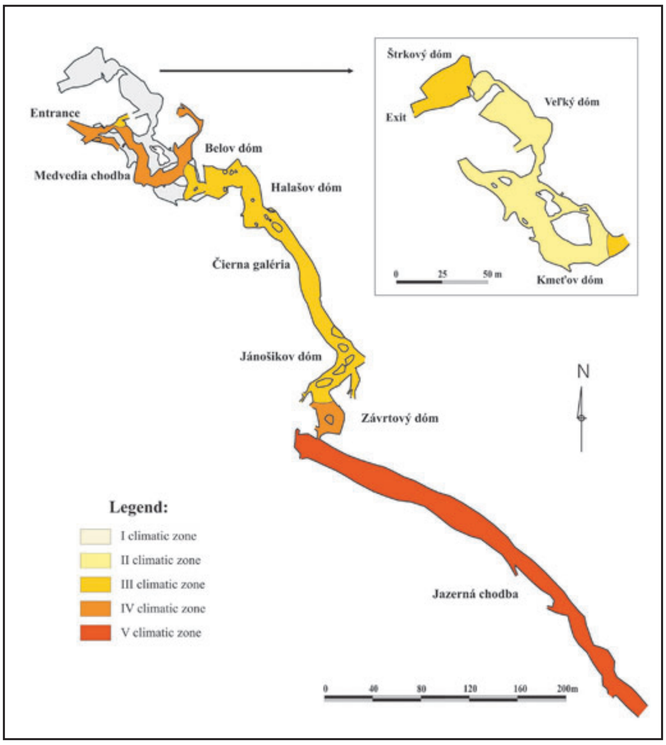

Fig. 12. The range of climatic zones in the Demänovská Ice Cave in 1971 (the coldest year in 1970 – 1982 period)

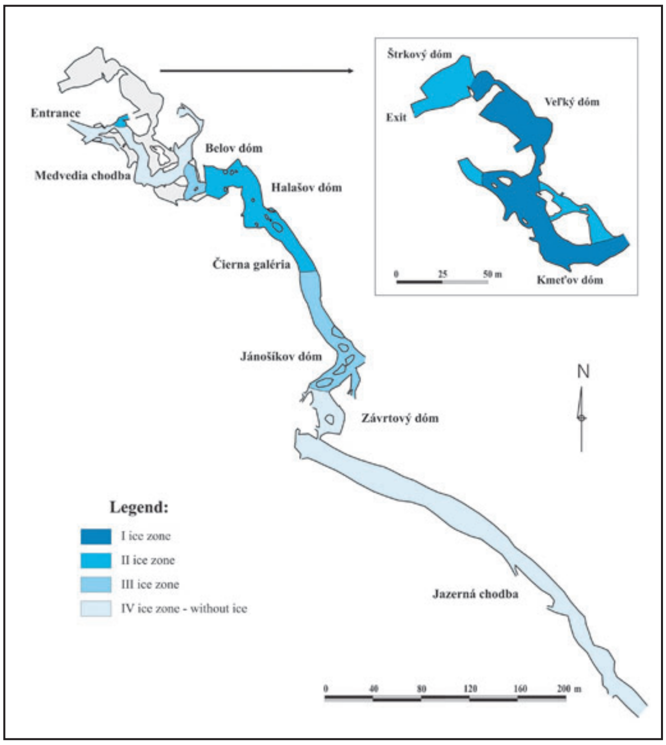

Fig. 14. The mean range of ice zones in the Demänovská Ice Cave in 2003 – 2005

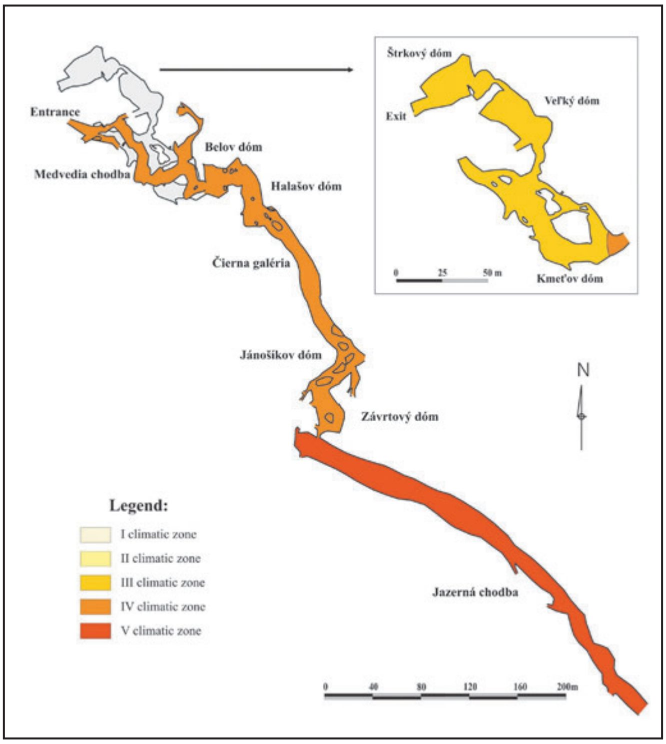

Fig. 13. The range of climatic zones in the Demänovská Ice Cave in 1975 (the warmest year in 1970 – 1982 period)

- I ice zone – ice forms (mainly ice monolith) appear all year long. This zone takes the least area of the cave. It is the zone of bottom ice occurrence as well as other ice forms. In spite of the slow degradation, most of the large ice forms last here all year long;
- II ice zone – ice forms are seasonal. The area of this zone is a bit bigger than the pervious one. Various forms of ice (stalactites, stalagmites, fiber ice and other) occur here from mid-winter to the beginning of thermal summer. In the summer season all these forms are completely melted.
- III ice zone – forms ice occur sporadically, and only during very frosty winters. During the winter of 2004/2005 and 2005/2006 they did occur, however in the winter of 2002/2003 and 2003/2004 these forms did not occur.
- IV "free of ice forms zone" (Jazerná chodba corridor, Závrtový dóm, Medvedia chodba and Entrance). Currently, no ice forms were observed in the zone. However, according to the information from the 1950s that was found in the literature, these forms did occur in the Medvedia chodba corridor and Entrance (Droppa A., 1957). The comparison of the position of the mean, long-term 0.5 °C yearly isotherm with the natural border of permanent ice occurrence in the I ice zone (Fig. 14) has shown that the area limited by the isotherm is, to a large extent, matching the area of permanent ice occurrence.

Tab. 7. The division of the Demänovská Ice Cave into ice zones.

Ice zones	Cave ice
I ice zone	All-year-long occurrence of bottom ice, all-year-long or seasonal occurrence of the other ice forms.
II ice zone	Seasonal occurrence of ice forms – a lack of bottom ice.
III ice zone	Occasional occurrence of ice forms.
IV ice zone	Ice forms don't occur.

The isotherm of 0.0 °C limits the area of its largest density. The fact that the range of 0.5 °C isotherm in the coldest year (1971) reached as far as Halašov dóm indicates that in the coldest years Belov dóm could have been filed with ice all year long. The occurrence of permanent ice in this hall before 1950 is mentioned by J. Otruba (1957, 1971) and was confirmed by A. Droppa (oral information). The division of the cave into climatic and ice zones was a basis for the delimitation of climatic-ice zones. It was done by superimposing of the results of the two presented divisions. As a result, the division of the cave into 5 climatic-ice zones and 1 zone that is free of ice forms was obtained (Tab. 8, Fig. 15).

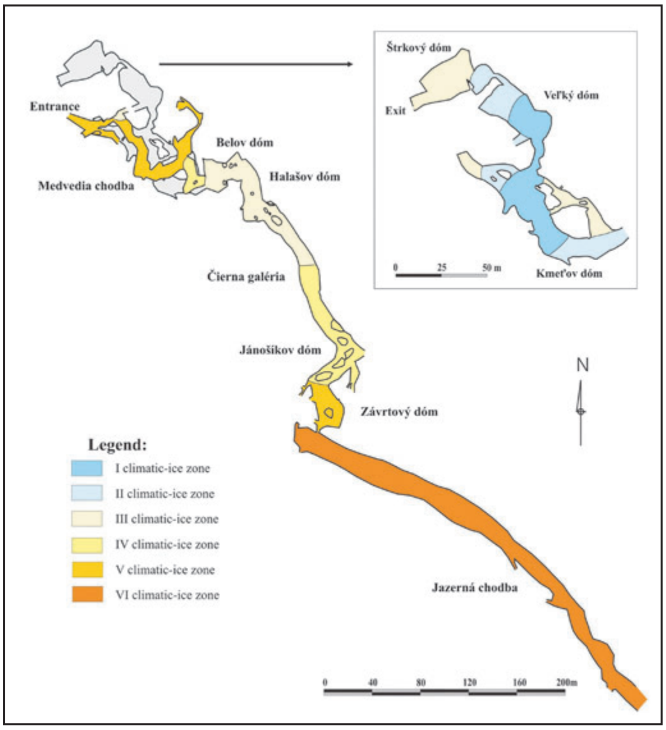

Fig. 15. The mean long-term range of climatic – ice zones in the Demänovská Ice Cave

CONCLUSIONS

The analysis sums up the results of the hitherto research on microclimate and ice filling of the Demänovská Ice Cave. The aim of the authors was to use this analysis as a basis for further study of the development of cave ice filling; and to indicate the threats that the natural climate changes and anthropogenic influence cause to the climatic and ice conditions of the cave.

Long-term, yearly, seasonal and periodical state of climatic and ice conditions in the cave are shaped by the course and changes of air flow between the valley and the interior of the cave. Changes of the microclimatic conditions as well as the changes of the range of ice forms occurence in the 1952 – 2006 period were the result of the changes in the natural circulation of air caused by the human intervention into the morphology of the cave.

The results of the available data analysis allow to conclude that already in the 1970s the climatic and ice conditions inside the cave reached the balance close to the original conditions from before the period when the exploration of the cave began, that is before 1950 – 1952. This new balance is also stable nowadays, and the range of the observed changes of the cave climate and its ice filling results from the changes of the climatic conditions outside the cave.

Similarly to other caves, there is lack of correspondence between temperature conditions inside the in cave and the valley in the Demänovská Ice Cave in the summer season. In the winter season, however, this correspondence is quite visible for air temperature in the Štrkový dóm and Veľký dóm; it diminishes as one proceeds deeper into the cave.

According to the long-term mean air temperature and amplitudes of temperature between the warmest and the coldest month, the cave was divided into climatic zones. 4 thermal and climatic zones were delimited and characterized (Fig. 11), as well as 3 zones that described the dynamics of the changes of air temperature in the cave.

The observations and measurements of ice inside the cave allowed for the delimitation and description of 4 zones of ice occurrence (Fig. 14). Comparison of the aforementioned classifications allowed for the delimitation of climatic-ice zones and set some rules for the relations between the ice filling of cave and the climatic conditions inside the cave and outside it (Fig. 15, Tab. 3). It was observed that:

- The years when mean air temperature in the winter season in the surroundings of the cave was > 0.4 °C were characterized by the diminishing of deposition of ice inside the cave and the diminishing of its

Tab. 8. The climatic-ice zones in the Demänovská Ice Cave (the interdependence of occurrence of climatic and ice forms).

Ice zones / Climatic zones	I ice zone Permanent occurrence of ice forms	II ice zone Seasonal occurrence of ice forms	III ice zone Occasional occurrence of ice forms	IV ice zone Without ice forms
I climatic zone	-	-	-	-
II climatic zone	I climatic-ice zone	-	-	-
III climatic zone	II climatic-ice zone	III climatic-ice zone	-	-
IV climatic zone	-	-	IV climatic-ice zone	V climatic-ice zone
V climatic zone	-	-	-	VI climatic-ice zone

quantity. The years when the mean air temperature in the winter season was < -1.0 °C were characterized by the largest quantity of ice;

- The area of the cave limited by the range of the mean yearly isotherm of 0.5 °C is more or less the range of permanent ice occurrence, while the isotherm of 0 °C delimits the range of ice monolith;
- The occurrence of several frosty winters in a row can cause a significant increase of the II and III climatic zones, which will probably lead to the increase of the areas of permanent and seasonal ice forms occurrence. In case of the occurrence of several warm winters, area of the aforementioned zones will probably become smaller and the development of ice forms and their range will be limited as well;
- The mean long-term yearly air temperature in the constantly iced part of the cave was -0.1 °C, in the area of seasonal and periodical ice phenomena occurrence it was 0.8 °C, an in the part without ice it was from 1.9 °C to 5.8 °C;
- The warmest months in the cave are August and September, while January and February are the coldest. As the distance from the openings grows, the occurrence of maximal and minimal air temperature is delayed and the number of days with temperature ≤ 0 °C decreases;
- The mean long-term yearly temperature of air for the entire cave was 2.1 °C and was 3.7 °C lower than the mean temperature of the valley air close to the openings leading into the cave. Mean relative humidity was 98 %.

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