MICROBIAL ORIGIN OF OPAL SPELEOTHEMS IN VENEZUELAN QUARTZITE CAVES (RORAIMA GROUP, GUYANA HIGHLANDS)

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Abstract
The largest and longest silicate caves in the world created in arenites of the Roraima Group in Venezuela have been explored on Chimantá and Roraima plateaus (tepuis) of Guyana Highlands. Geological and geomorphological research showed that most feasible way of the caves genesis is winnowing and erosion of unlithified or poorly lithified arenites. Dissolution is also present but it probably plays neither the trigger role, nor volumetrically important role in the cave-forming processes. The strongest dissolution/reprecipitation agent is the condensed air moisture which is most likely the main agent contributing to growth of siliceous speleothems. As such, it can be active only after, not before the cave is created. Siliceous speleothems are mostly microbialites except of some normal stalactites, cobweb stalactites and flowstones which are formed inorganically. They consist of two main types: 1. fine-laminated columnar stromatolite formed by silicified filamentous microbes (either heterotrophic filamentous bacteria or cyanobacteria) and 2. a porous peloidal stromatolite formed by *Nostoc*-type cyanobacteria. The initial stages of encrusted shrubs and mats of microbes were observed, too, but the surrounding arenitic substrate was intact. This is a strong evidence for the microbial mediation of the silica precipitation.

Keywords: speleology, tepuis, Venzuela, sandstone caves, siliceous speleothems, microbialites, cyanobacteria, stromatolites. Cueva Charles Brewer. Cueva Ojos de Cristal.

INTRODUCTION

In the last time, several Works emerged which apply the term karst to silicate caves that occur either in granites (Willems et al., 2002) or, more frequently, in sandstones (see the reviews in Wray, 1999, 2003). According to these authors dissolution, although slow, is the main process that forms the caves. For sandstone rock, the term “arenization” was introduced by Martini (1979). This term involves both – the dissolution of the cements in the arenitic rocks, with subsequent erosion and winnowing of the loose sand material. If the “arenization” theory was true, most of the sandstone caves could really be attributed to karst as the dissolution is considered there to be trigger process of the cave formation. The main proof of that the dissolution is important in silicate caves are silica speleothems which occur in most of the silicate caves. They are mostly composed of opal-A, which slowly turns to opal-CT and then to microquartz. The question remains, whether the silica dissolution is so important that the silicate caves can be really ranked among the karstic ones. This paper brings one of the first results of several speleological and scientific expeditions to Venezuelan Gran Sabana, Guyana Highlands (Fig. 1), where largest caves evolved in the sandstone plateaus called tepuis. Tepuis are the key area where sandstone “karstic” phenomena can be studied and where the term “arenization” is widely used (e.g. Urbani, 1986). In our last papers (Aubrecht et al. 2007; 2008) we bring different views on the genesis of sandstone caves and of siliceous speleothems

which occur in most of them, base on our geological, geomorphological, hydrogeochemical and speleological observations.

Fig. 1: Location of the studied table mountains

MATERIAL AND METHODS

The geological and speleological observations were focused on the differential weathering of various sorts of arenites of the Matauí Formation, Roraima Group on the Macizó Chimantá and Roraima tepui surfaces and in the caves – particularly in Cueva Charles Brewer and Cueva Ojos de Cristal (Fig. 1). Four sites with different lithification and erosion phenomena in arenites were sampled in detail for petrographic analysis (thin-sections and SEM) the results of which will be published later. Equally important was sampling of siliceous speleothems. A limited number of samples was collected for study to prevent excessive damage to the speleothem decoration of the cave. They were studied in petrographic thin-sections. Fresh speleothem surfaces in growth position, as well as surfaces of broken speleothems (some etched by hydrofluoric acid), were coated by thin gold films and observed under SEM. The samples were gold coated and then observed in JEOL JXA 840 A scanning electron microscope, with an accelerating voltage of 5 kV. Mineralogical composition of the speleothems was determined optically and by X-ray diffraction analysis (XRD). Analyses were performed with a DRON-3 analyser, using CoKα of the wavelength λ: 1.79021Å, filter Fe, voltage 30 kV, intensity 15 mA, diaphragms 1;1;0.1, or CuKα of the wavelength 1.54178 Å, filter Ni, voltage 40 kV, intensity 20 mA, diaphragms 1;1;0.5.
Speleothem surfaces were also sampled for microbiological analyses. Part of the samples was fixed in agar for further cultivation (about 20 samples – results not included yet); about 40 samples were fixed in formaldehyde (for microscopic observations only).

GENESIS OF THE SILICEOUS SPELEOTHEMS

Caves formed in silicate rocks are characterized by siliceous speleothems, in which the dominant mineral is opal. Unlike in carbonate speleothems, microbial mediaition is much more common in precipitation of siliceous speleothems. Siliceous speleothems commonly represent small forms, rarely exceeding 2 cm in size. In all the examined caves, peculiar forms of speleothems were found (see also Aubrecht et al., 2008). They have various shapes

and forms and they most of them bear signs of microbial origin (Fig. 2). Many of the speleothems remind classical stalactites and stalagmites known from limestone caves but their structure and genesis are different. Apart from variable shapes, the microbial speleothems show identical principal texture, corresponding to various stages of their evolution (Fig. 3). They consist of two principal zones: 1. laminated columnar stromatolite, consisting of non-porous compact opal, forms mostly the internal zones of the speleothems, 2. strongly porous zone formed by white chalk-like opal, represents accumulation of microbial peloids and forms mostly the outer zones of the speleothems. In some speleothems, both zones may alternate.

Fig. 2: Large microbial speleothem forms called "champignons" are frequently more than 30 cm in size (Cueva Charles Brewer, Chimantá). Photo: B. Šmída

The **columnal stromatolite zone** consists of finely laminated layers of pure opal, intercalated by some zones of filamentous microbialite, with thin filaments oriented in the direction of the stromatolite growth. SEM study of the etched surfaces of the columnal stromatolite showed that it mostly consists of concentric laminae formed by dense parallel tubes representing casts after filamentous microbes. The microbes are most similar to filamentous cyanobacteria from the order Oscillatoriales (Golubic, 1976). In other places, irregular, larger-scale, doublelayered cross-sections of microbe tubes occur. They resemble casts after cyanobacterial cells of the genus *Cyanostylon* or *Entophysalis* (Golubic, 1976). The **zone of peloidal microbialites** consists of ovoidal peloids of relatively uniform shape. They are densely packed, arranged in concentric laminae. The size of peloids varies from 0.1 to about 0.3 mm. Microscopic study revealed that the peloids are formed by *Nostoc*-type cyanobacteria. Fungal hyphae, metazoan and plant remains also subordinately contribute to speleothem construction. In many places, initial colonization of the surface by *Nostoc*-type cyanobacteria was observed, forming mats and shrubs covering the underlying arenites (Fig. 4)). The microbial filaments are commonly encrusted by white silica, whereas the surrounding arenites are intact. This is a strong evidence that the microbes were not only passively encrusted by silica but the

encrustation was microbially mediated, either by their metabolism, or by changing physico-chemical conditions. This phenomenon is common in the limestones but it was not yet evident for the siliceous microbialites. Some speleothems, e.g. the cobweb stalactites (Aubrecht et al., 2008) represent mostly inorganic precipitates, encrusting various structures, such as spider threads. There are also large inorganically precipitated stalactites and flowstones. Comparing the size of the speleothems from various caves, there seem to be dependence between the cave size and speleothems size. Cueva Charles Brewer hosts the largest recorded silica speleothems (up to several dm in size) whereas those in other caves were not so large (cm to dm. size).

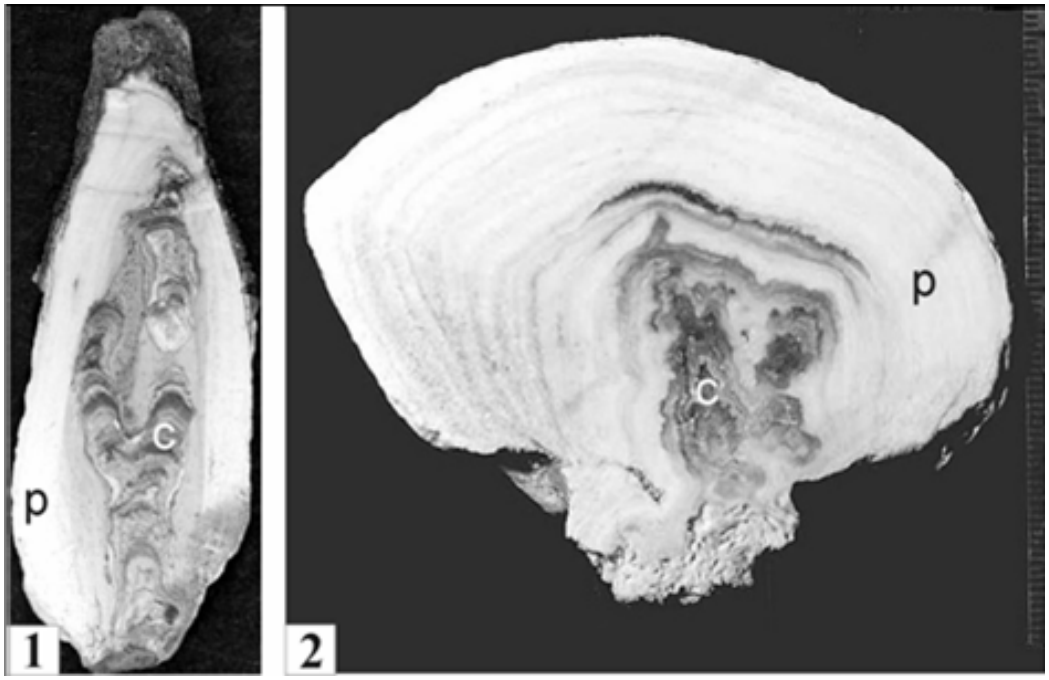

Fig. 3: Slabs of "muñeco" (1) and"champignon" (2) speleothemsfrom Cueva Charles Brewer (Chimantá) showing common principal inner structure, consisting on the columnal stromatolite (c) forming the inner zones and white, chalk-like peloidal layer (p). Photo: R. Aubrecht

Microbial origin of the siliceous speleothems was recognized by previous workers (e.g. Forti, 1994; Lévillé et al., 2000; Willems et al., 2002; Urbani et al., 2005) but very few of them attempted to make a closer description of the microbes. Siliceous microbialites of much larger forms are known from hot springs and geysers (opal sintres). These also contain abundant microbial assemblages, dominated by cyanobacteria, i.e. phototrophic organisms (Jones et al., 2001; Konhauser et al., 2001; 2003). Phototrophic organisms – diatomaceans – were also found to contribute to formation of similar speleothems in Japan and USA (Kashima et al., 1987; Kashima & Ogawa, 1995). These speleothems, however, occurred still close to the entrance, whereas speleothems presented in this paper came from the deepest parts of the cave. Therefore, it is surprising that considerable part of the central compact stromatolite of the speleothems is probably formed by cyanobacteria. Biological investigations of microbes of opal speleothems from similar sandstone cave on Sarisariñama Plateau (Cueva de los Guácharos – Kunicka-Goldfinger, 1982) showed mostly presence of heterotrophic microorganisms, the trophic life mode of which was adapted to decaying of excrements of bats and birds guarachos, as well as fruit remnants coming from their diet. What is the basis of microbe ecology in Cueva Charles Brewer is yet unclear. Presence of these otherwise phototrophic organisms in caves is not so surprising as it seems to be. Some cyanobacteria do not withstand an excess solar light that can damage their cells (Vincent & Roy, 1993; Quesada & Vincent, 1997). Some of them produce protective pigments in extracellular sheath

(e.g. *Lyngbya estuarii* produces pigment scytonemine – Kylin, 1937); others are even able to protect themselves against the excess light by boring the substrate, e.g. endolithic boring cyanobacteria *Hormathonema* and *Hyella* (Golubic, 1976). The genera *Fisherella* and *Calothrix* are even able to change their mode of life to slow heterotrophic in complete darkness (Whitton, 1987). Finally, the most convincing fact is that some cyanobacteria, e.g. *Geitleria calcarea* and *Scytonema julianum* were found to live in caves (Friedman, 1955; Bourrely & Depuy, 1973). It is obvious that the cyanobacteria in Venezuelan caves are also adapted to heterotrophic mode of life.

The reason for the size dependence between the caves and the speleothems is yet unclear. One of the possible explanations would be that the larger the cave is, the more siliceous material undergoes the dissolution/reprecipitation cycle. Larger cave corridors and galleries of the Cueva Charles Brewer have several times larger surface than other caves available for the condensed air moisture which plays the most important role in the cycle.

Fig. 4: Silica-encrusted shrubs forming an initial mat of Nostoc-type microbes on the quartzite substrate (Cueva Cañon Verde, Chimantá). Photo: B. Šmída

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REFERENCES

Aubrecht, R., Brewer-Carías, Ch., Šmída, B., Audy, M. & Kováčik, Ľ., 2008: Anatomy of biologically mediated opal speleothems in the world's largest sandstone cave Cueva Charles Brewer, Chimantá Plateau, Venezuela. – Sed. Geol., 203, 3-4, 181-195.

Aubrecht, R., Brewer-Carías, Ch., Kováčik, Ľ., Mayoral, F., Schlögl, J., Šmída, B., Vlček, L. & Lánczos, T., 2007: Microbial composition of opal stromatolites in Venezuelan sandstone caves. 9th Int. Symp. Fosil Algae, Croatia, 204-205.

Forti, P., 1994: Los depositos quimicos de la Sima Aonda Superior y de otras cavidades del Auyán-Tepui. Venezuela. Bol. SVE, 28, 1-4.

Friedman, I., 1955: *Geitleria calcarea* n.gen. et n.sp., a new atmophytic lime-encrusting bluegreen alga. – Bot. Not., 108, 439-445.

Golubic, S., 1976: Organisms that build stromatolites. In: Walter, M.R. (ed.): Stromatolites. Developments in Sedimentology 20, – Elsevier, 113-126.

Jones, B., Renaut, R.W. & Rosen, M.R., 2001: Microbial construction of siliceous stalactites at geysers and hot springs: Examples from the Whakarewarewa Geothermal Area, North Island, New Zealand. – Palaios, 16, 73-94.

Kashima, N., Teruo, I. & Kinoshita, N., 1987: Diatom, contributors of coralloid speleothems, from Togawa-Sakaidani-do Cave in Miyasaaki prefecture, Central Kyushu. – Japan Int. J. Spel., 16, 95–100.

Kashima, N. & Ogawa, T., 1995: A note on biogenic effect of coralloid speleothems in Round Mountain Lava Cave, Oregon, U.S.A. – J. Spel. Soc. Japan, 19, 8–12.

Konhauser, K.O., Phoenix, V.R., Bottrell, S.H., Adams, D.G. & Head, I.M., 2001: Microbial-silica interactions in Icelandic hot spring sinter: possible analogues for some Precambrian siliceous stromatolites. – Sedimentology, 48, 2, 415-433.

Konhauser, K.O., Jones, B., Reysenbach, A.-L. & Renaut, R.W., 2003: Hot spring sinters: keys to understanding Earth's earliest life forms. – Can. J. Earth Sci., 40, 1713-1724.

Kunicka-Goldfinger, W., 1982: Preliminary observations on the microbiology of karst caves of the Sarisariñama plateau in Venezuela. – Bol. SVE, 19, 133-136.

Kylin, H., 1937: Über die Farbstoffe und die Farbe der Cyanophyceen. – K. Fysiogr. Sällsk. Lund, Förh., 7, 131-158.

Léveillé, R.J., Fyfe, W.S. & Longstaffe, F.J., 2000: Geomicrobiology of carbonate–silicate microbialites from Hawaiian basaltic sea caves. – Chem. Geol., 169, 339-355.

Martini, J.E.J., 1979: Karst in Black Reef Quartzite near Kaapsehoop, Eastern Transvaal. – Ann. South Afr. Geol. Surv., 13, 115-128.

Quesada, A. & Vincent, W.F, 1997: Strategies of adaptation by Antarctic cyanobacteria to ultraviolet radiation. – Eur. J. Phycol., 32, 335-342.

Urbani, F., 1986: Notas sobre el orígen de las cavidades en rocas cuarcíferas precámbrias del Grupo Roraima. – Interciencia, 11, 298-300.

Urbani, F., Compère, Ph. & Willems, L., 2005: Opal-a speleothems of Wei-Assipu-Tepui, Roraima Province, Brazil. – Bol. SVE, 39, 21-26.

Vincent, W.F. & Roy, S., 1993: Solar ultraviolet-B radiation and aquatic primary production: damage, protection, and recovery. – Envir. Rev., 1, 1-12.

Whitton, B.A. (1987): The biology of *Rivulariaceae*. In: Fay, P. & van Baalen, C. (eds.): The cyanobacteria – a comparative review. – Elsevier, 513-534.

Willems, L., Compère, Ph., Hatert, F., Puclet, A., Vicat, J.P., Ek, C. & Boulvain, F. (2002): Karst in granitic rocks, South Cameron: cave genesis and silica and taranakite speleothems. – Terra Nova, 14, 355-362.

Wray, R.A.L. (1999): Opal and chalcedony speleothems on quartz sandstones in the Sydney region, southeastern Australia. – Australian J. Earth Sci., 46, 4, 623-632.

Wray, R.A.L. (2003): Quartzite dissolution: karst or pseudokarst? – Speleogen. Evol. Karst Aquif., 2, 1-9.

THE LIKA AND GACKA SINKING KARST RIVERS HYDROLOGY

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Abstract
In this paper a case of very special hydrological behaviour of two neighbouring sinking karst rivers, Lika and Gacka, (Dinaric karst of Croatia), is analysed. The Lika River has a torrential hydrological regime. At the Sklope gauging station its minimum, mean and maximum measured discharges in the 1951-2005 period were: 0 (dry) m3/s : 24.5 m3/s : 729 m3/s. During the same period the Gacka River, at the Vivoze gauging station, had the following characteristic discharges: 2.29 m3/s; 14.7 m3/s; 71.0 m3/s. While the flow regime of the Lika River is characterised by extremely and very quick changes of discharges, the Gacka River flow regime is unusually uniform. The objective of the investigations made in this paper was to analyse the extremely different hydrological behaviour of the two neighbouring sinking rivers in order to find its reasons. Master depletion curves defined for the two analysed rivers shows that the karst aquifer of the Gacka River is much more abundant than Lika's. The difference in the water temperature regime of the two neighbouring rivers is extremely high. At the Lika-Bilaj gauging station the minimum, mean and maximum measured water temperatures in the period of 1964-1991 were: 0.6 °C; 9.3 °C; 21.4 °C. During the period of 1964-2005 the Gacka River, at the Čovići gauging station had the following characteristic water temperatures: 6.4 °C : 9.1 °C : 11.6 °C. The resident time in the karst underground of water discharging from the Gacka karst springs is much longer than in the case of the Lika River. The most probable explanation for this unusual hydrological behaviour of the two neighbouring karst rivers is that water from the Lika River and its catchment recharges some karst springs of the Gacka River. It is concluded that the Lika River feeds the Gacka River with an average annual discharge of about 5.35 m3/s. This value is different during each year and depends on the hydrological situation. It is very probably higher during the wet years than during the dry ones.

Keywords: karst hydrology, sinking river, water temperature, Lika and Gacka Rivers (Croatia)

INTRODUCTION

The term "rivers system" is used for the system of connected river channels in a drainage basin (Bridge 2005). For rivers developed in ordinary conditions they are composed of three zones (Schumm 1977): the uppermost or production zone; the central or transfer zone; the downstream or deposition zone. It is well known that conditions which govern flow in karst regions strongly change karst rivers systems. They are generally very different in comparison with ordinary rivers systems which exist in non-karst regions.
Bonacci (1987) mentions that flow regime in open streamflows in karst depends mostly upon the interaction between the groundwater and the surface water. The groundwater levels in karst greatly depends upon the effective porosity of the matrix, while groundwater connections between different parts of karst massive as well as some open streamflows depend on the existence, features, and dimensions of karst conduits. Some of these conduits recharge, while some drain off water from the rivers in karst. Generally, recharging or drainage depends on the groundwater level.
In this paper the case of very special hydrological behaviour of two neighbouring sinking karst rivers Lika and Gacka will be analysed. Their catchments are located in the central part of the Dinaric karst region of Croatia. Figure 1 represents location maps indicating (a) the study area, and (b) the supposed catchment areas of the Lika and Gacka Rivers up to their swallow-hole zones where they disappear

into the karst underground. Their waters reappear on the surface about twenty kilometres away at many abundant coastal karst springs and submarine springs (vruljes) along the Adriatic Sea.

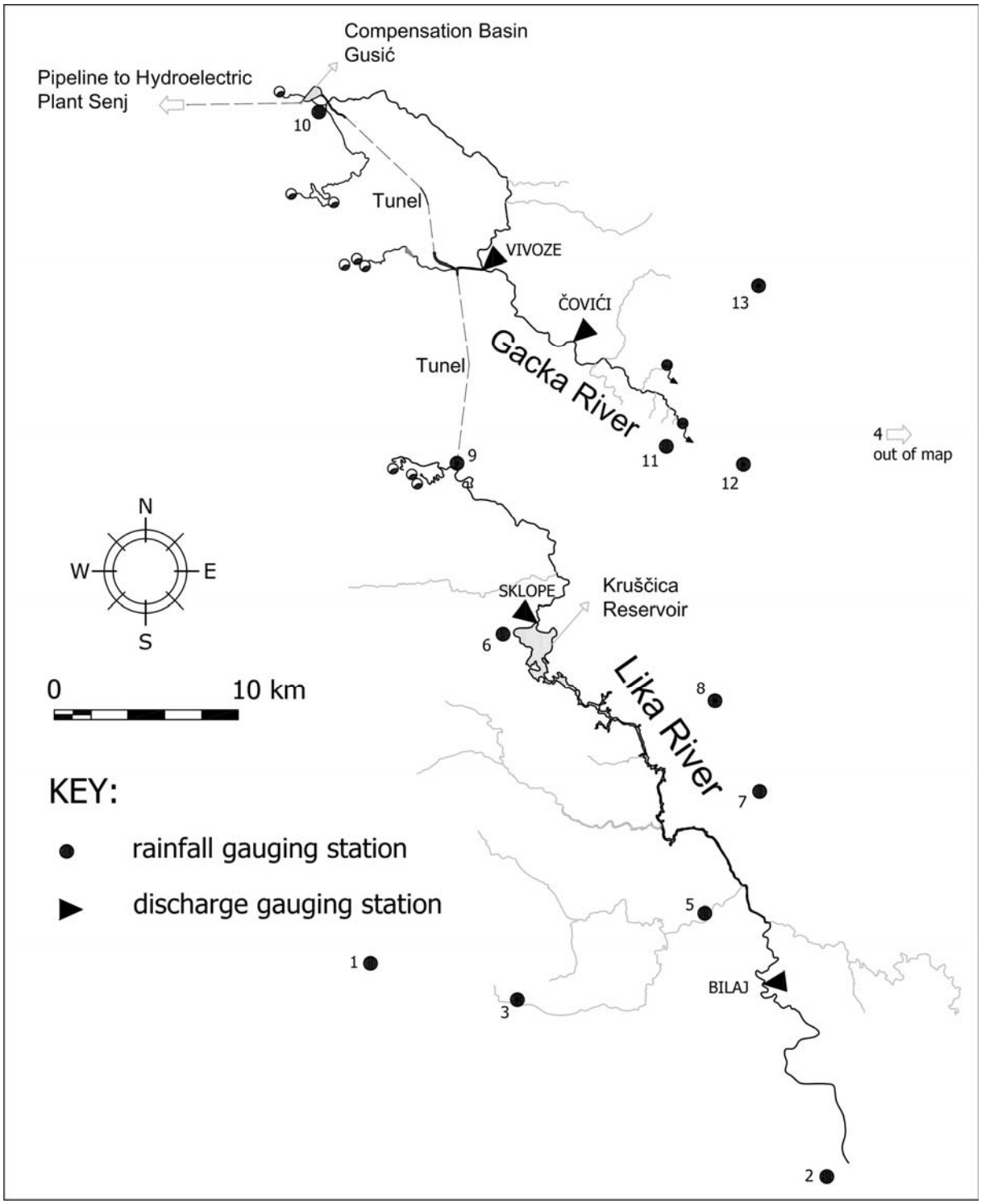

Fig. 1: Location map of the Lika and Gacka Rivers indicating the main ponor zones and karst springs, reservoirs, HEPPs, tunnels, canals, pipeline, and meteorological and hydrological gauging stations analysed in the paper

While the Lika River system is composed of three zones (Schumm 1977), the Gacka River system generally has only a downstream or deposition zone. The very different regulatory influence of karst at the closed locations could be seen from the Lika and Gacka Rivers

hydrological behaviour. The Lika River has torrential hydrological regime. At the Sklope gauging station (Figure 1) its minimum, mean and maximum measured discharges in the period of 1951-2005 were: 0 (dry) m3/s; 24.5 m3/s; 729 m3/s. During the same period the Gacka River at the Vivoze gauging station had the following characteristic discharges: 2.29 m3/s; 14.7 m3/s; 71.0 m3/s. While the flow regime of the Lika River is characterised by extremely and very quick changes of discharges, the Gacka River flow regime is unusually uniform. Due to this reason as well as due to the high quality of water, it represents an exceptionally valuable regional strategic water resource (Ožanić and Rubinić 1999). The objective of the investigations made in this paper is to analyse the extremely different hydrological behaviour of the two neighbouring sinking rivers in order to find its reasons.

MATERIAL AND METHODS

They are 13 precipitation gauging stations on Figure 1 showed that were analysed in this paper. During the analysed period (1951-2005) the average annual precipitations measured at these stations varied from a minimum of 1149 mm (at Lički Osik gauging station) to a maximum of 2270 mm (at Baške Oštarije gauging station).

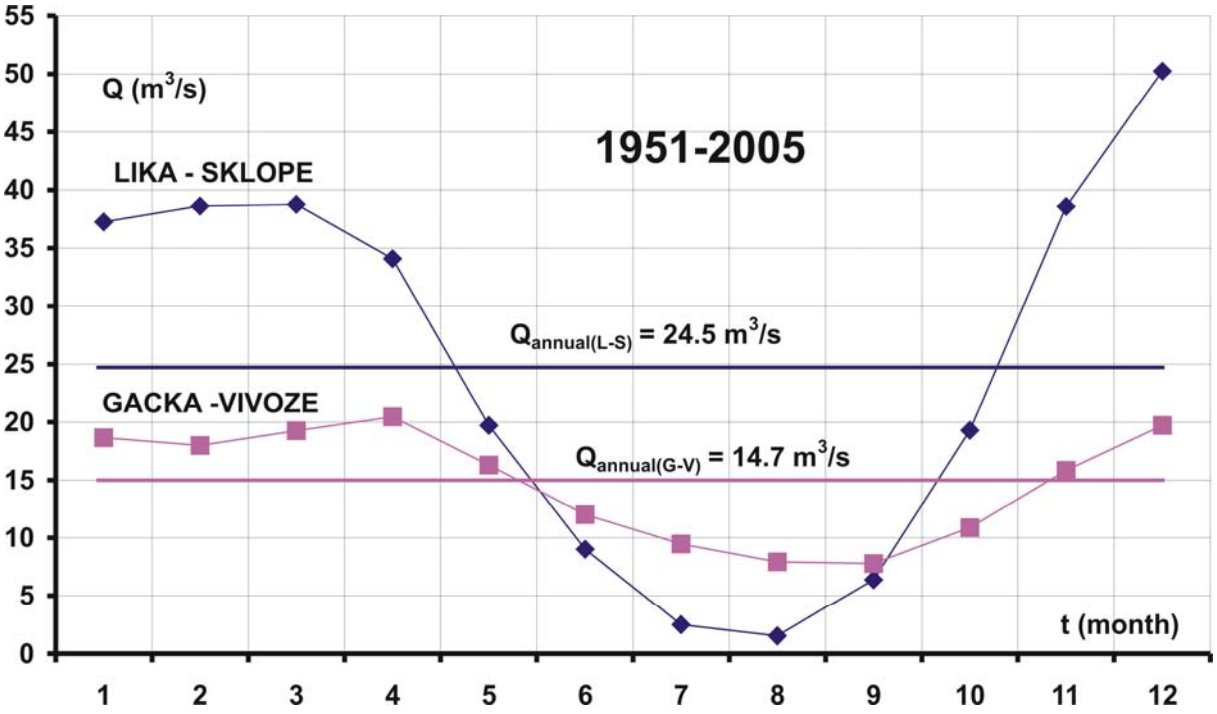

Fig. 2: Annual time series of average monthly discharges for Lika at Sklope QL-S and Gacka at Vivoze QL-S stations during the period of 1951-2006

Figure 12 represents an annual time series of average monthly discharges for Lika at Sklope QL-S and Gacka at Vivoze Q_{G-V} stations during the period of 1951-2006. The annual hydrologic regime of the Gacka at Vivoze is uniform while on the Lika at Sklope it is extremely variable. The time series of mean annual discharges of the Lika at Sklope in the period from 1930-2005 and of the Gacka at Vivoze in the period from 1951-2005 were subjected to the analysis. The RAPS analysis for the gauging station Sklope indicates that in the whole period there exist the following three sub-periods with different average annual discharges: 1) 32.04 m3/s for the first sub-period 1930-1944; 2) 25.78 m3/s for the second sub-period 1945-1981; 3) 21.68 m3/s for the third sub-period 1982-2005. The average annual discharge for the whole period (1930-2005) is 25.7 m3/s. A similar behaviour of mean annual discharges is on the profile of the Gacka River at Vivoze. The RAPS analysis indicates the

existence of two sub-periods with different average annual discharges: 1) 15.27 m3/s for the first sub-period 1951-1981; 2) 14.01 m3/s for the second sub-period 1982-2005.
Air temperature is measured only at the Gospić meteorological station. During the period of 1902-2006 (missing 1943-1945) the mean annual temperature varied between 7.0 and 10.5 °C with an average value of 8.7 °C. A maximum temperature of 38.8 °C was measured on 30 Jul. 1947, and a minimum of -33.6 °C on 17 Feb. 1956.
Water temperature is a relatively simple and inexpensive variable to monitor. At a Lika-Bilaj gauging station (Figure 1) the minimum, mean and maximum measured water temperatures in the period of 1964-1991 were: 0.6 °C; 9.3 °C; 21.4 °C. During the period of 1964-2005 the Gacka River at the Čovići gauging station had the following characteristic water temperatures: 6.4 °C; 9.1 °C; 11.6 °C. The difference in water temperature regime of the two neighbouring rivers is extremely high.
In this paper the Rescaled Adjusted Partial Sums method (RAPS) (Garbrecht and Fernandez 1994; Bonacci et al. 2008) was used for the purpose of analysing a time series, detecting and quantifying trends and fluctuations in records.

RESULTS AND DISCUSSION

All the previously mentioned analyses lead to the conclusions that the hydrological behaviour of two analysed rivers Lika and Gacka is unusual and unexpected, even for the deep and well-developed Dinaric karst terrain in which their catchments were developed. The Lika River has a completely torrential and intermittent hydrological regime. It dries up very often, during the last twenty years practically every year, while the Gacka River has a very well regulated hydrological regime and never dries up. It is very probable that their topographic catchments do not correspond to their hydrological catchments.
In accordance with the previous analyses the most probable explanation for the unusual hydrological behaviour of the two neighbouring karst rivers is that water from the Lika River and catchment recharges some karst springs of the Gacka River. This assessment could be supported by the fact that the altitude of the Lika River channel is higher than the exits of all the karst springs of the Gacka River. The investigation explained in this paper has pointed to the necessity of performing further detailed and karst-specific measurements and analyses. In order to protect extremely valuable groundwater and surface water resources of the Gacka River it is of the paramount importance to discover groundwater connections between two analysed rivers using tracing methods as well as isotopic and geochemical analyses (Pavičić 2001; Pavičić et al. 2003; Horvatinčić et al. 2007).

REFERENCES

Bahun S, Fritz F. 1972. Hidrogeologija Ličkog polja (The hydrogeology of Ličko polje). Krš Jugoslavije 8/3; 43-55.
Bojić D, Mandić M, Roller-Lutz Z, Lutz H, Kapelj S, Horvatinčić N, Krajcer-Bronić I, Sironić A. 2007. Isotopic composition of spring waters from Croatian karst regions: Gacka river area. Studia Universitatis Babeş-Bolyai, Geologia 52 (1): 9.
Bonacci O. 1987. Karst hydrology. Springer Verlag, Berlin. 184 pp.
Bonacci O. 2001. Monthly and annual effective information coefficients in Dinaric karst: example of the Gradole karst spring catchment. Hydrological Sciences Journal 46 (2): 287-299.
Bonacci O, Trninić D, Roje-Bonacci T. 2008. Analyses of the water temperature regime of the Danube and its tributaries in Croatia. Hydrological Processes 22 (7): 1014-1021.
Božičević S. 1984. Hydrogeology of the lost river Gacka in the Dinaric karst after completion of hydroelectric power plant Senj. Krš Jugoslavije 11/2: 13-70.
Bridge JS. 2005. Rivers and floodplains - forms, processes, and sedimentary record. Blackwell Publishing. Malden (USA). 491 pp.
Gajić-Čapka M, Patarčić M, Perčec-Tadić M, Srnec L, Zaninović K. 2003. Prostorna raspodjela srednjih godišnjih temperatura zraka i količina oborina u Hrvatskoj (Mean annual air temperature and precipitation spatial distribution in Croatia). Proceedings of 3. Croatian Conference of Water, Osijek (Croatia) 28 -31 May 2003:75-81.

Garbrecht J, Fernandez GP. 1994. Visualization of trends and fluctuations in climatic records. Water Resources Bulletin 30(2): 297-306.
Horvatinčić N, Kapelj S, Sironić A, Krajcar-Bronić I, Kapelj J, Marković T. 2007. Investigation of water resources and water protection in the karst area of Croatia using isotopic and geochemical analyses. Proceedings of Symposium Advances in Isotope Hydrology and its Role in Sustainable Water Resources Management, Vienna (Austria) 21 – 25 May 2007. Vol 2: 295-304.
Ožanić N, Rubinić J. 1999. Vodni resursi izvorišta Gacke (The Gacka spring water resources). Proceedings of 2nd Croatian Conference of Water, Dubrovnik (Croatia) 19 - 22 May 1999: 575-583.
Pavičić A. 2001. Hidrogeološka osnova zaštite voda izvorišta rijeke Gacke (Hydrogeologic bases for the Gacka springs water protection). Proceedings of Croatian Symposium "How protect waters in Croatia with respect to water supply and drainage", Rijeka: 229-238.
Pavičić A, Benamatić D, Pešt D, Marasović M. 2002. Water reservoir within the karst field overburden: Gusić polje, Croatia. Geologia Croatica 55 (1): 93-100.
Pavičić A, Kapelj S, Lukač J. 2003 The influence of the highway on the protected spring of Gacka river. RMZ - Materials and Geoenvironment 50 (1): 189-292.
Pavičić A, Renić A, Ivičić D. 2001. Groundwater tracing in the karst of Lika, Croatia. In: Seiler K-P & S Wohulich (eds) New Approaches Characterizing Groundwater Flow, Munich.
Ray JA. 2005. Sinking streams and losing streams. In: DC Culver, WB White (eds) Encyclopedia of Caves. Elsevier, Amsterdam: 509-513.
Schumm SA. 1977. The fluvial system. J. Willy, New York, 338 pp.

USE OF MATHEMATICAL MORPHOLOGY OF LANDSCAPE TO STUDY KARST AND THERMOKARST PROCESSES

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Abstract
The purpose of this work is to study regularity of structure and development of the morphological structures associated with karst and thermokarst processes. Within the framework of this work an attempt has been made to solve 2 problems: analyze regularity of space construction of the morphological structures associated with karst; analyze regularity of space construction of the morphological structures associated with thermokarst. In our work we use a method of mathematical morphology of a landscape - a branch of landscape science, investigating quantitative laws of landscape mosaics and methods of the mathematical analysis of these mosaics. Investigation was carried out for eight parcels in Australia, Russia and Alaska. The analysis has shown that a number of deductions of proposed mathematical model for karst depressions and thermokarst lake plains, in general are being corroborated by empirical data. The specified deviations, probably, are due to some non-uniformity of terrain.

Keywords: remote sensing, landscape pattern analysis, methods of mathematical morphology of a landscape

INTRODUCTION

The purpose of this work is to study regularity of structure and development of the morphological structures associated with karst and thermokarst processes.
Within the framework of this work an attempt has been made to solve 2 problems:
- analyze regularity of space construction of the morphological structures associated with karst;
- analyze regularity of space construction of the morphological structures associated with thermokarst.
In our work we use remote sensing data and method of mathematical morphology of a landscape. Mathematical morphology of a landscape is a branch of landscape science, investigating quantitative laws of landscape mosaics and methods of the mathematical analysis of these mosaics.
Theoretical basis of mathematical morphology of a landscape is formed by mathematical models of morphological structures – the quantitative dependences describing the basic properties of morphological structures. Canonical initial mathematical models play a special role in mathematical morphology of a landscape. They should develop in uniform conditions and under unique process.
In a nature conditions we as a rule have some combination of different processes. But basing on these models we can describe most of such combinations. And the most important thing is that with the help of those models, we can describe similar landscapes in quite different climate, geological and other conditions.

MATERIAL AND METHODS

The equations of the mathematical model of a morphological pattern for karst and thermokarst lake plains proposed by A.S. Viktorov [2, 3] were used for the analysis of data and forecast constructions. It is interesting, that mathematical models of a morphological structure associated with thermokarst and kars are similar.
They represent combination of the probabilistic mathematical relations reflecting the most essential geometrical features of the patterns. The equations include:
- Probabilistic distribution of a number of karst depressions and thermokarst lakes, which have appeared within a specified site during the given time interval (Poisson process).

$$P(\kappa, t) = \frac{(\gamma t s)^k}{k!} e^{-\gamma t s},$$

where γ – is an average of the reductions appearing on unit area for unit time; s – is a size of a test site; t – is a time.
- Probabilistic distribution of changes of karst depressions and thermokarst lakes areas (Winer random process relative to logarithms of areas)

$$F_r(x) = \frac{1}{\sqrt{2\pi}\sigma x\sqrt{t}} e^{-\frac{(\ln x - at)^2}{2\sigma^2 t}},$$

where α, σ - are distribution parameters, t - is lake age;

The first task of our work was to analyze regularity of space construction of the morphological structures associated with karst depressions and thermokarst lakes.
As it follows from the model, at the specific moment of time lake diameters should submit to lognormal distribution, given that lakes originated in comparatively short space of time and if spread in sizes of primary depressions is considered small. This deduction has been verified on series of reference parcels. Space pictures have been used as a source of information on morphological structure.
The researches were carried out on the basis of parcels, which are placed:
For karst depressions:

- in South Australia, Nullarbor plain (fig.1, fig.2)
- on East-European plain, near Kuibyshevskoe water storage (fig.3, fig.4)

For thermokarst lakes:

- in Khanty - Mansy autonomous region on Middle Ob lowland in a valley of the river (fig.5)
- on Alaska in the western part of Seward island (fig.6),
- on West Siberian plain, in area of the river Pjakupur (fig. 7) and in area of the river Vatyogan (fig. 8).

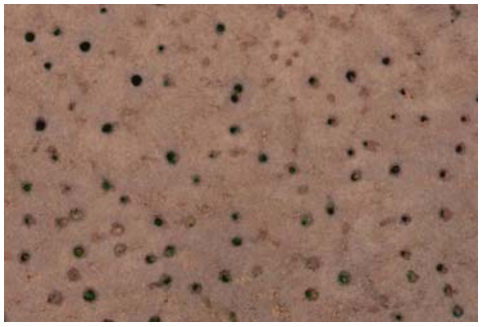

Fig.1. Fragment of a picture of the parcel 1

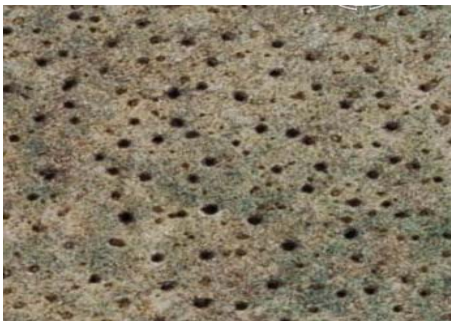

Fig. 2. Fragment of a picture of the parcel 2

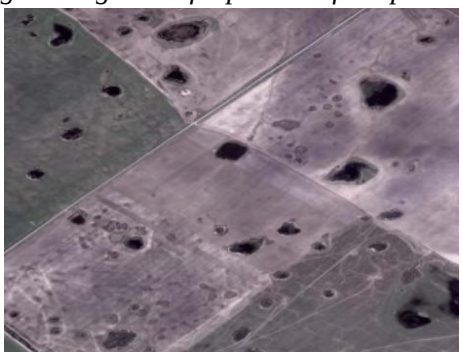

Fig.3. Fragment of a picture of the parcel 3

Fig. 4. Fragment of a picture of the parcel 4

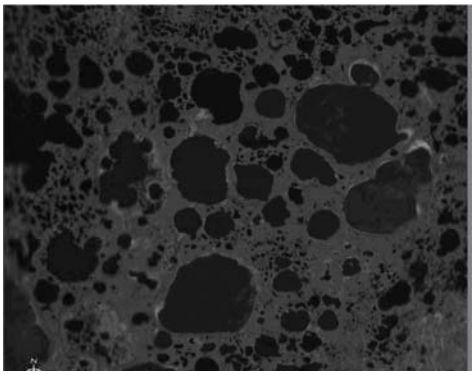

Fig.5. Fragment of a picture of the parcel 5

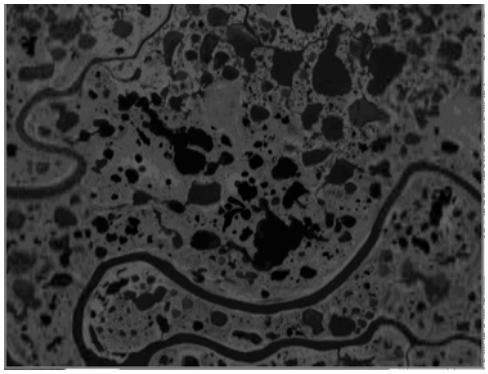

Fig. 6. Fragment of a picture of the parcel 6

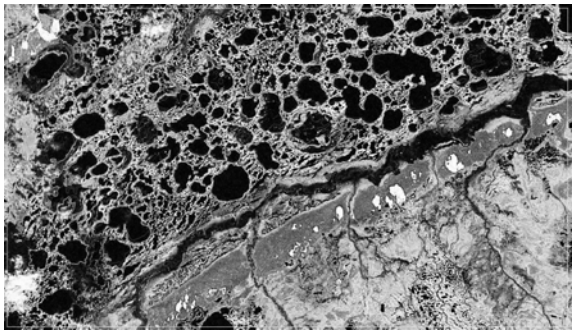

Fig. 7. Fragment of a picture of the parcel 7

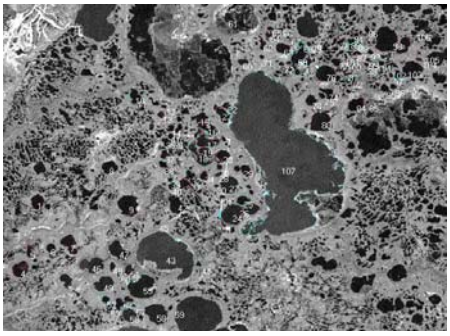

Fig. 8. Fragment of a picture of the parcel 8

These parcels numerical values were assigned using specially developed program Vektorizator and then the data of area, diameter and perimeter have been taken. After that, in the program Statistics the conformity of theoretical and empirical distributions was determined by Pirson's criterion (tab. 1).

Table 1

Parcels	χ^2	№ of degrees of freedom	Critical value χ^2 on the level 0,95 (0,99)
Parcel 1	10,82	3	7.815 (11.34)
Parcel 2	32.64	9	16.92 (21.67)
Parcel 3	2,68	1	3,84 (6,64)
Parcel 4	0,54	2	5.99 (9.21)
Parcel 5	0.09	1	3,84 (6,64)
Parcel 6	5,60	5	11,07 (15,09)
Parcel 7	4.02	4	9.49 (13.28)
Parcel 8	11,68	7	14,07 (18,48)

We have received a good conformity between theoretical and experimental data. On all the parcels value of criterion corresponds to a significance value 0,95 on one parcel – to a significance value 0, 99, and on another one parcel – haven't received conformity between theoretical and experimental data

Thus, research shows, that for the selected parcels in a whole the theoretical deduction about lognormal distribution of areas proves to be true.

The analysis of model shows also, that at the specific moment of a time the location of karst depressions and lakes should submit to Poisson distribution. On the same reference parcels the distribution of centers of dipressions and lakes was analyzed.

For this purpose in program Vektorizator a region of interest with assigned numerical values was outlined, and the quantity of the centers on a random field (in this case – a circle) of a constant size was calculated. The position of fields was defined with the help of the random-number generator, doing 100 casts. Statistical distributions of centers were obtained. For each parcel several experiments were made with circles of different area. After that, with the help of the program Statistics, distribution graphs were plotted, their parameters were obtained and the conformity to Poisson distribution (tab. 2) was determined.

Table 2

File	Field size (pixel)	Circle size (pixel)	λ	χ^2	Number of degrees of freedom	Critical value χ^2 on the level 0,95 (0,99)
Parcel 1	692x434	38	0.38	2.78	1	3,84 (6,64)
		54	0.58	5.84	1	3,84 (6,64)
		71	1.14	9.47	2	5.99 (9.21)
		100	2.21	11.28	4	9.49 (13.28)
Parcel 2	238x30	24	0.97	13.02	2	5.99 (9.21)
		34	1.79	22.17	3	7.815 (11.34)
		52	4.27	32.21	6	12.59 (16.812)
		46	3.53	21.79	5	11,07 (15,09)
Parcel 3	404x84	42	0.68	1.64	1	3,84 (6,64)
		54	0.95	0.95	2	5.99 (9.21)
		74	2.44	64.61	4	9.49 (13.28)
		96	3.05	20.58	4	9.49 (13.28)
Parcel 4	30x410	26	0.52	0.046	1	3,84 (6,64)
		41	1.53	2.77	3	7.815 (11.34)
		58	2.68	6.45	5	11,07 (15,09)
		75	4.37	6.45	6	12.59 (16.812)
		103	6.52	8.46	7	14,07 (18,48)
Parcel 5	521x580	70	1.28	1.12	2	5.99 (9.21)
		90	1.76	0.41	3	7.82 (11.34)
		119	3.25	6.35	4	9.49 (13.28)
Parcel 6	562x470	61	1.55	0.72	3	7.815 (11.34)
		79	2.3	10.03	4	9.49 (13.28)
		128	7.21	10.25	8	15.51 (20.09)
		52	1.14	6.39	2	5.99 (9.21)
		128	7.21	7.40	8	15.51 (20.09)
Parcel 7	541x77	114	19,87	12.35	11	19.68 (24.73)
		87	10,83	4,89	4	9.49 (13.28)
		68	9,15	8,25	9	16.92 (21.67)
		52	6,71	3,97	7	14.07 (18.48)
		42	3,28	10,87	4	9.49 (13.28)
		31	1,52	2,25	3	7.82 (11.34)

For parcel 1 most every values of criterion of conformity of empirical distribution to theoretical Poisson distribution do not surpass critical on a significance level 0,99. For a parcel 2 – they are no conformity, for parcel 3 – they are two values of criterion of conformity of empirical distribution to theoretical Poisson distribution do not surpass critical on a significance level 0,95. Parcels 4, 5, 6 – we have received a good conformity between theoretical and experimental data. on a significance level 0,95. And for parcel 7 two values of criterion surpass critical on a significance level 0.95, but meet a significance level 0.99.

RESULTS AND DISCUSSION

Thus, a number of deductions of proposed mathematical model for karst depressions and thermokarst lake plains, in general are being corroborated by empirical data. The specified deviations, probably, are due to some non-uniformity of terrain. The obtained conclusions have essential practical value. The researches on a whole confirm validity of the model, which, in turn, allows giving the estimated forecast of risks for linear, areal, and point objects [3].

REFERENCES

1. Viktorov A.S. 1998. Mathematical morphology of a landscape. Tratec: Moscow; 180
2. Viktorov A.S. 2006. Main problems in mathematical morphology of a landscape. Nauka: Moscow; 252.
3. Zolotarev G.S. 1983. Engineering geodynamics. Moscow University: Moscow;328.
4. Ivashutina L.I., Nikolaev V.A. 1969. About analysis of landscape structure of natural regions. Moscow University bulletin, Geography 4: 49-59.
5. Simonov Yu.G. 1972. Regional terrain analysis. Moscow University: Moscow; 251.

CALCITE MOONMILK FROM CAVES IN THE MORAVIAN KARST: MICROBIOLOGICAL AND GEOLOGICAL ASPECTS

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Abstract
Calcite moonmilk from five caves in the Moravian Karst was examined for the presence of culturable microorganisms (bacteria and fungi) and mineral composition. Sampling sites were in Sloupsko-šošůvské Caves, Císařská Cave, Suchožlebská zazděná Cave, Kateřinská Cave and Horní v Chobotu Cave. Seventy bacterial strains were isolated from the samples. Most of the strains were gram-negative non-fermenting rods. The majority of them were classified as fluorescent pseudomonads. Ten different cultures of sporulating fungi belonging to eight genera and one culture of non-sporulating fungus were isolated from four samples of moonmilk. The identified species and genera were *Beuveria bassiana*, *Isaria farinosa, Cladosporium subtilissimum, Geomyces pannorum* var. *pannorum, Mortierella alpina, Oidiodendron truncatum, Engyodontium rectidentatum* and *Mucor* sp. Moonmilk was composed of calcite and a variable content of water (-H_2O) (34–85.8 %). The amount of crystalline water (+H_2O) oscillates between 0.88 and 3.13 %. Its stucture is micritic, sparitic and fibrous. Moonmilk occurs in relatively wide range of atmospheric cave conditions.

Keywords: bacteria, calcite moonmilk, cave mycobiota, fibrous calcite, Moravian Karst, *Pseudomonas*

INTRODUCTION

Moonmilk is a kind of cave deposit. Its basic features are a microcrystalline structure and a relatively high water content (40-80%). Mineral composition of this speleothem is variable. Moonmilk consists predominantly of calcite in the limestone caves. It can also consist of other carbonate and non-carbonate minerals. Macroscopically, moonmilk appears to be soft and plastic in the wet form. It is crumbly and powdery after desiccation and mostly white but it can be coloured too. Moonmilk forms coatings on the walls, speleothems and sediments, or it constitutes speleothems itself. Moonmilk occurs in a wide range of geographical latitudes and altitudes from tropical to high alpine karst (Hill & Forti 1997).

The mechanism of formation has not been sufficiently explained. The origin of moonmilk is a frequently discussed topic. There are hyphotheses proposing a microbial or non–microbial origin or both (Borsato *et al.* 2000, Gradziński *et al.* 1997, Hill & Forti 1997, Northup *et al.* 2000, Onac 1995, Richter *et al.* 2007). Abiogenic precipitation from supersaturated seepage water is taken into consideration as microorganisms are not always present (Borsato *et al*. 2000) or their presence does not necessarily have to take part in the moonmilk genesis. The microbial origin of moonmilk may consist in active or passive role of microorganisms.

The Moravian Karst is an area formed by devonian and lower carbonian limestones (upper eifel – lower visé). There are two complexes of strata – shallow-water limestones (eifel–frasn/famen) and deeper-water limestones with shale layers (frasn/famen-lower visé). The samples of moonmilk were collected in caves in the nothern part of the Moravian Karst. They were formed in two facies of shallow-water limestones (Lažánecké limestones and Vilémovické limestones). The entrance parts of the caves are between 345 and 464 meters above see level (Přibyl 1984). The parameters of the studied caves are shown in Figure 1. The Moravian Karst has a temperate climate.

Fig. 1: Parameters of studied caves.

	Altitude (m asl.)	Host rock	Underground stream	Number of entries	Lenght of galleries	Denivelation
Sloupsko-šošůvské Caves	464	VL	Yes	5	6000 m	94 m
Císařská Cave	461	VL	Yes	2	250 m	21 m
Suchožlebská zazděná Cave	366	LL	No	1	135 m	10–15 m
Kateřinská Cave	345	LL	No	1	950 m	63 m
Horní v Chobotu Cave	396	LL	No	1	90 m	10 m

Host rock- LL lažánecké limestones, VL- vilémovické limestones

MATERIAL AND METHODS

Microbiology

Four samples of moonmilk for microbiological analysis were collected in four caves in the Moravian Karst. The sampling was conducted in two periods.

In the first period, the samples were collected aseptically and on the same day transferred to laboratory for the

analysis which was aimed at the isolation of strains (bacteria and fungi). The samples were screened by using the dilution-plating method. Macromonas medium (MM), NWRI-agar and King B medium (selective medium for fluorescent pseudomonads) were used for the bacteria isolation. The agar plates were inoculated with the volume of 0.1 ml of the suspension and incubated at 10°C for 7 days. Randomly chosen colonies (on MM, NWRI-agar) were picked up and pure cultures were analysed. On the King B medium only fluorescent colonies were picked up. After the gram staining, the isolated strains were characterized by biotyping. After that, all the gram-negative strains were characterized by whole-cell protein analysis by SDS-PAGE (Pot *et. al.*1994). Protein profiles were obtained from cultures cultivated on NA at room temperature. The normalization of patterns was performed with BioNumerics software. The cluster analysis was conducted on the matrix of correlation values by the unweighted pair group method using arithmetic averages (UPGMA). A selected group of gram-negative strains was also characterized by ribotyping (Popovic *et al.* 1993).

Malt Extract Agar (2%) was used for the isolation of fungal strains. The agar plates were inoculated with 0.2 ml suspension and incubated at 16°C for two weeks. Colonies of different species of microscopic fungi were isolated and transferred on an appropriate diagnostic medium. The isolates of filamentous fungi were observed under the light microscope and their determination to species or genera level was based upon microscopic and macroscopic morphological characteristics.

In the second period, additional sampling was conducted to determine the total cell number of cultivable bacteria in 1g of wet moonmilk. Trypton-soya agar, NWRI-agar and Nutrient agar (NA) were used for this enumeration method. The moonmilk was aseptically homogenized with glass beads in the volume of 35 ml of physiological solution and diluted (10x, 100x). The volume of 0.1 ml of accordant dilution was spread on the plates and incubated at 15°C. After 5 and 10 days the colonies were counted and the number of CFU per 1g of the moonmilk was determined.

Geology

Eight samples of moonmilk were collected from 5 caves for geological analyses. Two samples were taken from Sloupsko-šošůvské Caves *(from Moonmilk Cave and Elizabeth´s Cave).* One sample was taken from Suchožlebská zazděná Cave *(entrance part),* Kateřinská Cave *(Main Chamber,)* Horní v Chobotu Cave *(entrance part)* and three samples from Císařská Cave *(White Chamber, Nagel´s Chamber)*. The temperature (^{o}C) and relative humidity (%) of cave atmosphere were measured by the digital device GFTH 200 (Greisinger electronic GmbH) at the same time. These characteristics were repeatedly measured in an interval of 3 months. The partial pressure of CO_2 in the cave atmosphere was once measured by the device ALMEMO 2290-4 with the infrared detector FYA600CO2H, Ahlborn GmbH.

Water content ($-H_2O$) was determined by comparing the weights of the moonmilk samples before and after dehydratation at 110°C. Content of crystalline water ($+H_2O$) was determined by Penfield method at 900°C with Pb_3O_4. The microstructure was observed using the polarizing microscope JENALAB (ZEISS). Mineralogy was examined by the X-ray diffractometer STOE Stadi P. The chemical composition and microstructure were investigated by the Electron Micro Probe Analyser Cameca SX 100 on the dehydrated samples coated with graphite film.

RESULTS AND DISCUSSION

Microbiology

Bacteriology Altogether 70 psychrotrophic bacterial strains were isolated from the samples of moonmilk. Out of these, 60 strains were isolated on MM and NWRI-agar and additional 10 gram-negative fluorescent strains on selective King B medium. All of the 60 strains were gram-negative non-fermenting rods except for 2 gram-positive isolates. Out of 58 gram-negative non-fermenting rods, 39 strains represented fluorescent pseudomonads. The number of fluorescent pseudomonads isolated from samples from a particular cave and the distribution of the groups mentioned above are given in Figure 2. The results of biochemical tests revealed some atypical strains among the pseudomonads (decarboxylation of lysine together with negative decarboxylation of arginine - 11 strains from Kateřinská Cave, 4 strains from Suchožlebská zazděná Cave; positive aesculine hydrolysis - 1 strain from Císařská Cave, 2 strains from Suchožlevská zazděná Cave). The remaining gram-negative rods were not identified by biotyping.

Fig. 2: Groups of isolated strains and their distribution.

	Caves				Total
	Císařská	**Horní v Chobotu**	**Kateřinská**	**Suchožlebská zazděná**	
Isolated strains on MM and NWRI-agar	12	18	11	19	60
Gram-negative strains	11	17	11	19	58
Gram-positive strains	1	1	0	0	2
Fluorescent pseudomonads	4	9	10	16	39
Fluorescent pseudomonads (%)	**36.36**	**52.94**	**90.9**	**84.21**	/

Furthermore, two dendrograms were obtained after the numerical analysis of protein electrophoregrams of gram-

negative strains. The first dendrogram represented grouping of all gram-negative strains (58), including strains isolated on King B medium (10). Thereafter, the second of 148 entries showed similarities of isolated fluorescent and some non-fluorescent strains of presumptive pseudomonads with pseudomonads deposited at CCM. The dendrogram clusters correlate with the biochemical profiles and the origin of the samples. There were e.g. homogenous clusters of nitrate reducing strains, nitrate and nitrite reducing strains, and decarboxylation of lysine positive strains. One aesculine positive fluorescent strain was even clustered together with other aesculine positive CCM strains of pseudomonads, which were published by Švec *et. al* (2004). This finding also correlated with the results of ribotyping. Generally, the results of ribotyping verified the equivalence among previous findings. In most cases, there were analogous groupings. In conclusion, pseudomonads from Kateřinská Cave and Suchožlebská zazděná were very similar by whole-cell protein analysis and ribotyping and there were also similarities in their biochemical profiles.

The results of the enumeration method are showed in Figure 3. Although there were no considerable differences in the numbers of colony forming units (CFU), considering the media used and the origin of the samples, the best numbers were obtained on the TSA. Generally, there were 10^3 to 10^6 CFU in 1g of wet moonmilk. Similar data were published by Mulec *et al.* (2002).

Fig. 3: Number of CFU per 1 gram in wet moonmilk considering used media and origin of the sample.

Caves	NWRI-agar	TSA	NA
Císařská Cave	$6.3x10^3$ CFU/g	$4.8x10^4$ CFU/g	$7.4x10^3$ CFU/g
Horní v Chobotu Cave	$2.8x10^6$ CFU/g	$3.5x10^6$ CFU/g	$1.5x10^5$ CFU/g
Kateřinská Cave	$1.3x10^6$ CFU/g	$9.6x10^5$ CFU/g	$5.9x10^5$ CFU/g
Suchožlebská zazděná Cave	$9.1x10^3$ CFU/g	$1.2x10^4$ CFU/g	$1.9x10^4$ CFU/g

Mycology Ten different cultures of sporulating fungi belonging to eight genera and one type of sterile mycelium were isolated from four samples of moonmilk. Most species were found in Suchožlebská zazděná Cave. The identified genera and species were *Beuveria bassiana*, *Isaria farinosa, Cladosporium subtilissimum, Geomyces pannorum* var. *pannorum, Mortierella alpina* and *Mucor* sp. *B. bassiana* and *I. farinosa* are entomogenous fungi on troglobiotic insects (Samson *et al.* 1984) and were found on aragonite in Zbrašov Aragonite Caves as well (Bosák *et al.* 2001). Other isolated species are common in soil or plant material. *Mucor* species are regarded as true coprophilous fungi. They were isolated directly from colonies on bat guano in the caves of the Slovakian and Moravian Karst (Nováková 2004, 2006) as well as from aragonite, atmosphere and soil in the caves of the Moravian Karst (Bosák *et al.* 2001). The occurrence of one unidentified *Mucor* species was detected in Horní v Chobotu Cave. The other unidentified species of the genus *Mucor* and *Mortierella, G. pannorum* var. *pannorum* and *Oidiodendron truncatum* were isolated from moonmilk in Kateřinská Cave. *O. truncatum* is a common inhabitant of humus layers in forest soil. Species of *Mortierella* are generally capable of decomposing chitin and were found on insects although they are not typical insect parasites (Kubátová 2005). Only one microscopic fungus *Engyodontium rectidentatum* was obtained from Císařská Cave. This species was described from plant material and insects as well as from aragonite and air in caves (Bosák *et al.* 2001). Regarding microscopic fungi, no relation between the substrate (moonmilk) and a particular group of fungal species was proved. The species diversity in each sample is affected by many factors of caves environment (temperature, humidity, availability of light, substrate for fungal growth, speleomicrofauna, visitors).

Geology

The moonmilk in the five selected caves forms white, 0.5–8 cm thick coatings on the walls. It occurs near the entrances or near the ground surface. The temperature of the cave atmosphere varied in the range of 3.9–12.5 °C. The lowest average temperature was detected in Suchožlebská zazděná Cave (7.8 °C) and the highest in White Chamber in Císařská Cave (10.1°C). The relative humidity varied from 69.5 to 91.2 %. The lowest average relative humidity was in White Chamber in Císařská Cave (80.4 %) and the highest in Suchožlebská zazděná Cave (89.6 %). The content of CO_2 ranged in the cave atmosphere from 700 to 1190 ppm. The content of water in moonmilk oscillated from approximately 34 to 85.8 wt. %. The proportion of crystalline water in the samples was in the range of 0.88 to 3.13 wt. %. A relatively high content of crystalline water indicated that the samples may also contain hydrated minerals (for example monohydrocalcite).

Analyses of the mineral composition by using the X-ray diffractometer revealed that the specimens consisted only of calcite. There were no differences in outcomes between wet and dry samples. Hydrated minerals were not detected probably because of low content and high detection limits of the X-ray device.

Fine needle-shaped fibres, nanofiber veils, rods and polycrystals (probably calcite) in micritic and sparitic matter were observed in the microstructure of moonmilk. The surface of fibres was either smooth or with serrated edges (parallel growth of rhombohedra). Mineral grains were observed in extremely rare cases (calcite or dolomite, silica and aggregations Fe oxides). The structure of moonmilk appears to be recrystalized in some cases. Chemical analyses by

EMPA revealed that moonmilk was mainly composed of near pure calcium carbonate $CaCO_3$ (about 98%). In the sample from Horní v Chobotu Cave a higher content of Mg (0.077–0.256 wt. %) was detected. A very low content of other elements was detected in some samples (Si 0.03–0.445 wt. %, S 0.033–0.078 wt. % and P 0.031–0.063 wt. %).

From the occurence of moonmilk in caves with different atmospheric conditions can be assumed that the formation of moonmilk was not directly related to the distinctive temperature and humidity of the cave atmosphere. Probably, the main factor managing the formation of moonmilk was the saturation of source water with respect to calcite and its input to moonmilk coatings.

Biotic compound (bacteria and microscopic fungi) in moonmilk samples of mentioned caves was surprisingly proved by common methods of cultivation. The genus *Pseudomonas* was the dominant bacterial taxon in all studied environments which represented in two cases even more than 80% of isolated strains. The pseudomonads are commonly known for their genetical heterogenity and considerable adaptability. Their presence in the cave environment and also moonmilk was mentioned by Mulec *et al.*(2002). The biochemical activity of both microbial members might be inconsiderable in the formation of moonmilk.

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References

Borsato, A., Frisia, S., Jones, B. & van der Borg, K. 2000: Calcite moonmilk: crystal morphology and environment of formation in caves in the Italian Alps.—Journal of Sedimentary Research, 70, 5, 1171-1182.

Bosák, P., Vašátko, J., Cílek, V., Dumnická, E., Hanuláková, D., Horáček, I., Jeník, J., Kopecký J., Marvanová, L., Mlejnek, R., Růžička, V. & M. Zacharda, 2001: Czech Republic. – In: Juberthie C. and Decu V. (eds.), Encyclopaedia Biospeleologica, Tom III, 1405–1426, Moulis and Bucarest.

Gradziński, M., Szulc, J. & Smyk, B., 1997: Microbial agents of moonmilk precipitation. - In: Jeannin P.Y.(ed) Proceedings 12th International Congress of Speleology, vol. 1. Swiss Speleological Society, La Chaux-de-Fonds, 275-278.

Hill, C.A. & Forti, P., 1997: Cave Minerals of the World (2nd edition). - National Speleological Society, Huntsville, Alabama.

Kubátová, A. & L. Dvořák, 2005: Entomopathogenic fungi associated with insect hibernating in underground shelters. - Czech Mycol., 57 (3-4), 221 – 237, Praha.

Mulec, J., Zalar, P., Hajna, N. Z, & Rupnik, M., 2002: Screening for culturable microorganisms from cave environments (Slovenia). Acta Carsologica. 31/2, p. 177-187.

Northup, D. E., Dahm, C. N. & Melim, L. A., 2000: Evidence for geomicrobiological interactions in Guadulpe Caves. - Journal of Cave and Karst Studies, 62, 2, 80-90.

Nováková, A., 2004: Saprotrophic microscopis fungi in caves of the Slovak Karst National Park. - In: Bella, P. (Ed.), Investigation, Exploatation and Preservation of Caves, 4th Scientific Conference with International Participation, 162-168, Liptovský Mikuláš.

Nováková, A., 2006: Microscopic fungi of Chýnov Caves and the Na Turoldu Cave (Czech Republic). - In: Bella, P. (Ed.): Research, Exploitation and Protection of Caves 5. 26. - 29.9. 2005, 211-213, Demänovská Dolina.

Onac B. P., 1995: Mineralogical data concerning moonmilk speleothems in few caves from Nothern Norway. - Acta Carsologica, 24, 429-437.

Popovic, T., Bopp, C.A., Olsvik, O. & Kiehlbauch, J.A., 1993: Ribotyping in molecular epidemiology. In: D.H. Persing, T.F. Smith, F.C. Tenover, T.J. White (eds.), Diagnostic molecular microbiology: principles and applications. pp. 573-583. ASM Press, Washington, USA.

Pot, B., Vandamme, P. & Kersters, K., 1994: Analysis of electrophoretic whole-organism protein fingerprints. In: Chemical Methods in prokaryotic Systematics, pp. 493-521. Edited by M. Goodfellow and A.G.O´Donnell. Chichester: Wiley.

Přibyl J., Vodička J., Kuzdasová Z., Hofírková S., 1984: Přehled údajů o jeskyních Moravského krasu, textová část 1. - ČSAV, Brno.

Richter D.K., Immenhauser A., Neuser R.D. 2007: Electron backscatter diffraction documents randomly orientated c-axes in moonmilk calcit fibres: evidence for biologically induced precipitation. - Geophysical Research Abstracts, 9, 02714, 1-11.

Samson, A. R., Rombach, C. M. & A. K. Seifert, 1984: *Hirsutella guignardii* and *Stilbella kervillei*, two troglobiotic entomogenous hyphomycetes. – Persoonia, 12, 123-134, Leiden.

Švec, P., Štegnerová, H., Durnová, E. & Sedláček I., 2004: Characterization of esculinpositive *Pseudomonas fluorescens* strains isolated from an underground brook. Folia Microbiol. (Praha). 49(6): 725-30.

GENERATIONS OF TECTONIC EVENTS AND THEIR INFLUENCE ON GENESIS OF THE CAVES (SLOVAK REPUBLIC, HIGH TATRA MTS., ÚPLAZ MASSIF)

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Abstract
Cave-related data was collected during the structural field mapping. From the measured data we were able to separate six monogenetic groups of discontinuities. We divided the complex of these groups into two populations of discontinuities. As the compare criterion we used the tectonic tilting of the High Tatra Mts. Via the back-rotation of this tilted group we obtained their original orientation. Individual generations of these monogenetic groups were further timed be means of orientation of paleostress axis and tectonic regimes, based on the general knowledge of the studied area. All the mentioned groups controlled both the development and orientation of caves.

Keywords: High Tatra Mts, speleology, tectonic structures, discontinuities, structural analyse.

INTRODUCTION

The studied area is located in north region in the High Tatra Mts. within the Úplaz massif, which is the NW ridge of the Mt. Kolovy štít. This study area is rich on the forms of karst (Pavlarčík, 1976, 1981, 1984). Caves Verných, Čiernohorská Nižná, Veterná, Kamenné oči, Suchá diera, Mokrá diera a Javorinka are situated in Gutenstein member and massive organogene limestones of tomanova formation (Matějka & Andrusov in Nemčok et al., 1993). During the structural field mapping of the presented caves the collected cave-related data were completed with the surface-measured data (Pavlarčík, 1983).

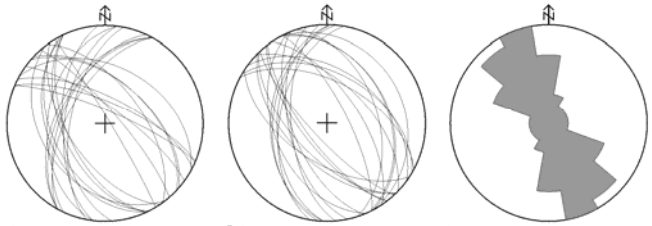
METHODS AND ESTABLISHED DATA

For the measured data was used structural field mapping in presented caves. The measured values we were able to separate from polygenetic population of discontinuities be means of structural analyse to six monogenetic groups (Kučera, 2005, 2007). The complex of six monogenetic groups we have divided into two groups, based on their compared orientation to the paleostress axes. As the comparation criterion we used the tectonic tilting of the High Tatras Mts., dated from Sarmatian to Pannonian age. The High Tatras Mts tectonic tilting was given based on bedding of paleogene sediments on mountainside with S0 0/25 – 0/35º, axis of rotation is horizontal E-W direction (ρ 90/0°) and measurement of rotation is positive value 27º. Via the back-rotation of the group of tectonic failures affected by the measured tilting (0/27°) we have obtained their original orientation.

Individual generations of failures were further timed, based on the general knowledge of the studied area (Kováč, 2000; Lukniš, 1973).

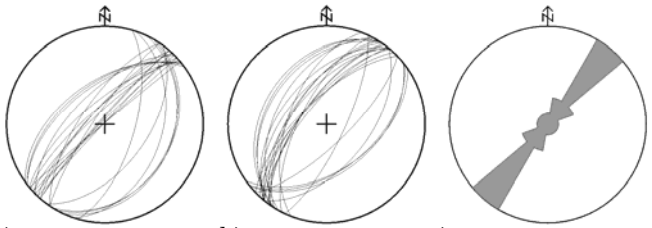
The Ottnangian to early Badenian failures are supposed to belong to the lower generation, representing the early stage of the Tatras upheaval (Kráľ, 1977; Kováč et al., 1994). This stage was characterized by the extensional tectonic failures of NE – SW direction and 30 to 70° angle of dipping (Fig. 1). The second group, affected by tilting, generated under extensional regime, is timed to late Badenian. The direction of failures was measured as NW – SE with 55 - 60° angle of dipping (Fig. 2). The third generation of the failures originated under compressional tectonic regime. It`s paleostress axis is oriented NE – SW, while these failures can be regarded as a conjugated strike-slip system of

Sarmatian age (Fig. 3). After this time the High Tatras Mts. block rotated horizontally and the later generations of failures were generated under normal orientation of the paleostress axes. As the oldest monogenetic group we regard those which were generated under N - S extension and have dipping 60°. The conjugated system of discontinuities mirrors an extensional normal-slip system, generated probably during the final stages of the Tatras tilting (Fig 4). After this stage, there started since Pleistocene a compressional tectonic regime with NNW – SSE axis, coincident with the present orientation of the principal stress axes (Fig. 5). As the youngest failures we can regard the discontinuities, connected with gravitational sliding. These failures were generated by gravitational collapse of the massif stability, due to a deep erosion generate by a glacier of Rissian, and later of Wurmian age (Fig.6). The motion along the sliding planes was enabled also by a proper orientation of a significant mylonite zone.



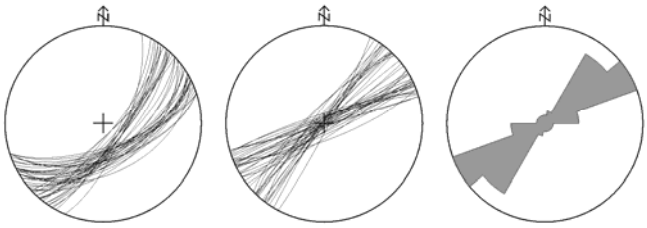
a) *b)* *c)*

Fig. 1) Ottnangian - early Badenian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



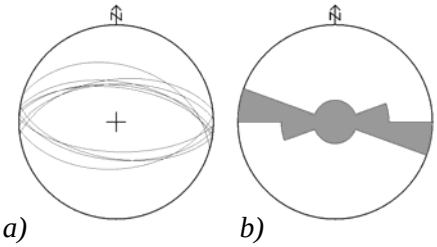
a) *b)* *c)*

Fig. 2) late Badenian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



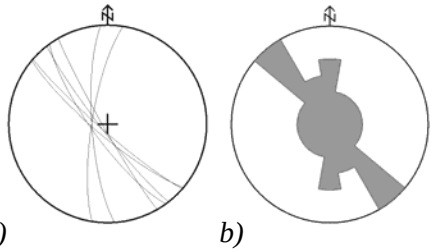
a) *b)* *c)*

Fig. 3) Sarmatian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



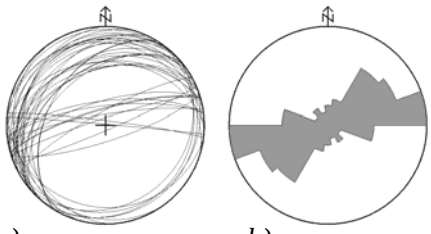
a) *b)*

Fig. 4) Late Miocene
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.



a) *b)*

Fig. 5) since Pleistocene
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.



a) *b)*

Fig. 6) late Rissian - recent
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.

RESULTS

The measured values we were able to separate to six tectonic events and timed it.

Monogenetic group conjugate discontinuities generated under extensional tectonic regime. Extension regime is in tendency NE-SW. Population of discontinuities is timed to Otnang – lower Badenian.

Monogenetic group conjugate discontinuities generated under extensional tectonic regime. Extension regime is in tendency NW-SE. Population of discontinuities is timed to late Badenian.

Monogenetic group of the conjugated discontinuities with a very good orthorombic symmetry generated under extensional tectonic regime. It`s paleostress axis is oriented NE – SW, while these failures can be regarded as a conjugated strike-slip system of Sarmatian age.

Monogenetic group of the conjugated discontinuities with a good orthorombic symmetry generated under extensional tectonic regime. Extension regime is in tendency N-S. Population of discontinuities is timed to Sarmatian - ? Panonian.

Monogenetic group of the conjugated discontinuities with a good orthorombic symmetry generated under compressional tectonic regime. Compressional regime is in tendency NNW-SSE. Population of discontinuities is timed since Pleistocene to recent.

Monogenetic group conjugated with gravity sliding. The discontinuities are represented by shallow sliding surfaces with gentle NW tilting and vertical tear off fractures with NE-SW orientation. The mentioned group of discontinuities come to existence as consequence of gravity movement caused by collapse of rock massif disturbed by deep glacial erosion.

All the mentioned groups of discontinuities controlled both the development and orientation of caves.

REFERENCES

Kováč, M., Kráľ, J., Márton, E., Plašienka, D. & Uher, P., 1994: Alpine uplift history of the Central Western Carpathians: Geochronological, paleomagnetic, sedimentary and structural data. Geol. Carpath., 45, 2, pp. 83-96.

Kováč, M., 2000: Geodinamický, paleogeografický a štruktúrny vývoj karpatsko-panonskeho regionu v miocéne: Nový pohľad na neogénne panvy Slovenska. Vyd. Slov. Akad. Vied, Bratislava, 204 s.

Kráľ, J., 1977: Fission track ages of apatites from somegranitoid rocks in West Carpathians. Geol. Zbor. Geol. Carpath. 28, 2, 269-276.

Kučera, M., 2005: Analýza tektonických štruktúr jaskýň v masíve Úplazu vo Vysokých Tatrách a ich vplyv na vývoj jaskynných priestorov. Mineralia Slov., 37, 230-233.

Kučera, M., 2007: New data on tectonic behaviour of High Tatras caves. 13th International Cave Bear Symposium, pp 20.

Lukniš, M., 1973: Reliéf Vysokých Tatier a ich predpolia. Vyd. Slov. Akad. Vied, Bratislava 1975 s.

Nemčok, J., Bezák, V., Janák, M., Kahan, Š., Ryka, W., Kohút, M., Lehotský, I, Wieczorek, J., Zelman, J., Mello, J., Halouzka, R., Raczkowski, W., Reichwalder, P., 1993:Vysvetlivky ku geologickej mape Tatier 1: 50 000. Bratislava, GÚDŠ, 135s.

Pavlarčík, S., 1976: Vplyv základných geologických štruktúr na vývoj krasu mädzi Kolovou a Sirokou dolinou vo Vysokých Tatrách. Diplomová práca, Katedra geologie a paleontologie, Prírodovedecká fakulta UK. Bratislava. 68 s.

Pavlarčík, S., 1981:Geologický a geomorfologický výskum krasu v širšej oblasti javorovej doliny vo Vysokých Tatrách. Záverečná správa. Manuskript, Správa Slovenských jaskýň – Múzeum Slovenského krasu. Liptovský Mikuláš 97 s.

Pavlarčík, S., 1983: Použitie geologických metod pri mapovaní jaskýň. Spravodaj SSS. 14, 4, 4-11.

Pavlarčík, S., 1984: Speleologický výskum krasových javov obalovej jednotky severnej strany Vysokých Tatier. Slovenský kras, 17, 41-67.

PALEOKARST AND ASSOCIATED SEDIMENTS AT DUBCI GEOSITE IN DALMATIA, SOUTHERN CROATIA

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Abstract
This short paper brings preliminary results of sedimentological study of Dubci bone-breccia site as an update to former research. The study site is located on the saddle between the mountains Omiška Dinara and Biokovo 404m a.s.l. The site was discovered already at the end of 19th century during road construction between Makarska and Zadvarje. The road cut exposed a cross section through a paleocave covered with coarse clastic sediments in alternation with paleosols. The Dubci site is of Cromerian age (Malez, 1967), one of several Lower Pleistocene sites in Dalmatia with bone breccias rich in fossil skeletal elements of macr mammals and micro mammals. Detailed geological context of the Dubci site was first described by Malez (1967). More recent study of the site indicates even more complex origin of this paleocave and associated sediments, which comprise three sedimentary units. New sediment samples revealed presence of well preserved ostracod fauna, glass spherules and microtectites of probable impact origin, black glass shards, rare microscopic fish bones, benthic and pelagic foraminifers, and particles of various allochthonous lithologies, which all give new input for interpretation of the Dubci site.

Keywords: Croatia, Early Pleistocene, paleocave, cave sediments, coarse clastic sediments, paleosol, spherules, shards, foraminifers, ostracods, geosite

INTRODUCTION

The study site Dubci is located 404 m above modern sea level, on the saddle between the mountains Omiška Dinara and Biokovo. It became exposed by the road construction between Makarska town at the coast and Zadvarje in the hinterland of Biokovo. The road cut opened two subvertical crossections, NW and SE, about 50 m long and 8 m high, which transected a paleocave covered with Pleistocene sediments. Near the end of the 19th century, at the time of road construction works, bone breccia rich in fossil fauna was discovered. Paleontological determinations were done by Gasperini (1885, 1887), Toula (1907) and Thenius (1958). In 1964 Malez (1965a, 1965, 1967) collected new fossil material, performed detail paleontological study and described geological context of the site. He determined the Early Pleistocene - Cromerian age of the sediments based on fossil fauna (Malez 1965b, 1967).
Recently, due to the road cut widening, additional geological study, conducted by the Institute of Quaternary paleontology and geology, was carried out for the purpose of geosite conservation, since the site Dubci is on the rim of the Nature park Biokovo. Special conditions for the road widening were given, and during construction works, all the waste material was collected for separation of bone breccia. Refreshed and clean road sections were then studied in detail, and new samples of sediments were collected for sedimentary and paleontological analyses.

MATERIAL AND METHODS

The filed work comprised detailed mapping of the sections in scale 1:100, detailed description of sediments and sampling. In sediment layers containing large debris, diameter of ten largest clasts was measured, and the mean clast size was calculated. Sediment samples were prepared for analysis by standard method of dissolving and wet sieving (Kummel and Raup, 1965). Preliminary microscopic analysis of silt to fine gravel fractions were done to obtain particle composition. Glass spherules and some mineral grains, found in sand fraction (sieve 0.90mm), were analyzed by SEM coupled with EDAX in the electron microscopy lab of the Geological Department of the Faculty of Science in Zagreb. Further analyses are in process.

RESULTS AND DISCUSSION

The paleokarst (paleocave) and associated Pleistocene sediments are found in the reverse fault zone within the Upper Cretaceous limestones which dip at 40˚ northeastwards (Marin□i□ et al, 1969). Three sedimentary units have been recognized: 1 - paleocave unit, 2 - lacustrine unit, 3 - alluvial unit. All three units are observable on the NW section, whereas on the SE section only the unit 3 is present (Fig. 1). The Units 1 and 2 were studied at NW section, and the Unit 3 at SE section. The Unit 1 was formerly described as Eocene clastics - flysch (Malez, 1967).

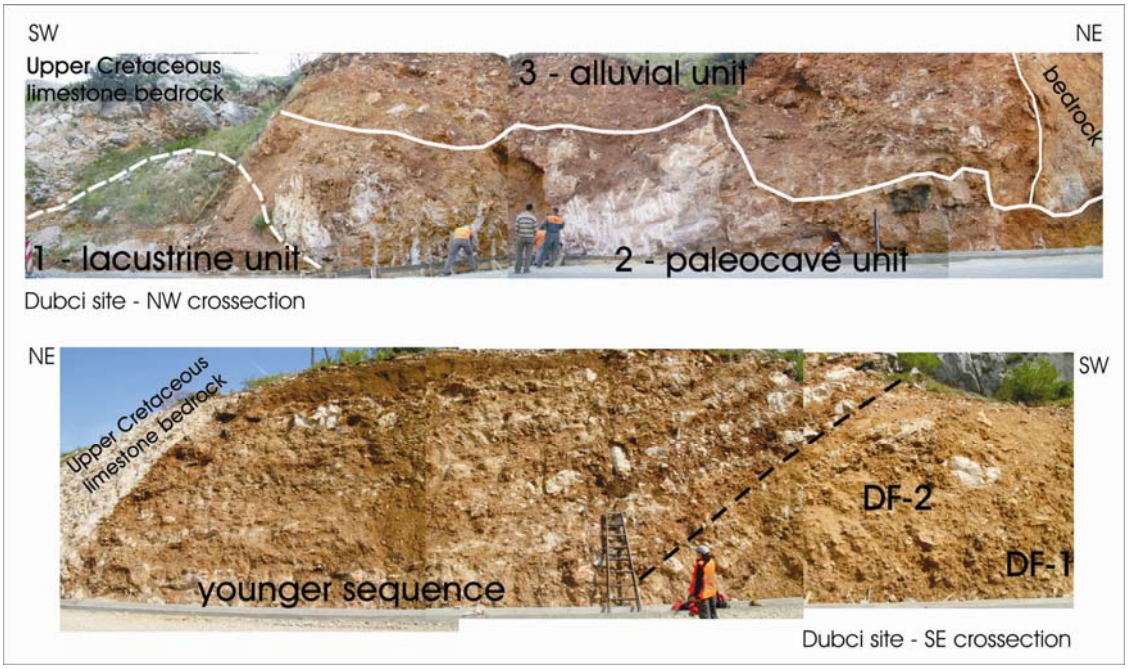

Figure 1. Dubci geosite.

Unit 1. There is a massive stalagmite in growth position, 10 m across and 6 m high, which represents a relict of a big cave, which must have had at least 50 m hanging wall during its active period in post-Cretaceous time. On the left side of the massive stalagmite there are variously oriented limestone blocks overgrown with speleotheme, which seams to be contemporaneous with the massive stalagmite. On the right side of this stalagmite there are limestone cobbles and boulders, and collapsed and broken thin columnar stalactites/stalagmites, which are partly overgrown by younger

tabular speleotheme and partly buried under rock debris. There are two locations of yellowish to red-brown sandy clay accumulations, which probably represent remnants of cave sediments filling large hollows. The sand fraction of clays contains calcite and quartz grains, opaque mineral grains, rock particles and juvenile ostracods *Candona* sp., *Cypridopsis* sp., *Mixtacandona* sp., and adult species *Eucypris* cf. *pigra* (Fischer), the later two indicating shallow fresh water pond environment. A limestone boulder on the left side (2 x 5 m) is a part of rock debris accumulation and is in direct contact with slightly contorted fine grained lacustrine sediments of Unit 2.

Unit 2. A sequence consists of coarse gravel layer, composed of predominantly well rounded gravel of quartz, quartzite and other metamorphic rocks, and an alternation of clay laminae, clayey silt and clayey sand laminae or thin layers, some composed only of quarts sand. Fine grained sediments contain rare, probably resedimented benthic and planktic foraminifers, juvenile ostracods, mica, opaque minerals, black glass shards, quartz and calcite crystal grains, limestone, quartzite and other metamorphic rock particles. Juvenile ostracods *Candona* sp., *Cypridopsis* sp. and *Heterocypris* sp. are indicative of shallow, fresh water (maximum oligohaline) environment, and occur from the beginning of Pleistocene until present. Transparent glass spherules and high temperature bipyramide quartz crystals were found in sand fraction of the gravel layer. They are probably of impact origin, but not resedimented from the Eocene clastics, which also contain transparent glass spherules but of different chemical composition (Marjanac et al, 2004, 2006a, 2006b).

Unit 3. This alluvial unit comprises an alternation of coarse clastic sediments and more-or-less preserved paleosols. They lay over steep and tectonized Upper Cretaceous limestones. Their bedding dip is 40° northeastwards, decreasing to subhorizontal at sharp contact with Upper Cretaceous limestones in the front. As visible on the NW section, these sediments buried the paleocave after it had been destroyed probably by erosion and collapse, possibly in pre-Pleistocene time. These sediments are well exposed on SE section. Ten coarse clastic layers are differentiated. All coarse clastic layers consist of around 70% rock debris - cobbles and boulders of the mean clast size in span from 56,3 cm to 94,7 cm. Sorting is very poor. Clasts are sharp-edged or subrounded. Rarely occur well rounded pebbles. Rounded gravel and sand is common. Clast imbrication indicating downslope transport is recorded in all layers. The first two layers are four meters thick each, and are debris flow (DF) sediments with very low matrix content. Matrix is clayey silt of yellowish light brown color. Matrix of DF-1 layer contains rare small bone fragments, planktic and benthic foraminifers, ostracods, glauconite grains, mica, opaque minerals, quartz grains and bipyramide quartz crystals, transparent glass spherules, microtectites, sulphur and carbon particles, rare microscopic fish bones. Abundant glauconite grains occur as nodules or have shape of planktic foraminifers without tests, probably all resedimented from the Upper Eocene glauconitic limestones and marls. Rare planktic foraminifers with hollow tests were found, which indicates they are contemporaneous to the sediment. Besides resedimented ostracods from Eocene sediments, there are Pleistocene ostracods *Candona* cf. *neglecta* Sars, *Mixtacandona* sp. and *Potamocypris* sp. indicative of a close spring fresh water coming to a ponded water basin. Glass spherules, the same as those in the Unit 1, togeather with microtectites, black glass shards, sulphur and carbon particles, planktic foraminifers, fish bones and bipyramide quartz crystals, make a group of particles indicative of an impact event that might have occurred in the Lower Pleistocene.
The other layers of a younger sequence above DF layers, originated probably by rock avalanches or even debris saturated snow avalanches, which is indicated by nearly vertical position of a boulder in one of them, and concentration of large debris in the zone of low angle dip. Paleosol formed on every coarse clastic layer, after it was filled and covered by fine grained material. The paleosol was than completely or partially eroded by the following rock avalanche. Paleosols are reddish-darkbrown (5YR 5/6). This younger succession of sediments contains fossil bones and bone fragments of macromamals, micromamals and birds. They occur as localized accumulations, and are

found in clayey matrix or mixed with rock debris and cemented, forming bone breccia. According to findings of Malez (1967) this fossil fauna should also belong to Chromerian group. The sand size fractions contain black glass shards and abundant mica flakes, which may indicate on influence of volcanic activitiy during Middle Pleistoncene as documented in central Italy for the period between 350ky and 560ky (Marcolini et al, 2003).

Considering the new data it is likely that sedimentation and events occured in much longer time span than just Cromerian, which equates to only Günz-Mindel Interglacial of the European Alpine region. Sediment characteristics indicate on both cold and snowy, and warm climate periods.
Threafter, the aim of further studies of the Dubci site is to reviel its event stratigraphy, and to define source areas especially of metamorphic rocks, which are not found today in the closer surroundings.

REFERENCES

Gasperini, R., 1885: Contributo alla conoscenza geologica del diluviale Dalmato, *Ann. Dalmatico*, 2, Zara.

Gasperini, R., 1887: Secondo contributo alla conoscenza geologica del diluviale Dalmato, *Progr. dell Scuola Reale Sup. di Spalato* a 1886-87, Split

Kummel, B. & Raup, D., 1965: *Handbook of Paleontological Techniques*, W. H. Freeman and Company, San Francisco, pp. XIII + 852.

Malez, M., 1965a: Paleontološka istra⟩ivanja kvartara u 1963. godini, *Ljetopis JAZU* 70, Zagreb.

Malez, M., 1965b: Der altpleistozäne Fundort Dubci in Mitteldalmatien, *Bull. scient., Sec. A,* 10, 12, Zagreb.

Malez, M., 1967: Donjopleistocenska fauna koštane bre□e kod sela Dubci u Dalmaciji, *Rad Jugoslavenske akademije znanosti i umjetnosti*, 345, 55-100.

Marcolini, F., Bigazzi, G., Bonadonna, F. P., Centamore, E, Cioni, R. & Zanchtta, G., 2003: Tephrochronology and tephrostratigraphy of two Pleistocene continental fossiliferous successions from Italy. Journal of Quaternary Science, 18/6, 545-556.

Marin□i□, S., Korolija, B., Mamu⟩i□, P., Magaš, N., Majcen, □., Brki□, M. & Ben□ek, Đ., 1969: *Tuma□ OGK List Omiš K 33-22*, Savezni geološki zavod, Beograd, pp. 51.

Marjanac T., Bermanec V. & Premec-Fu□ek V., 2004: Late Eocene megabed with glass sphaerules and microtectites in eastern Adriatic flysch (Croatia). 32th International geological congress, Florence 2004, Abstracts 1, 542

Marjanac T., Bermanec V., Premec-Fu□ek V., Marjanac Lj. & Tomša A.M., 2006a: Eocene glass spherule-bearing turbidites in eastern Adriatic flysch - evidence of multiple impacts into sedimentary targets? 40th ESLAB 1st International Conference on Impact Cratering in the Solar System. 8-12. May 2006, Noordwijk, Abstract Book, 135

Marjanac T., Bermanec V., Premec-Fu□ek V., Marjanac Lj. & Tomša A.M., 2006b: Glass spherules in Upper Uocene flysch of Croatian Adriatic - evidence of an impact into carbonate target? ESLAB-40. First International Conference on Impact Cratering in the Solar System. 8-12 May 2006 ESTEC, Noordwijk ESA CD WPP-266.

Thenius, E., 1958: Über einen Kleinbären aus dem Pleistozän von Slowenien nebst Bemerkungen zur Phylogenese der plio-pleistozänen Kleinbären, *Razpr. SAZU, Cl.* 4, 4, Ljubljana.

Toula, F., 1907: Rhinoceras Mercki Jäger Österreich, *Jahrb. d. k. k. geol. R. A.*, 57, Wien.

GLACIAL SEDIMENTS IN DINARIC KARST

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Abstract
Dinaric karst in Croatia hosts, among other, rather extensive sediments of Pleistocene age, some of which are interpreted as of glacial, proglacial and periglacial origin. The detailed field study of northern Adriatic islands and Croatian eastern Adriatic coast, as well as southern Velebit Mt. revealed presence of ice derived sediments, sediments reworked by glacial meltwaters, glaciolacustrine sediments, as well as glacial, periglacial and glaciotectonic features. The age of these sediments is so far constrained only by ostracod fauna found in associated lacustrine sediments which yield an Early Pleistocene age. More precise age determination may become available by dating of tillite cements, which at the moment of writing were not completed.

Keywords: Adriatic, Dinarides, glaciation, Pleistocene sediments, diamictons, moraine, kame-terrace, eratics

INTRODUCTION

The continuous study of glaciation of Croatian Dinarides progressively provides more data on its extent and variety of facies. So far, glacial deposits were recognized at several localities in rather large area, on the Risnjak Mt. (Bognar & Prugove□ki 1997), Northern Velebit Mt. (Bognar et al. 1991), Kvarner, Southern Velebit Mt., Dalmatia, and Knin and Drniš area. There are probably many other localities with glacial sediments, but are not recognized as such due to insufficient research.
The key questions in recognition of glacial sediments are: a) could these sediments originate by other non-glacial processes, b) what can be concluded on grounds of sediment geometry and facies, c) where is provenance of debris found in studied sediments and what is their most likely transport avenue. Skeptics= major argument is that the studied sediments, interpreted as moraines, were deposited from debris-flows. However, it is important to note that interpretation must be a result of extensive study of whole sediment succession, and must take into account the whole set of observational data such as deposit (sedimentary body) geometry, its structure and texture, relationship with other depositional units, sediment composition and provenance of debris.
The presented results and interpretations have accumulated during 20 years of our research in coastal Dinarides and are partly published elsewhere (Marjanac et al. 1990, Marjanac & Marjanac 1994, 1999, 2004 a, b), but a large number of presented data has not been published yet. Some of the ideas, like Dinaric model of glaciation are still Aunder construction@. Key sections (Fig. 1) are located on Krk (A) and Pag (B) islands, in Senjska Draga (C), on Veliko Rujno (D), in Velika Paklenica (E), in Seline (F), □rilo (G), at the coast of Novigradsko (H) and Krinsko (I) more, in Obrovac (J) and □egar (K). This study was part of the research projects 1-09-084, 119-303, 0119-401 and 119-0000000-1164 funded by the Croatian Ministry of Science.

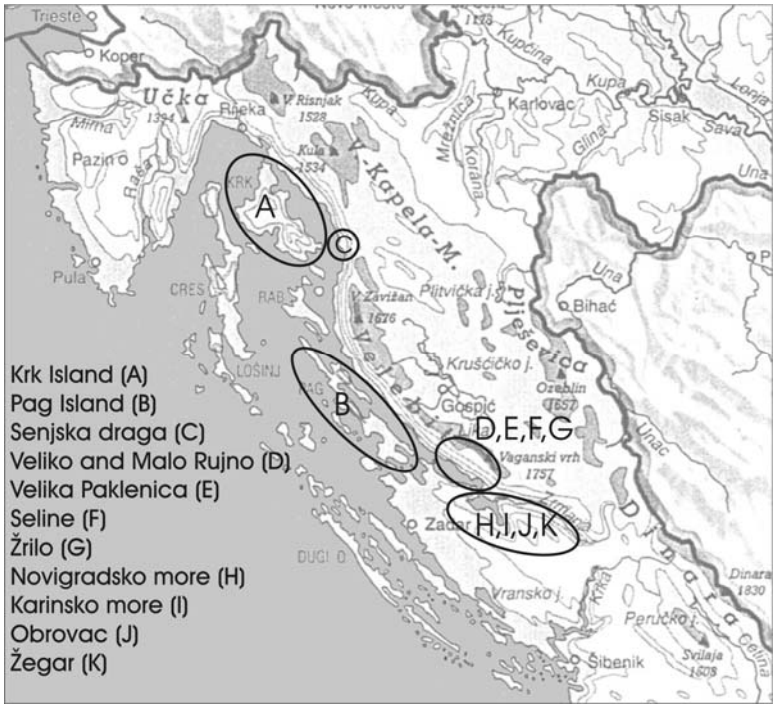

Figure 1. Study areas.

RESULTS AND DISCUSSION

A set of sediment types and sedimentary bodies are recognized in the studeid areas, which document ice-contact and periglacial depositional environments, as well as several phases of ice advance and retreat.

Fine-grained sediments herein comprise silty clay, clayey silt, silt, sand and gravel deposits. Except for silt and finest-grained sand, which may be also of aeolian origin, all of the lithologies indicate deposition in aquatic environment by stream flow and suspension deposition, in other words lacustrian and fluvial environments.

Lacustrian sediments are represented by alternation of silty clay-clayey silt-silt to very fine sand - varved sediments deposited in proglacial lakes which were occupying southern part of the Velebit Channel. Proximal facies occur in Seline, at Novigradsko more, Karinsko more, and near □egar. Many dropstones are found in sediments at Seline section and Novigradsko More coastal section. Distal facies is well exposed at key section □rilo. At well visible contact (Fig. 2), large rip-up clasts incorporated in the overlying ground moraine document a large-scale erosion of the underlying glaciolacustrine sediments. Erosion of glaciolacustrine sediments by younger moraine is also visible at Novigradsko more coastal section. There also occur ice-wedge casts in glaciolacustrine sediments.

Calcareous sands/sandstones and gravel deposits represent a variety of fluvial environments. Meandering fluvial channels are exposed on Krk and Pag islands, and Novigradsko more. These large fluvial channels (5-15 m deep and 25-100 m wide) have originally been ice-marginal rivers flowing between ice tongue and valley slope. There drainage basin and tributary system is missing today. Sediments left by those rivers built parts kame-terraces charcteristic for the ice-marginal zone, and their erosional remnants are found on Krk and Pag islands between 50 and 200 m a. s. l.. Sand and gravel deposits also represent breaded stream deposits and are interpreted as sandur - the periglacial outwash plane sediments (northern Dalmatia study area).

Figure 2. Key section Žrilo. Ground-moraine overlying deformed glaciolacustrine varved sediments.

Coarse-grained sediments comprise pebble-cobble-boulder deposits. They are matrix-supported to grain-supported diamictons containing angular to rounded rock debris, or occur as isolated boulders. Diamictons are commonly unsorted to poorly sorted, poorly- to well cemented, unorganized sediments with the largest clasts commonly around 1 m, exceptionally larger thyn 25 m in diameter (Velika Paklenica).

The matrix-supported diamictons are interpreted as tills or tillites, and form sedimentary bodies which locally occur as valley-marginal bodies (Krk island latteral moraines associated with kame-terraces), valley-longitudinal ridges (Veliko Rujno medial moraine, previously interpreted as terminal moraine, Nikler 1973), valley-normal walls (Velika Paklenica De Geer moraines), and valley-bottom sheets (Velika Paklenica ground-moraines). Glacial striae were found on some cobbles and boulders at several study sites (Veliko Rujno, Novigradsko more, Velika Paklenica, rilo, Obrovac).

Diamictons are composed of "local" lithologies, which are common throughout the Dinaric mountains, so it is difficult to decipher their provenance. However, clasts of Permian siltstones, and Lower Triassic micaceous sandstones give some idea of provenance because their occurrence is limited to two areas, upper reaches of the Velika Paklenica valley and the hinterland of the Knin city in Dalmatia.

Taking into consideration that these diamictons might be debris- or mud-flow deposits, it must be noted that matrix content of these diamictons is insufficient to suspend the largest clasts. Taking also into account their position in the field, the flow must have been of enormous size, and should have climbed the far side of Novigradsko More, after crossing its 30 m deep basin and suffering significant flow expansion. In the case of Novigradsko More, the closest high mountainous relief as a possible source of this hypothetical mud flow, is located ca. 20 km away.

The grain-supported sediments are interpreted as breccia or conglomerate, and locally matrix filled interspaces between clasts, whereas locally the sediment is open-work and the interspaces are filled with calcite cement. They can be organized, normal or inverse graded, clasts imbricated, or on the contrary can have chaotic fabric. These sediments commonly built valley-marginal terraces. They are interpreted as kame-terraces with characteristic slopeward bedding dip, the ice-contact sedimentary bodies, whose erosional remnants occur on Krk and Pag islands. Breccias and conglomerates aslo occur as subvertical valley walls - Krk island and Velika Paklenica lateral moraines.

Clast-supported openwork sediments with chaotic fabric are recognized as snow and ice avalanche deposits. These sediments occur in valley-normal fashion and probably form small avalanche cones (Krk island, Velika Paklenica, but also on Biokovo Mt.).

Sediment wedges filled with clast-supported chaotic debris, sometimes with clasts lining the walls, occur

in variety of sizes; from ca. 2 m up to ca. 10 m in depth, and 1 m to 6 m wide, and are interpreted as filled ice-wedge casts (Krk Island, Rab Island, Pag Island, Velika Paklenica, Novigradsko More).
Isolated boulders (extraclasts) occur scattered in the studied areas. Some are obviously rockfall and rock-failure sediment, but some like on the Pag island and Southern Velebit lithologically do not match nearby topographic sources and some stand on topographic highs. These extraclasts are interpreted in terms of eratic blocks which have been ice-driven and left at their present position after glacier retreat. Eratic blocks on Bojinac on the Southern Velebit Mt. occur above 800 m a.s.l. and stand on karstified (fluted) rock surfaces on topographic highes, which they could not reach by gravity. They are 8 - 25 m across.

AGE

The glaciation in Dinarides certainly post-dates karstification, because moraines locally comprise large clasts of fluted limestones, and eratic blocks stand on the fluted bedrock. However, the only direct evidence of its age are just poorly preserved ostracods recovered from the lacustrine sediments in Ravni Kotari (Malez & Soka 1969), which indicate generally Middle Pleistocene age. Independent research in Montenegro (Phil Hughes, personal communication) showed that the age of cements in tillites reaches ca. 350.000 years BC, what is broadly consistent with the available palaeontological age.

CONCLUSION

Study of the Pleistocene sediments in the coastal Dinarides and eastern Adriatic islands revealed their glacial or periglacial origin. It was possible to approximate limits of Pleistocene glacial extent at key sections on Krk and Pag islands, rilo and Novigradsko More. We assume that the glacial history in the Eastern Adriatic was dominated by at least two major glacial episodes, with one warm (? interglacial) period between, as documented by paleosol and traces of higher vegetation, although not discussed in this paper. Each glacial episode, however, comprised several pulses of glacial advance followed by retreat, as documented by succession of studeid sediments, de Geer moraines and glaciotectonic deformations. The glaciation was very extensive and the valley glaciers crossed the present Velebit channel, after descending from the high mountains down to 30 and maybe more metres below the modern sea-level.

REFERENCES

Bognar A., Faivre S. & Paveli J., 1991: Tragovi oledbe na Sjevernom Velebitu. (Glaciation traces on the Northern Velebit). *Geografski glasnik 53,* 27-39. Zagreb

Bognar A. & Prugove ki I., 1997: Glaciation Traces in the Area of the Risnjak Mountain Massif. *Geologia Croatica 50/2,* 269-278, Zagreb.

Malez M. & Soka A., 1969: O starosti slatkovodnih naslaga Erveni kog i egarskog polja. *III Simpozij dinarske asocijacije 1,* 81-93 Zagreb

Marjanac Lj. & Marjanac T., 1999: Polyphase kame terraces on the Island of Pag (Eastern Adriatic, Croatia). Field Symposium on Pleistocene Stratigraphy and Glacial Chronology, Southern Estonia 1999, Abstract volume, 34-35, Tartu 1999

Marjanac L. & Marjanac T., 1994: Slopeward-dipping terraces on NE Adriatic islands, Pleistocene low altitude kame-terraces? Abstracts 15th Regional Meeting IAS Ischia, 271-272.

Marjanac Lj. & Marjanac T., 2004a: Glacial history of Croatian Adriatic and Coastal Dinarides. In: Quaternary Glaciations - Extent and Chronology (ed. by J. Ehlers & P.L. Gibbard). Developments in Quaternary Science, 2a, Elsevier. 19-26.

Marjanac Lj. & Marjanac T., 2004b: Quaternary glacial and associated deposits of Velika Paklenica and Rujno (Southern Velebit Mt., Croatia). In: Adriatic-Dinaric Mesozoic carbonate platform, environments and facies from Permian to recent time. 32th International geological congress, Florence - Italy, August 20-28, 2004, Field-trip guidebook - P53, 27-29.

Marjanac T., Marjanac Lj. & Oreški E., 1990: Glacijalni i periglacijalni sedimenti u Novigradskom moru. *Geol. vjesnik 43, 35-42,* Zagreb.

Nikler L., 1973: Nov prilog poznavanju oledbe Velebita. *Geol. vjesnik 25 (1971), 109-112,* Zagreb.

THE IMPACT OF BLASTING ON CAVE VELIKA PEĆA

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Abstract
Cave Velika Peća is situated near Grabovac village, which is positioned in the background of mountain Biokovo on the part of Šestanovac-Zagvozd motorway. The cave is a natural speleological object which is an important archeological site too. Velika Peća consists of limestones, upper Cretaceous.
On the part of motorway route above the cave test blasting was made with the purpose of evaluating the possibility of damage beginning in limestones in the cave and measuring seismological impacts of blasting with calculation of permitted mass of explosive charge.
The route of Šestanovac-Zagvozd motorway which is under construction passes close to the cave. The technology of excavation includes drilling and blasting. The nearest distance of final slope from the cave is 10 m. The impact blasting and propose drilling blasting parametars for the future were determinated towards execute measuring of oscillation velocities on the occasion of test blasting. On the occasion of blasting oscillation velocities of the ground were measured with transport seismographs and deformations with LVDT sensors. Six points of monitoring for a test blasting field MP-1 were placed and eight points for a test blasting field MP-2. Mass of the explosive charge of blasting field MP-1 was 25,5 kg and for a MP-2 36,0 kg with the sequence of milisecond delay blasting. During the both blasting measuring oscillation velocities of the ground in points of monitoring in the cave were under the permitted standard DIN 4150. LVDT sensors did not record any deformations on the measured points on the limestones of Cave Velika Peća. Intensity of shaking caused by blasting was determinated by measuring the oscillation velocities of the ground in points of monitoring. Permitted oscillation velocities of the ground for the cave is middle value of a permission velocities between the historical monument and the apartament v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for a continuation of blasting works on the part of motorway route above the cave. Applied standard is DIN 4150 with frontier permission of oscillation velocities from v_{per}=1,0 cm/s.

Keywords: limestones, blasting, seismological impacts of blasting, deformations, archeological site

INTRODUCTION

Cave Velika Peća is situated near Grabovac village, which is positioned in the background of mountain Biokovo on the part of Šestanovac-Zagvozd motorway *(Fig. 1)*. The cave is a natural speleological object which is important archeological site. The object was blessed and dedicated to religous aims *(Fig. 2)*. The entrance of the cave is on 414 m a.s.l. between tops Lisača 576 m a.s.l. and Velika Orljača 909 m a.s.l.

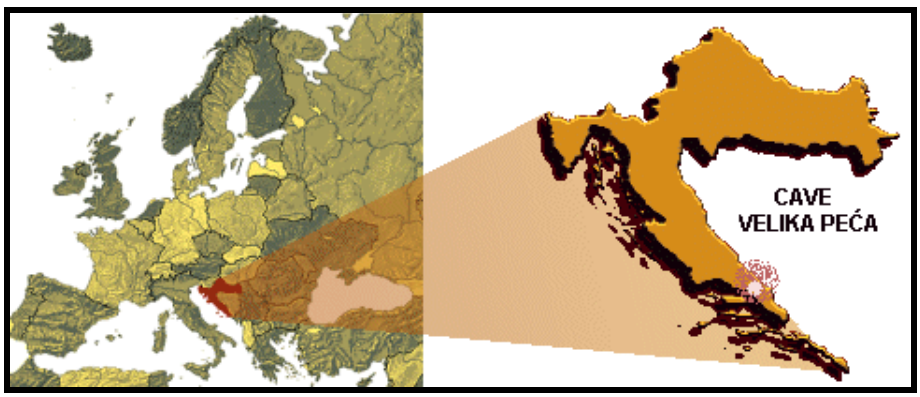

Fig. 1: Location map with regional view

Velika Peća is the cave in formation what is obvious for a numerous stalactites and stalagmites *(Fig. 3).* Speleological prospect have established a fact that the cave is a ramify type. Space of the cave is in the Dinaric zone with typical karst landscape, specific surface, underground and solution shapes. The cave consists of limestones upper Cretaceous. Shabbing of limestones rocks take its rise sediments in form of pebbles and clay.

Fig. 2: Entrance in Cave Velika Peća

Fig. 3: Inside Cave Velika Peća

The route of Šestanovac-Zagvozd motorway which is under construction passes close to the cave. The original route of motorway was moved 10 m towards N because it was necessity to preserve site Velika Peća. On the part of motorway route above the cave test blasting was made with the purpose of evaluating the possibility of damage beginning in limestones in the cave and measuring seismological impact of blasting including the calculation of permitted mass of expolosive charge.

MATERIAL AND METHODS

Measuring the oscillation velocities of the ground and deformations

Two test blasting field MP-1 from st. 44+625 m to st. 44+645 m and MP-2 from st. 44+400 m to st. 44+410 m were exploded. MP-1 contain 120 wells and MP-2 contain 60 wells which was main explosive charge amonal-patron Ø 60 mm. Initiation was with nonelectric system initiation with conectors slowless 25 i 42 ms. Maximum mass of the explosive charge of blasting field MP-1 was 25,5 kg and for a MP-2 36,0 kg with the sequence of milisecond delay blasting. On the occasion of blasting oscillation velocities of the ground were measured by transport seismographs type Instantel Minimate, Instantel Minimate plus, Instantel Minimate plus 8 i Instantel Blastmate Series III *(Fig. 4)* which are applied by ISO 9001 standard.

Fig. 4: Seismograph Instantel Blastmate Series III

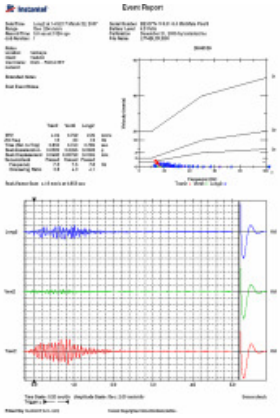

Fig. 5: Trajectories of oscillation velocities

Six points of monitoring for a test blasting field MP-1 were placed and eight points for a test blasting field MP-2. Trajectories of the oscillation velocities were recived *(Fig. 5)*. On the occasion of blasting, deformations were measured by LVDT sensors in two points inside Cave Velika Peća *(Fig. 6)*.

Fig. 6: Measured deformations with LVDT senzors inside Cave Velika Peća

Establish a fact about intensity of shaking

Intensity of shaking caused by blasting was determined by measuring the oscillation velocities of the ground in a points of monitoring. On the occasion of seismological impacts of blasting at the test blasting on the part of motorway route above the cave instruments were used to evidence frequency oscillations of the ground automatically for every measured value and for a three components of oscillation velocities. After that DIN 4150 standard results diagram was drawn.

Estimate permitted mass of the explosive charge

Within several years of monitoring and measuring the dependance between oscillation velocities, mass of the explosive charge and distance between motorway and blasting field were established by M. A. Sadovski equation *Eq. (1)*:

$$v = k\left(\frac{\sqrt[3]{Q}}{R}\right)^{n} \qquad \textit{Eq. (1)}$$

Where are: $\boldsymbol{v}$ – oscillation velocities of the ground (cm/s), $\boldsymbol{Q}$ – mass of the explosive charge (kg), $\boldsymbol{k}$ – coefficient of blasting way, $\boldsymbol{R}$ – distance between place of monitoring and blasting field (m), $\boldsymbol{n}$- smother coefficient of seismic waves and $\frac{\sqrt[3]{Q}}{R} = \rho$ represent mass of explosive charge.

$$v_{r1} = k\,\rho_1^n \qquad \textit{Eq. (2)} \qquad \text{and} \qquad v_{r2} = k\,\rho_2^n \qquad \textit{Eq. (3)}$$

At the blasting time $\boldsymbol{Q}$ and $\boldsymbol{R}$ were known. Coefficients $\boldsymbol{k}$ and $\boldsymbol{n}$ were calculated from the system of equation *Eq. (2)* and *Eq. (3)*.

$$n = \frac{\log\frac{v_{r1}}{v_{r2}}}{\log\frac{\rho_1}{\rho_2}} = \frac{\log\frac{v_{r1}}{v_{r2}}}{\log\frac{R_2}{R_1}} \qquad \textit{Eq. (4)} \qquad \text{and} \qquad k = \frac{v_{r1}}{\rho_1^n} = \frac{v_{r2}}{\rho_2^n} \qquad \textit{Eq. (5)}$$

Computer programme calculates coefficients $\boldsymbol{n}$ *Eq. (4)*, $\boldsymbol{k}$ *Eq. (5)* and permitted mass of explosive charge with the sequence of milisecond delay blasting. Measured oscillation velocities of the ground applied DIN 4150 standard and the criteria for some type of buildings was determined: 0,5 cm/s for the buildings and the historical monument, 1,5 cm/s for the apartaments and 4 cm/s for the industrial buildings.

Permitted oscillation velocities of the ground for the cave is middle value of a permission velocities between the historical monument and the apartaments v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for the continuation of blasting works on the part of motorway route above the cave. Permitted mass of the explosive charge of blasting with the sequence of milisecond delay blasting for eastern direction (Ploče) was taken from measured point MO-1>MO-2 at the blasting field MP-1. For the western direction (Split) permitted mass of the explosive charge of the blasting with the sequence of milisecond delay blasting was taken from measured point MO-V/1>MO-V/2 for the blasting field MP-2.

RESULTS AND DISCUSSION

On the basis of test blasting, tests gave parameters for maximum values of explosive charge for a distant blasting work. Results of test blasting are in *Table 1* and *Table 2* and were under the permitted DIN 4150 standard.

Points of monitoring	Distance from the MP-1 m	Max mass of the explosive charge kg	Oscillation velocities of the ground cm/s			
			v_l	v_v	v_t	v_{rez}
MO-1-way - MM+8-1	36,0	25,5	2,41	2,86	2,98	3,74
MO-2-way - MM+8-2	60,0	25,5	1,69	1,46	1,69	2,23
MO-3- way - MM 5421	88,0	25,5	1,14	0,483	1,45	1,55
MO-4- way - BM II	111,0	25,5	0,864	0,622	0,559	1,02
MO-5-cave - MM +	86,0	25,5	<0,1	<0,1	<0,1	<0,1
MO-6-cave - BM III	102,0	25,5	<0,1	<0,1	<0,1	<0,1
Deformations – LVDT sensors (mm)						
MO-5-cave - LVDT-1	under the sensitiveness of instrument (0.0396 mm)					
MO-6-cave – LVDT-2	under the sensitiveness of instrument (0.0396 mm)					

Table 1. Results of measuring test blasting field MP-1 from st. 44+625 to st. 44+645

Points of monitoring	Distance from the MP-2 m	Max mass of the explosive charge kg	Oscillation velocities of the ground cm/s			
			v_l	v_v	v_t	v_{rez}
MO-1-way - MM+8-1	31,0	36,0	3,25	1,75	4,53	4,56
MO-V/1-way - V-1, MB	41,0	36,0	1,36	1,42	1,87	2,19
MO-2-way - MM+8-2	58,0	36,0	1,37	0,952	1,30	1,79
MO-V/2-way - V-2, MB	73,0	36,0	1,65	0,914	1,60	2,34
MO-3-way - MM 5421	78,0	36,0	1,07	0,914	1,63	1,69
MO-4 - BM II	102,0	36,0	0,0127	0,483	0,787	0,87
MO-6-cave - BM III	111,0	36,0	0,343	0,203	0,178	0,436
MO-5-cave - MM +	127,0	36,0	0,0254	0,127	0,165	0,209
Deformations – LVDT sensors (mm)						
MO-5 - LVDT-1	under the sensitiveness of instrument (0.0396 mm)					
MO-6 - LVDT-2	under the sensitiveness of instrument (0.0396 mm)					

Table 2. Results of measuring test blasting field MP-2 from st. 44+400 to st. 44+410

Location:		**Cave Velika Peća**		
Type of explosive:		**Amonal Ø 60**		
No. blasting field:		MP	1	2
No. points of monitoring:		MO=	2	2
Explosive charge (kg)		Q=	25,5	36
Velocities in MO-1 (cm/s)		v_{r1}=	3,740	4,560
Velocities in MO-2 (cm/s)		v_{r2}=	2,230	2,190
Distance MP to MO-1 (m)		R1	36,00	31,00
Distance MP to MO-2 (m)		R2	60,00	41,00
Permitted oscilation velocities (cm/s)		v_{per}=	1,00	1,00
Distance for MP-1 and MP-2				
min	Rmin	18	m	
max	Rmax	100	m	
interval	Rz	1	m	
CALCULATE INFORMATIONS				
R for MP-1	Q for MP-1	R for MP-2	Q for MP-2	
18	0,06	18	1,24	
19	0,08	19	1,46	
20	0,09	20	1,70	
25	0,17	25	3,33	
30	0,30	30	5,75	
35	0,47	35	9,14	
40	0,70	40	13,64	
45	1,00	45	19,42	
50	1,37	50	26,64	
55	1,82	55	35,46	
60	2,37	60	46,03	
65	3,01	65	58,53	
70	3,76	70	73,10	
75	4,62			
80	5,61			

Table 3. Permitted mass of the explosive charge of the blasting with the sequence of milisecond delay

During the both blasting measuring oscillation velocities of the ground in a points of monitoring in the cave were under the permitted DIN 4150 standard. LVDT sensors did not record any deformations on the measured points on the limestones of Cave Velika Peća *(Table 1, Table 2)*.

Intensity of shaking, caused by blasting, was determined by measuring the oscillation velocities of the ground in a point of monitoring. Permitted oscillation velocities of the ground for the cave is a middle value of a permission velocities between the historical monument and the apartament v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for a continuation of blasting works on the part of motorway route above the cave. Applied standard is DIN 4150 with frontier permission of oscillation velocities from v_{per}=1,0 cm/s. Results of the measuring during test blasting field MP-1 and MP-2 eliminated possibility of initiating damage in Cave Velika Peća.

In SE direction towards Ploče oscillation velocities from 1 cm/s on the bedrock of the cave were accomplished. In the cave the oscillation velocities were twice smaller. Maximum mass of the explosive charge of blasting with the sequence of milisecond delay blasting can not be more then 15 kg. In NW direction towards Split maximum mass of the explosive charge of blasting with the sequence of milisecond delay blasting can not be more then 36 kg *(Table 3)*.

This documented data provided and described the importance of blasting, measuring seismological impacts of blasting and any deformations in limestones and other karst sediments. Blasting should be the top priority for all local and regional planning process in karst areas specially when we work on or near the caves, archeological sites, industrial buildings and historical monument in karst region.

REFERENCES

Ester, Z., 2005: Miniranje I, Eksplozivne tvari, svojstva i metode ispitivanja. Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 176 pp.

Ester, Z. & Dobrilović, M., 2007: Izvještaj o mjerenjima seizmičkih utjecaja miniranja i proračun dozvoljenih količina ekspolozivnog punjenja na djelu trase iznad Velike Peći, pokusna miniranja 22.03.2007. Arhiv Rudarsko-geološko-naftnog fakulteta, Zagreb.

Ester, Z. & Dobrilović, M., 2007: Izvještaj o mjerenjima seizmičkih utjecaja miniranja i proračun dozvoljenih količina ekspolozivnog punjenja na djelu trase iznad Velike Peći, miniranja 03.04.2007. Arhiv Rudarsko-geološko-naftnog fakulteta, Zagreb.

Garašić, M., 1991: Morphological and hydrogeological classification of speleological structures (caves and pits) in the Croatian karst area. (Morfološka i hidrogeološka klasifikacija speleoloških objekata (spilja i jama u krškom području). Geol. vjesnik, 44, Zagreb.

Garašić, M. & Cvijanović, D., 1984: Uzročna veza između pojave lokalnih potresa i speleoloških objekata u kršu. (Rapport de cause a effet entre les seismes et les phenomenes speleologique dans le karst localises). Zbornik predavanja 9. jugosl. Speleol. Kong. Karlovac (1974), Zagreb, 431-441 pp.

Krsnik, J., 1989: Miniranje. Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 180 pp.

Raić, V., Ahac, A. & Papeš, J., 1976: Osnovna geološka karta SFRJ 1:100.000. List Imotski K 33-23. Inst. geol. istraž. Sarajevo (1962-1967). Savezni geol. zavod, Beograd.

Raić, V. & Papeš, J., 1978: Osnovna geološka karta 1:100.000. Tumač za list Imotski K 33-23. Inst. geol. istraž. Sarajevo (1968). Savezni geol. zavod, Beograd.

SPECIES RICHNESS FROM POOLS AND DRIPS IN SELECTED ROMANIAN CAVES

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Abstract
The epikarst fauna was studied in two caves of Padurea Craiului Mountains (NW Romania) during the period November 2005 – May 2006. Sampling of two drips and one pool in each cave was performed with a procedure which allowed continuous collecting. The dominant component in terms of abundance and species richness within the faunal assemblage was copepods. In the focus of this study was the estimation of cyclopoid copepods richness from dripping water and pools with clay and calcite bottom. Sampling completeness was examined from a local point of view. Statistical analyses were performed using EstimateS version 7.5 software. Based on species accumulation curves and Chao estimates of total diversity it was determined that seven months of sampling period was not sufficient to identify all expected species in drips and pools from Ungurului cave. In the case of Vântului cave three months of sampling from two drips and one pool were proved to be enough to reach the plato of all expected species. This work represents the first Romanian study of fauna from percolation water which contributes to the understanding of ecology and biogeography of cyclopoid copepods in subterranean habitats. Results are in accordance with the recent study from Slovenia which showed that epikarst is a rich habitat for a wide variety of animals.

Keywords: Specie richness, caves, Romania, epikarst, Copepoda, accumulation curves, biospeleology

INTRODUCTION

The epikarst is the zone which is above the cave and it is the most upper layer of the rock beneath the soil. For invertebrates this habitat has already been established as a biodiversity hotspot (Pipan, 2005). A potential to find specialized troglobiotic organisms in such environments is very high (Pipan & Culver, 2007) The inaccessibility of epikarst makes direct faunal examination impossible that is why communities inhabiting epikarst should be sampled indirectly by collecting and filtering dripping water in caves from trickles and pools. From percolating water numerous groups of animals have been collected: Nematoda, Copepoda, Oligochaeta, Ostracoda, Isopoda, Acarina, Diplopoda, Collembola, Araneae, Coleoptera, Insects larvae, Bathynellaceae (Pipan, 2005, Pipan & Culver, 2005a). The most common and the most abundant group of animals in the epikarst is Copepoda (Crustacea). Pipan (2005) made in Slovenia up-to date the most extensive research of epikarst copepods, by sampling continuously thirty-five drips in six caves for more than one year. The species richness of cave fauna, which was obligated to adapt aphotic and food-scarce conditions was difficult to quantify, especially in the terms of regional patterns (Pipan & Culver, 2007).
The aim of this study was the investigation of the regional diversity patterns of Cyclopoidea (Copepoda, Crustacea) from drips and pools, copepod richness and sampling completeness in two caves in Romania. Further in the paper, the sampling sufficiency in the two caves was studied.

MATERIAL AND METHODS

This study was conducted in two caves, Ungurului cave and Vântului cave from Padurea Craiului Mountains (NW Romania, Fig. 1). Ungurului cave and Vântului cave are part of the Crisul- Repede karst basin and are both developed in Ladinian (middle Triassic) limestone. Caves are geographically close to each other and are equipped for tourist visit as show caves. Vântului cave is the longest cave in Romania (50 km). Ungurului cave is a well known show cave in Transilvania, the cave is long 1.5 km with a large entrance (dimension of the entrance 22 by 32 m). In each cave two drips and one pool were selected for the study. Sampling sites in Vântului cave were near to the entrance, 30 and 40 m

respectively along the subterranean river. In Ungurului cave one drip was situated near to the entrance (25 m), the second drip and pool were deep in the cave (500 m). Sampling was conducted in the period from October 2005 till May 2006.
The sampling of percolating water was performed by taking samples from drips using a continuous sampling technique (for reference see Pipan, 2005), and by filtering water from pools filled with seeping water from the walls. For water filtering a net of mesh size 60 µm was used. Samples were preserved in 90 % alcohol.
For computation of abundance-based and incidence-based statistical analyses EstimateS software, version 7.5 (Colwell, 2005) was applied. For analyses four drips and two pools were used; two drips and one pool from Ungurului cave and two drips and one pool from Vântului cave. Data on abundance were summed over the sampling season. Accumulation curves were based on Mao-Tau estimates of species richness (Colwell et al., 2004), and total expected number of species on Chao's and ACE abundance-based estimator.

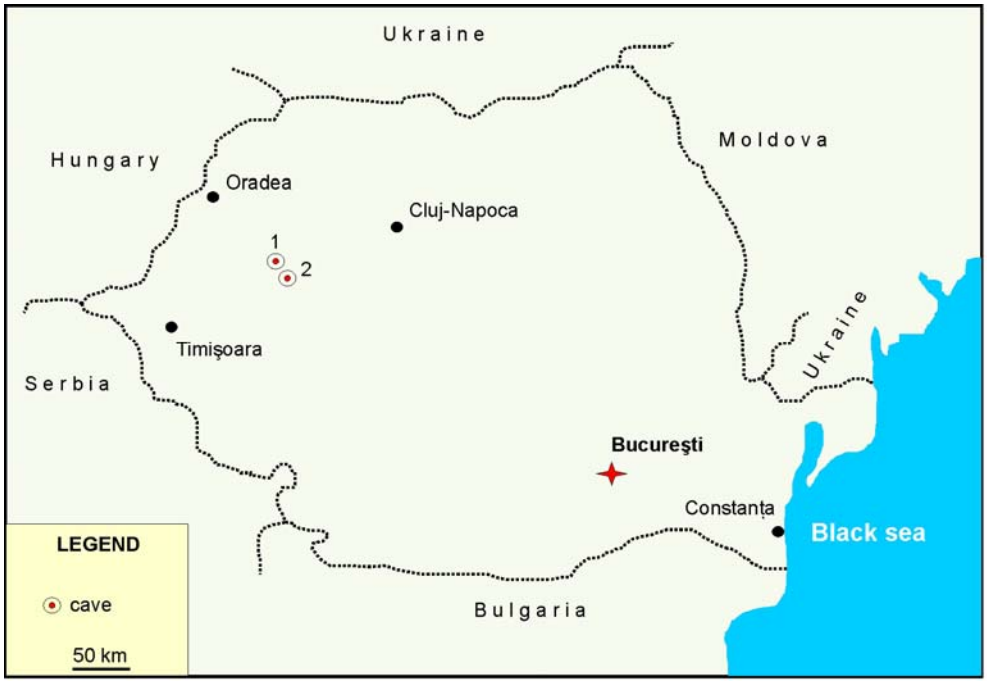

Fig. 1: Map of the study area in Romania (1- Ungurului cave, 2- Vântului cave).

RESULTS AND DISCUSSION

In Ungurului cave and Vântului cave 10 groups of invertebrates were identified what indicated high level of biodiversity (Table 1). This can be annotated to the heterogeneity of microhabitats in the karst unsaturated zone (Oarga, 2006).
In both studied habitats, drips and pools, the most abundant faunal group was Copepoda (Cyclopoida and Harpacticoida). Interestingly, in both caves in the same habitat the presence of various species was noticed. More evidently in Ungurului cave in one sampled pool four species of cyclopoids were identified (*Acanthocyclops reductus reductus*, *Speocyclops troglodytes*, *Eucyclops* sp, and *Megacyclops* sp.; Table 2). This can be attributed to large quantity of organic matter in sampled pools with clay sediment at the bottom and to the presence of guano which was observed in the immediate vicinity of the sites. Biodiversity and its patterns at local and, to some degree, at regional scales are controlled by productivity (Gibert and Deharveng, 2002).

Table 1: Invertebrate groups found in Ungurului and Vântului cave in November 2005-May 2006

Animal groups/ Caves	Pestera Vântului	Pestera Ungurului
Nematoda	+	+
Gastropoda	+	+
Oligochaeta	+	+
Aranae		+
Acarina	+	+
Ostracoda	+	+
Copepoda	+	+
nauplia	+	+
Amphipoda		+
Colembolla		+
Insecta- larvae	+	+

From five species collected from drips and pools in Ungurului cave and Vântului cave, two were stigobionts (*Speocyclops troglodytes* and *Acanthocyclops reductus reductus*). *Acanthocyclops reductus reductus* was found for the first time in Ungurului cave and Padurea Craiului Mountain (Oarga, 2006; Iepure et al., in preparation).

Table 2: Cyclopoid species from trickles and pools in Ungurului and Vântului caves

Cyclopoida	Pestera Vantului		Pestera Ungurului	
	trickles	pools	trickles	pools
Acanthocyclops reductus reductus (Chappuis, 1925)	+		+	
Acanthocyclops sp.			+	+
Speocyclops troglodites (Chapuis, 1925)	+	+		+
Eucyclops sp.				+
Megacyclops viridis (Jurine, 1921)				+

Species accumulation curves for sampled drips and pools for both caves are shown in Fig. 2 and Fig. 3. If the species accumulation curves reach an asymptote the sampling should be complete (Pipan and Culver, 2007). For Ungurului cave (Fig. 2) there was no indication that the specie accumulation curve (Mao-Tau) reached the asymptote. Chao 1 estimates of total species-richness were higher than the observed number of species. At the scale of this particular cave and sampled habitats (two drips and one pool) sampling was not sufficient to capture most of the species. In the case of Vântului cave, the species accumulation curve appeared to reach the asymptote (Fig. 3). Based on the results we can conclude that three months sampling was probably sufficient to find the majority of present species from epikarst habitat. The fact that *Eucyclops* sp., and *Megacyclops* sp. were found only once in Ungurului cave (Table 2) in the same pool can be explained with incomplete sampling or these two organisms can be considered accidental dwellers for this cave. Results of statistical analysis showed that in the case of Ungurului cave continuous sampling should be performed to reach the asymptote value of total species richness.

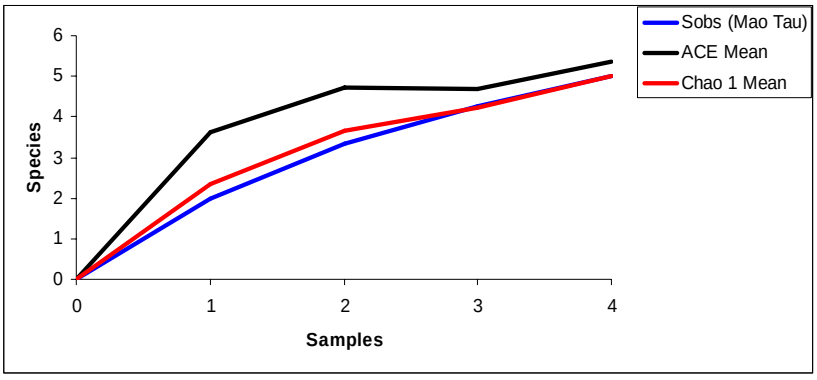

Fig. 2: The species accumulation curves for Ungurului cave.

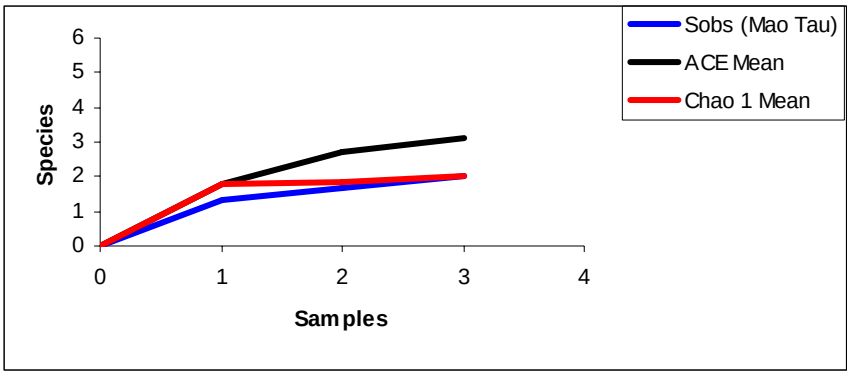

Fig. 3: The species accumulation curves in Vântului cave

This work represents the first Romanian study on epikarstic fauna with the method developed by Pipan (2005) which contributed to understanding of ecology and biogeography of cyclopoid copepods in subterranean habitats.

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REFERENCES

Colwell, R.K., Mao, C.X., Chang, J., 2004: Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85: 2717-2727.

Colwell, R.K., 2005: EstimateS: statistical estimation of species richness and shared species from samples version 7.5. User's Guide and application published at http://purl.oclc.org/estimates.

Gibert, J., Deharveng, L., 2002: Subterranean ecosystems: a truncated functional biodivesity. Bioscience 52, 6: 473-481.

Oarga, A., 2006: Groundwater Faunal Assemblages in Different Habitats of Padurea Craiului Mountains (NW Romania). Unpublished M. Sc. Thesis. Babes-Bolyai Univesity, Cluj-Napoca, 63 p.

Iepure S., Pipan T., Oarga A., in preparation: On subterranean species of the genus *Acanthocyclops* (Copepoda, Cyclopoida) from central and south-eastern Europe, with re-description of three species.

Pipan T., 2005: Epikarst- a Promising Habitat. Ljubljana, ZRC Publishing, 101 p.

Pipan, T., Culver, D.C., 2005a: Estimating biodiversity in the epikarstic zone of a West Virginia cave. Journal of Cave and Karst Studies, 67: 103-109.

Pipan, T., Culver D.C., 2007: Regional species richness in an obligate subterranean dweling fauna-epikarst copepods. Journal of BioGeography 34: 854-861.

FROM STABLE ISOTOPIC RECORD TO PALEOCLIMATE RECONSTRUCTION

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Abstract
This short paper presents results of test of a correlation method based on MC-simulations. From one speleoterm two analytical profiles are made, these two profiles (testing data) represent the same records but they have different density of sampling. The results of this experiment show that the method works and it could be useful for correlating profiles with different sampling density.

Keywords: MC-methods, correlation, stable isotopes, palaeoclimate reconstruction.

INTRODUCTION

The first two steps in a way to palaeoclimate reconstruction are field and analytical investigations. As a result usually many analytical profiles are created. The first question on this stage is. - How we could correlate these profiles?

The first real problem which we have to overcome in the correlation process - is a time scale construction. Very precise, high density stable isotope records are used usua1ly as a palaeoclimatic tools. As a time scale estimator a series of numerical dating resu1ts is used. The samples for dating are collected with less density then for stable isotope analyses. But for stable isotope record presentation an age of all analyzed points is needed. Age-depth model construction is necessary for precise and reliable time scale of any stable isotope record. After this step we can arrange the isotopic data in a time scale.

What are the next problems? - Is time scale accuracy good enough for precise correlations? What is the final record confidence bends?

Firstly, usually every profile is based on a different number of analyses. It means that any isotopic curve uses different number of points. Basic question is how we can test if record changes reflect climatic or sampling density/position changes.

Secondly, every measurement is characterized by some uncertainty. Our analytical points have two kinds of uncertainties: first from time scale and second from stable isotopes measurements. The question is how measurement uncertainties affect correlation process.

MATERIAL AND METHODS

We take two sampling profiles from one speleoterm. (*Fig.1)* It was sampled in two sides. On first side 92 samples (N-points curve), on second side only 37 samples were taken (n- points curve). For this two sampling profiles the analyses of carbon stable isotopic ratio were made. We know that these two analytical profiles are represented by the same palaeoclimatic record. The questions arises here how sampling density influences the palaeoclimatic records interpretation? To answer this question we use monte-carlo simulations. Our algorithm reflects non-uniformity of sampling, stable isotopic ratio measurement uncertainties and uncertainty of time scale model.

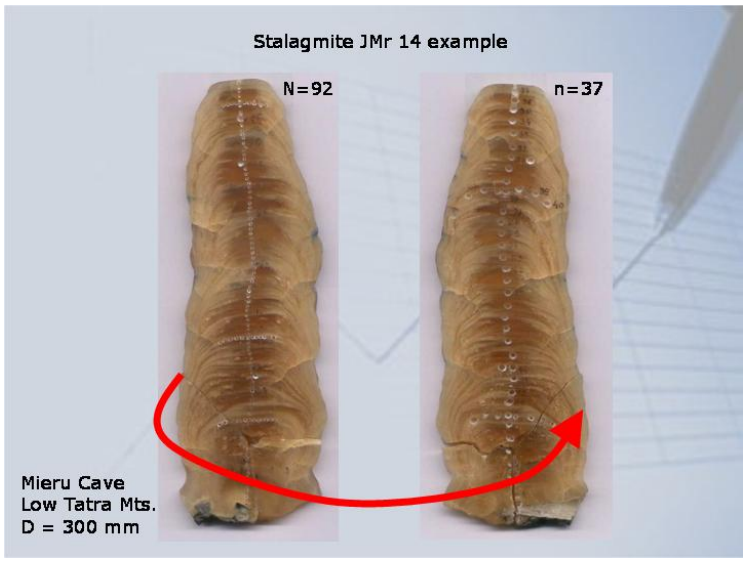

Fig 1: Sampling material.

RESULTS AND DISCUSSION

This data is good for testing of this method. Tests show that this method of correlation work property, and could be useful for correlation profiles with different sampling density.
Our two profiles have been well correlated. *(Fig.2)* Almost 80% of 37-points curve is in 65% confidence interval.
Why we use mc-simulations for answer to this problem?
-nonparametric.
-no specific assumptions.
-easy to transform algorithms for new applications.

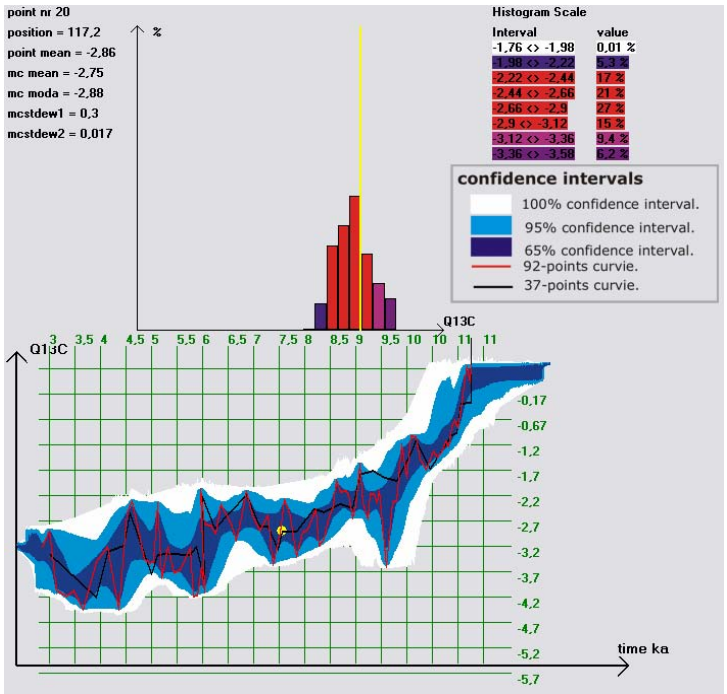

Fig.2: Results for carbon curves.

PALAEOMAGNETIC RESEARCH OF CAVE SEDIMENTS IN SLOVENIA IN 2007

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In 2007, sampling of cave fill for palaeomagnetic analysis was performed in several caves in the Classical Karst (SW Slovenia). Standard palaeomagnetic analyses were used (thermal and alternating field demagnetisation, magnetic susceptibility measurements, etc.). Paleomagnetic parameters (inclination, declination) indicate that the respective tectonic block has rotated since the deposition of karst sediments (Tabs. 1 to 3). The rotation differs in different time intervals of the infilling of cave passages and in different karst areas. Repeated sampling in some profiles, especially Divaška jama, Trhlovca, Markov Spodmol, confirmed that only high-resolution approach can ensure reliable results.

Divaška jama is situated near village of Divača, Classical Karst. It represents horizontal 700 m long cave with phreatic loops. About 2 m of laminated clays and silty and sandy clays are covered by flowstone layer and clays at about 370 m a.s.l. (about 2 m deep pit). Sampling was performed in 1997 (22 samples), 1998 (22 samples) and 2004 (60 samples). Sediments are characterized by a large scatter of the NRM intensities (0.7–301 $mA.m^{-1}$) and MS values (74–3,435 x 10^{-6} SI units).

Table 1: Mean palaeomagnetic directions, Divaška jama.

	Polarity	Mean palaeomagnetic Directions		A_{95} [°]	k	n
		D [°]	I [°]			
Divaška jama	N	354.36	58.15	5.57	24.26	26
	R	183.64	-46.78	4.7	15.3	58

Note – explanations for Tables 1 to 3: N – normal polarity, R- reverse polarity; D, I - declination and inclination of the remanent magnetization after dip correction; α_{95} - semi-vertical angle of the cone of confidence calculated according to Fischer (1953) at the 95% probability level; k - precision parameter; n - number of analyzed samples

The original analysis with relatively large distance between sampling points resulted in geometry of magnetozones which was interpreted as straddling the Brunhes/Matuyama boundary (0.78 Ma) and Jaramillo subzone (0.99–1.07 Ma; Bosák, Pruner & Zupan Hajna 1998). The magnetostratigraphy obtained from high-resolution analysis shows more complicated picture. The upper part of the profile is N polarized but with two R polarized magnetozones, the lower part of the section is R polarized. The new high-resolution results offer quite uncertain interpretation, with clear possibility of age greater than both 1.25 Ma (Th/U dates from speleothems within the profile) and 1.77 Ma (base of Olduvai subchron), i.e. identical to the Trhlovca Cave – a part of the same cave system – and some other sites situated in the Kras.

The fill of Divaška jama represents one of clear examples of temporary interruption of speleogenetic and cave-forming processes. After an infilling phase dated to more than 1.2 and/or 1.77 Ma, the cave was inactive for a long time. Deposition was renewed only after 540 ka, i.e. after a break lasting 0.7 to 1 Ma. This time-span is documented by erosion of old cave fill and by deposition of morphologically rich speleothems.

The palaeomagnetic research of clay/silt coatings of speleothems in distant part of the cave was performed too, but without any detailed results (only detected polarity of individual

samples). Calcite crust above clay coatings was dated to about 107 (+17/-15 ka) limits the time of deposition of laminites above speleothem horizon (top dated to 270-540 ka) to about 92-540 ka. The reason for the renewed filling of the cave by water is not clear, but it may be connected with a change of the hydrological system such as rise of the water table, blockage of outflow routes, etc.).

Trhlovca Cave is 142 m long and 22 deep, situated on the south-western side of the planated surface of Divaški kras. The main part of the cave is an approximately 15 m high, about 3 m wide and 60 m long meandering canyon following a N–S direction at 404–419 m a.s.l. We sampled sedimentary profile at 420 m a.s.l. and from overlying laminated flowstones several times (1997, 1998, 2004, 2005 and 2006), taking a total of 246 samples for paleomagnetic analyses. Sediments are characterized by a large scatter of the NRM intensities (0.02–302 $mA.m^{-1}$) and MS values (-15–3,710 x 10^{-6} SI units).

Table 2: Mean palaeomagnetic directions, Trhlovca.

	Polarity	Mean palaeomagnetic Directions		α_{95} [°]	k	n
Trhlovca		D [°]	I [°]			
	N	346.4	51.15	3.18	14.86	130
	R	148.87	-59.19	7.37	5.31	68

The laminated sediments from Trhlovca were expected to be younger than Jaramillo normal polarity event within the Matuyama reverse epoch. Preliminary results of palaeomagnetic research (Bosák, Pruner & Zupan Hajna 1998; Bosák et al. 2000b) suggested a substantially older age for sediments in the cave. The arrangement of the detected magnetozones was interpreted as Brunhes/Matuyama boundary (0.78 Ma) and Jaramillo subchron (0.99–1.07 Ma). The high-resolution re-sampling of the whole profile has changed this interpretation. The arrangement of R and N polarized magnetozones, starting with the flowstone crust and continuing through the sedimentary profile is clearly older than 1.77 Ma (base of the Olduvai subchron).

Markov spodmol Cave is 868 m long horizontal cave formed on the S edge of the blind valley on the southern rim of Pivka basin. The profile is situated about 150 m from the entrance is preserved in side passage or large niche of the main corridor. The section of fluvial sediments studied is about 4 m thick; the true depth is greater but the lower part is below the level of the permanent lake. Profile is composed of inter-bedding of clays and silts with some sand lenses at the base. Thick flowstone covers sediments. The site was sampled during several visits (2004, 2005, 2007), resulting in four palaeomagnetic profiles. Palaeomagnetic profile B overlaps the lower part of the profile A. The profile C is part of profile A (duplication 0.13-1.10 m) and the profile D is the duplication including deep-well of profile B (2.50-3.60 m). A total of 140 oriented laboratory samples were studied for their palaeomagnetic properties from profiles (A, B, C and D). Sediments from profiles A and C (0.075–2.865 m) are characterized by an NRM intensity from 0.5 to 167 $mA.m^{-1}$ and MS values from 79 to 1,070x10^{-6} SI units. Sediments from profiles B and D (2.5–3.6 m) are characterized by an NRM intensity from 0.3 to 7 $mA.m^{-1}$ and MS values from 63 to 247 x 10^{-6} SI units.

Table 3: Mean palaeomagnetic directions, Markov spodmol.

Markov spodmol A	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	352.26	41.38	5.17	13.12	56
	R	159.63	-53.72	30.12	4.32	5
Markov spodmol B	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	328.53	37.87	6.94	23.97	17
Markov spodmol C	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	1.61	52.81	4.14	52.01	22
	R	-	-	-	-	-
Markov spodmol D	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	332.95	38.69	11.2	8.23	19
	R	139.91	-68.13	20.37	15.75	3
	R?	344.74	-25.78	16.52	10.27	7

The profiles A and C showed N palaeomagnetic direction. There are also shorter excursions (R) or transient polarized zones (N–R) in the long N magnetozone. The profiles B and D showed only N palaeomagnetic direction.

The age of the fill can be interpreted as follows: the upper laminated clay was deposited within the normal Brunhes chron, the multi-colored clays and sands/gravels were deposited in Matuyama or Gauss chrons, and the lower laminated clay is older than the middle sequence. Traces of *in situ* weathering in the lower part of the profile indicate a quite prolonged hiatus in deposition. The creation of a weathered zone under subsurface conditions needs prolonged time and warm/humid external climate. The weathering supports a rather higher age of the profile.

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KARSTIC HYDROLOGICAL ECOSYSTEM OF CEMERNICA MOUNTAIN, WESTERN SERBIA

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Abstract
The territory of the Republic of Serbia is characterised by vast karst terrains (30% of its total territory). Sets of various ecosystems have been formed on such significant areas, representing almost untouched "pearls of nature". Abundance in water, hundreds of distinctive sorts of flora and fauna, fresh air and other climatic factors arouse growing interest in these terrains, not only from scientific point of view, but even more from economic, and tourist industry view, as well. Bearing in mind that more than 70 karst springs are used for the water supply of towns in Serbia the sustainable development of karst hydrological ecosystems is a high priority in further development. One of such karst terrains is Cemernica Mountain in Western Serbia.

The complete Cemernica mountain karst aquifer is dealt with in this paper. Hydrogeological investigations and the clarification of hydrological ecosystem, water flows across and through Cemernica mountain represent a fundamental element both in the further development of ecology and environmental protection on this mountain.

Keywords: hydrogeoecology, water balance, water quality, karst

THE APPLIED METHODOLOGY

The evaluation of quantitative and qualitative features of Cemernica Mouintain groundwater, the knowledge of geological and tectonic relations on the terrain, and the sustainability of the unique karst hydrogeological Cemernica mountain ecosystem have caused using a fully complex methodological approach to the system. Cause-effect relations among investigated parameters caused the application of various methodogolical procedures, often multidisciplinary ones.The general and schematized model of the applied exploration concept is shown in Table 1.

Table 1: The Applied Methodology of Hydrogeological Explorations along Cemernica Mountain.

HG Recon.	Isotopic	Capacity monitoring of wells & springs	Baseflow analises + same as in flow		Balance methods	Field sampling	MAC lists Chemical analyses	MAC standards Vulnerab. mapping
Geophysics	Chemistry							
Aerial ph.	Hydrology				Non-balance methods	Physical		
GIS	Climate					Chemical	Temperature	
Methods				**Cemernica karst aquifer**	methods			
Delineation	**Recharge**	**Flow**	**Discharge**		**Reserves**	**Quality**	**Use**	**Vulnerab.**
Parameters					parameters			
Horizontal	Rainfall	Transm-issivity	Natural discharge		Aq. volume	Bacteriolog.	Water supply	Illegal dumping
Vertical	Percolation				GW storage	Physical		
Depth of Karstificat.	Other aq. inflow	Effective porosity	Artficial discharge		Reserved	Chemical	GW bottling	Farming
					Av. yield	Isotopic	Wellness	Fertilisation
Volume	Surf. water interaction	Groundwat. direction	Baseflow calculation		Max. yield	GW origin	Recreation	Diary industry
Geometry					Min. yield	Gen. coeff.	Sport	

BASIC GEOLOGY AND TECTONICS

The Cemernica montain massif is made of limestone mass of Triassic age (karst aquifer) surrounded by Carboniferous, Permian and Jurassic deposits (hydrogeological barrier). From spatial pont of view, as the height grows, from periferial to central, heighest parts of the massif, the age of geological units goes from older to younger ones. Triassic rock masses-collectors occupy central parts of the massif and like a limestone "island" rise above water impermeable parts of the terrain. Rock formations of

Lower Cretaceous of Seis and Campil beds as aureoles close the limestones of Anisian and farther grade into the oldest geological formations on the terrain- of the Carboiferous and Permian ages. The Triassic island is made of massive limestones of a complex rupture composition with abrupt changes of the terrain inclination.Young tectonic movements occurring at the end of the Tertiary and in the Quarternary affected significantly the formimg of faults and joints. Neotectonic activity has been recorded through morphologic forms of recognized ruptures. The area of Cemernica mountain is intensively faulted, where two fault systems of hectameter and kilometer dimensions, with clear marks in the relief in the form of elongation of corries and dry valleys, dominate. The Tectonic setting, the systems of fault formations, their orientation, size and mutual intersections cause groundwater movement and their discharge.

AQUIFER DELINEATION

Northern part of the Cemernica area differs in height from southern part with highly pronounced hypsometric difference pointing out the block structure of the terrain. The depths of occurence of Triassic formations can be followed from west to east, the change of which is directed to the reducing of thickness of Anisian sediments, which corresponds to the direction of the terrain inclination. Central part of the massif is singled out by height as elongation hearth west-east, with differently oriented line distribution of plate and well shape corries. The total area of the karst aquifer amounts 21km^2.

RECHARGE, FLOW AND DISCHARGE

The aquifer recharges through precipitation, open hydrogeological structure and the high level of karstification of the terrain intensify the process additionally. The complexity of the geological setting and tectonic features hinder the delineation of the watershed for all four spring, while the disagreement.of topografic drainage divide with the hydrogeological one, makes the process of delineation of the recharge area for all four springs even more complex (Fig.1). Mutual relations of groundwater collectors and their communication and quantitative relations in case of karst system are caused by hydrogeological barriers, fault zones with an active function or without it. The mountain massif is drained in four main springs, of different yield, distributed in an arrow from south west to south east part of the terrain. The yield drops from west to east, as well as the thickness of Middle Triassic limestones. The uniqueness of Cemernica karst ecosystem water balance is caused additionally by mountain climate, relief, the area covered by forest and unequal degree of karstification of the terrain.

WATER QUALITY AND PROTECTION

The groundwaters of the Cemernica karst massif are of an exceptional quality. Similar chemical composition characterises all four springs with minor fluctuating in mineralization and pH value. The groundwaters are hydrocarbonate-calcium type (HCO_3-Ca), the mineralization of 225-290mg/l, and pH values 7.5-7.7, while temperatures fluctuate between 8 and 10^o C. The muddiness of water has the value lower than 5°Co-Pt scale during the whole hydrologic cycle on three springs except the one where in the period of high waters periodical muddiness occur. The openness of the hydrogeological structure increases vulnerability of groundwaters and opens the way to bacterial and other pollutions. The emphasis is on the protection of the natural regime of the Cemernica environment, with established zones of sanitary protection as safety measures for insurance from undesirable consequences of pollution and disturbance of natural balance.

GROUNDWATER USE

The possibility of utilization of the Cemernica karst system as to groundwater exploiting is varied. First of all, it can be seen in the possibility for the water supply of surrounding towns, groundwater bottling, for the needs of sports and wellness centres,etc..

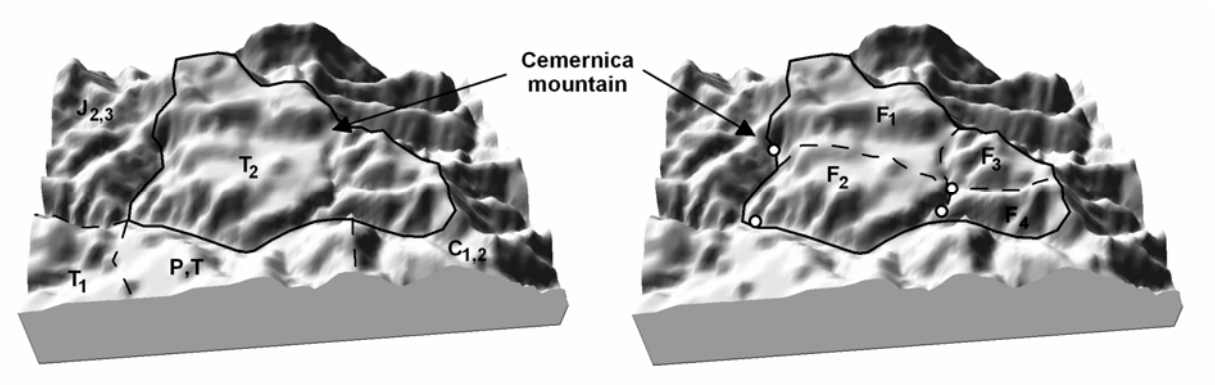

Fig.1: Investigated model of Cemernica Mountain, western Serbia.
Legend to left model: geological setting – $C_{1,2}$-Carboniferous graywacke; P,T-Perm-Triassic quartz conglomerate;T_1-Marl and shale;T_2-Massive limestone;$J_{2,3}$-Ophiolithes
Legend to right model – the surface catchment areas of the investigated springs: F_1-Curcica spring; F_2-Stitkovo spring; F_3-Bursac spring; F_1-Kusica spring

Table 2: Calculated water balance parameters of the Cemernica Mountain karst aquifer.

Area No.	Spring Name	Min/Max Yield	Average yield	Precipi-tation	Surface catchment	Evapo transpiration	Surface run-off	Effective infiltration
		$Q_{max.}/Q_{min.}$	$Q_{av.}$	P	F	E	Q	$i_{ef.}$
		m^3/s	m^3/s	mm/a	km^2	mm/a	%	mm/%P
F_1	Curcica spring	0.05-0.35	0.120	1009	12.3	342	36	300/30
F_2	Stitkovo spring	0.02-0.11	0.048	1009	5.2	342	37	293/29
F_3	Bursac spring	0.004-0.02	0.008	1009	2.3	342	56	101/10
F_4	Kusica spring	0.008-0.03	0.011	1009	1.5	342	43	232/23

CAVES OF MACIZÓ CHIMANTÁ AND RORAIMA TEPUY IN LA GRAN SABANA AREA (ESTADO BOLÍVAR, VENEZUELA)

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Abstract
The paper describes the speleological discoveries of several international expeditions to the table mountains in Gyana Highland, in the border area of Venezuela, Brasil and Guyana. Three table mountains (tepuis) were attended – Macizó Chimantá, Kukenán, Roraima and we discovered more than 30 caves in total length of more than 30 km. After the last expedition, "Tepuy 2007", which scientific tasks were geological, geochemical and biological field research, the longest one – Cueva Ojos de Cristal is 16 140 m long and it is the longest cave in silicious rocks in the world. Nowadays, the 4.8 km long cave Cueva Charles Brewer with the hall "Gran Galería Karren y Fanny" (400 000 m3) and the passages of average 30 × 60 m, is the largest cave in quartzites in the world.

Keywords: caves, Venezuela, Cueva Charles Brewer, Cueva Ojos de Cristal, Chimantá, Roraima, speleology, tepuis, quartzite karst.

INTRODUCTION

In february 2007, four experts for Venezuelan table-mountain caves, Charles Brewer-Carías, Branislav Šmída, Federico Mayoral and Marek Audy organized an expedition with duration of one month, to the underground of the Chimantá and Roraima massifs in Guyana Highlands of northern South America – southeastern Venezuela, State Bolívar (Fig. 1). The team of speleologists and scientists consisted of 16 persons from Venezuela (SVCN/Grupo Espeleológico de la Sociedad Venezolana de Ciencias Naturales, Caracas), from Slovakia (SSS/Slovak Speleological Society and Commenius University, Faculty of Natural Sciences, Bratislava), from the Czech Republic (ČSS/Czech Speleological Society), Croatia (KS HPS/SO PD Željezničar Zagreb) and also three journalists (TV, press). The longest and biggest quartzite caves of the world where again explored during the stay, discovered by us in 2002 and 2004 (Cueva Charles Brewer, nowadays its known length is 4.8 km and the Cueva Ojos de Cristal cave system with known length by now more than 16 km). Beside standard speleological exploration, topography, photodocumentation also focusing on complex evaluation of natural phenomenons, survey, measurement, sampling (rock material, biospeleothems, water, minerals, microbiological and biospeleological material) also new big cave sites where discovered.

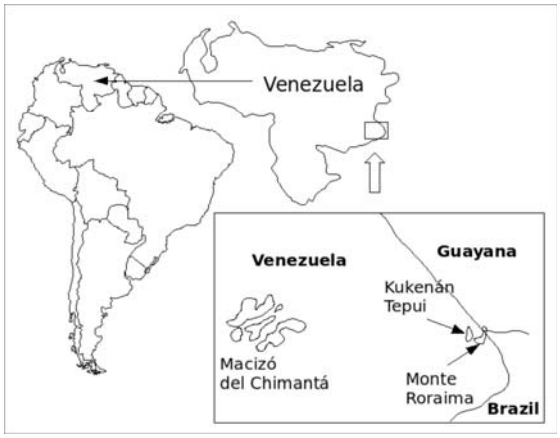

Fig. 1: Location of the studied table mountains

EXPEDITION "TEPUY 2007" – EXPLORATION AND RESEARCH

On the one of the 10 partial mesetas (tepuis) of the Chimantá massif with areal extent of 1470 km^2 the Czech subgroup discovered new cave Sistema de la Araña in length 2.5 km and the central Slovak-Venezuelan-Croatian team accomplished mapping of the cave Cueva Cañon Verde in length 1.2 km, discovered and partially explored by Slovak-Venezuelan team in the year 2005. Both of the cave sites, which have several cave entrances located in megadepressions (e.g. the Cueva Cañon Verde have a southern entrance located in depression with extent of 80 × 150 m and approx. 60 m of depth) consist of extensive fossil corridors (to the 50 m of width and 20 m of height), as well as a little bit lower situated canyon-like galleries with heights 10 to 15 m and widths 10 to 30 m, with rivers in their bottoms. In the first above mentioned cave is well developed including also the lowest situated, juvenile and probably periodically flooded zone of corridors with hundreds of sandstone pillars (Fig. 2), in the second one is situated a big dome with dimensions 50 × 100 m and also numerous dangerous collapses (chokes) and labyrinths. In both caves numerous clusters of young ("alive") and older, already opalized "Champignones" (special speleothems, built up by cyanobacterias, first time recognized by us in the Cueva Charles Brewer cave; Šmída et al. 2004) as well as other unique speleothem forms, e.g. the "muñeco" type, in enormous clusters built up on the bottom by thousands of individual pieces, or curtain-like gypsum speleothems so-called "crepe paper" type. New attitude to genesis of those speleothems, base on our geological, geomorphological, hydrogeochemical and speleological observations, brings the papers Aubrecht et al. (2007; 2008)


Fig. 2: The sandstone pillars – the key to genesis of the caves in karst on table mountains – Cueva de la Araña, Macizó Chimantá. Photo: M. Audy – R. Tásler & R. Bouda

The next of the new discovered caves, the Cueva Juliana (Fig. 3) at length 1 km having smaller height, maximum to 5 m and 10 – 20 m wide corridor, is a young karst spring, active during flooding events, with numerous lakes. This site is situated approx. 70 m below the active river in the Cueva Charles Brewer, aside from attractive, 30 m high waterfall. This cave was not explored to the end, because lack of time – is continued further. The next two caves (Cueva Croatia and Cueva de Bautizo de Fuego) are forming cascade-abyssal systems, with length 200 m and 400 m and depth -50 m. They are younger caves, very similar to caves recognized on the plateau of the Auyantepuy. The first one of them was explored by the Croatian team, the next one, with more extensive horizontal gallery near the bottom and smaller river was discovered by the Slovak-Venezuelan team.

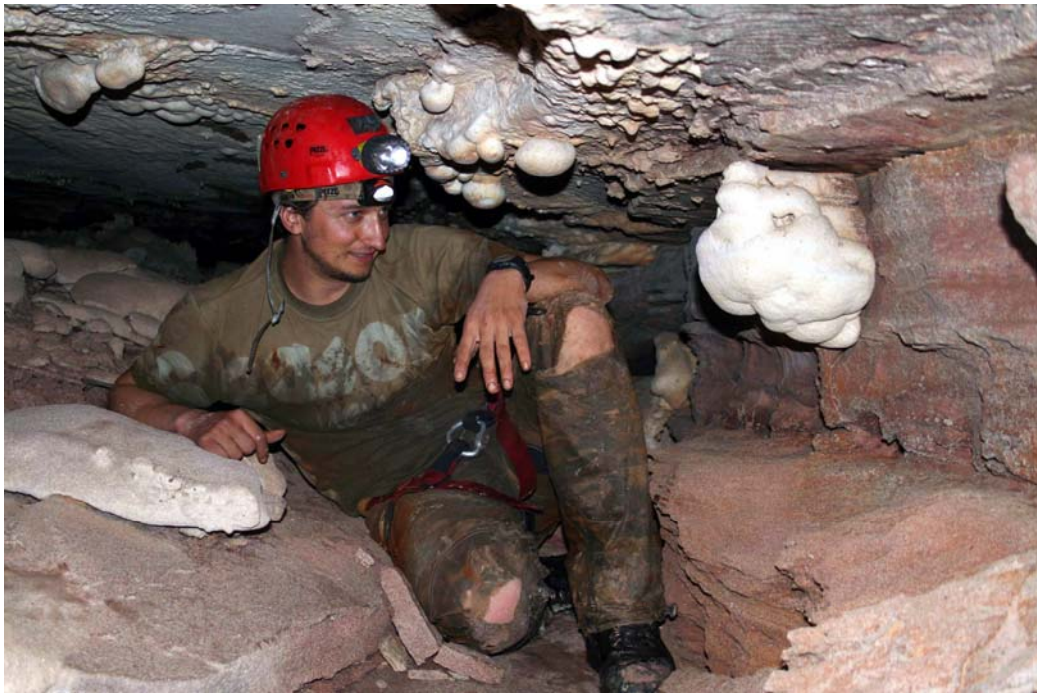

Fig. 3: Biospeleothems of "champignones" type in Cueva Juliana, Macizó Chimantá. Photo: L. Vlček

The Cueva Zuna is formed by 300 m long, relatively straight, 30 m wide fossil gallery. Slovak-Croatian team took together also an extensive half-open -100 m deep abyss (dimensions of the entrance are 80 x 100 m). However it leads through its bottom, among collapses and jungle only to the 150 m long cave fragment named Tetris. Within other newly mapped and known sites the remarkably one is the almost 150 wide cave portal, temporarily named as "Cueva el Diente", localized only from the air, during helicopter flight. The continuation behind the portal is collapsed (approx. 100 m of smaller cracked areas), on the opposite direction is eroded to the amazing, luminous, approximately 50 m wide bridge (Puente de Diana).

Now the third longest cave of the Chimantá massif remains the Cueva del Diablo (2.3 km long and -80 m deep), with corridor width in some places up to 50 m and two more than 80 m wide domes, discovered and explored in 2005. The deepest known and explored site remains the Sima Noroeste (-130 m), with crack collapse by dimensions of 60 × 400 m. It is remarkable that this site is continuation down at least next 30 m and we assume that it is connection to the big horizontal cave.

During expedition repeatedly tried to break through the end collapses of the monstrous cave of Cueva Charles Brewer, against the river current (the length of the cave lengthened up to 4782 m, the vertical distance remain +110 m), but without remarkable progress. This cave with commonly 50 – 80 m wide corridors (Fig. 4) and the monumental hall of "Gran Galería Karen y Fanny" by volume approximately 400000 m^3 remains further the biggest quartzite cave in the world. Cueva Charles Brewer was localized first time in 2002 and explored in 2004 under the leadership of Charles Brewer-Carías and friends (e. g. Šmída et al. 2005a; b; c; d; e).

Fig. 4: The waterfall Cascada Vanessa in Cueva Charles Brewer – the picture shows the common size of corridors in this cave. Photo: M. Audy.

During the "Tepuy 2007" expedition more than 5 km of cave spaces was documented on the Chimantá, further exploration perspectives are more then promising. Remarkably, that since the year 2004 during several stays we explored almost 15 km of caves on this plateau (Fig. 5).
During our last stay a numerous geological documentation was done, as well as rock samples for thin sections (investigations in microscope) and geochemical analyses were taken, from different positions and layers in quartzites in the walls of the Cueva Charles Brewer itself as well as from the surface. Moreover water samples were taken from the underground river from this and other caves, also from creeks and swamps on the plateau and field measurement were performed: pH, conductivity, water and air temperature, discharge. The same day spectrophotometrical analyses of the water samples were performed, the following items were measured: Fe, SiO_4^{4-}, PO_4^{3-}, Al, NO_3^-, Cl^- and total acid capacity, analyses of stable isotopes of H and O will be done later using the taken samples (Lánczos et al. 2007).
The expert for herpetofauna of tepuis, C. Barrio, catched and identified small endemic frogs (Ecaudata), lizards (Sauria) and snakes (Serpentes). Ethological observation and extensive cave fauna collecting were performed by all members of the team: e.g. flatworms (Turbellaria), miniature snails (Gastropoda), numerous species of spiders and harvestmans (Araneida, Opilionidea), millipedes (Diplopoda) and centipedes (Chilopoda), colossal cave cicadas from the Hydrolutos sp. family, two species of scorpions, within insects e.g. troglobiontic ground beetle-like beetles or white flies. Finally, expert for speleothemes, geologist R. Aubrecht further explored in details and sampled different types of speleothems, organic red mud (so-called barro rojo), various opal-sinters, microbiocoatings and biomaterials (also alive materials in agar), as well as cyanobacteria from the surface of the plateau and creeks (in identification of these we will continue) and together from Ch. Brewer-Carías continued in elaboration of typological system of the spelethems occuring locally. Samples taken in caves and and the surface which were transported to Europe will be further investigated in laboratories by the participants of the expedition "Tepuy 2007", scientists of the Faculty of Natural Sciences, Comenius

University in Bratislava, as well as other invited experts in natural sciences, apparently with international participations. The well-known Slovak film-maker P. Barabáš prepared an adventorous-documentary movie dedicated to discoveries and exploration in the caves of the Chimantá mountain titled as „Tepuy“ (K2 Studio, Bratislava). This movie is presented on several world festivals dedicated to mountain themes.

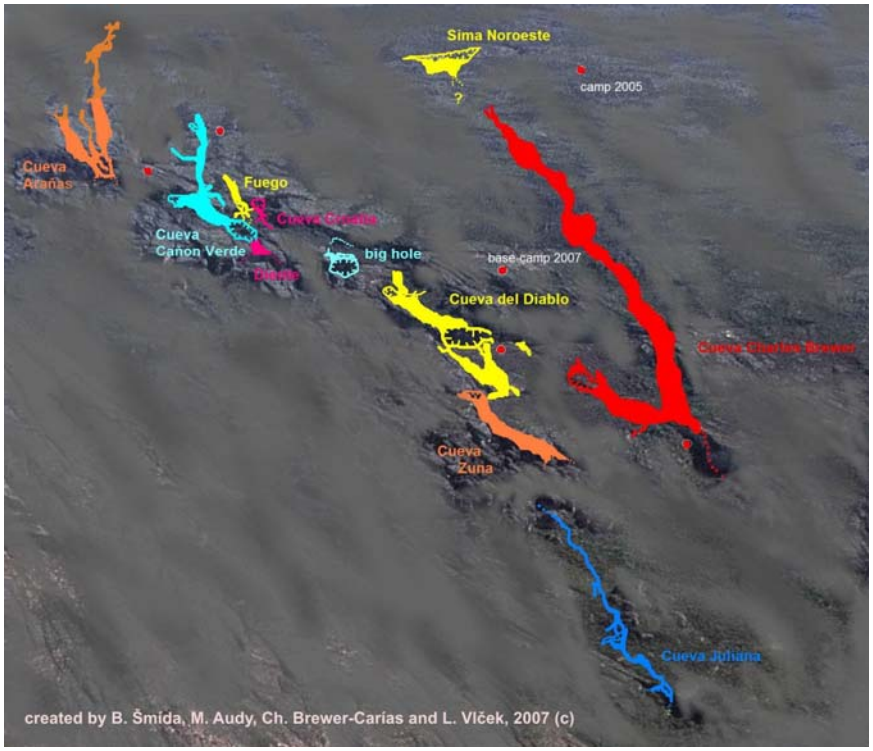

Fig. 5: Schematic location of the new-discovered caves on Chimantá table mountain. Created by B. Šmída, M. Audy, Ch. Brewer-Carías & L. Vlček

The second part of the exploration programme of the expedition was again dedicated to the Roraima Mountain, where the Slovak-Czech couple M. Audy and Z. Ágh discovered in the 2002 year up-today the longest cave system of the world developed in sandstones, names as Cueva Ojos de Cristal (Kryštálové oči in Slovak, Crystal Eyes Cave in English). This action, 5th in row expedition (with Slovak, Croatian and Venezuelan participants) in the second half of February 2007 elongated this cave to 16 140 m, by connecting with two other caves – Cueva de Gilberto and Cueva Fragmento Marginal. The labyrinth-like cave system of originally independently discovered and explored, today connected parts consist of lower (max. 5 to 8 m of height, in average only 2 m), in some places only 30 – 40 cm up to 15 – 20 m wide corridors, which are densely interconnected to each other. Today are known several entrances to the cave, they are standard cave entrances, some of them located in closed hole basins, in vertical walls of the mountain and also as 20 – 30 deep abysses, genetically named by us as “pokemon” (e. g. Šmída et al., 2003). The biggest room of the cave is the “Hall of Mother SSS”, with dimensions of 40 × 50 m. The essential progress was reached here during our expedition Kukenán/Roraima 2006, when a team of Slovak speleologists by 6 members under leadership of B. Šmída discovered and mapped more than 4 km of new corridors. This year we explored more in details also a 100 m long cave Cueva Lago Gladys (Fig. 6), discovered in the past by Ch. Brewer-Carías. The Cueva Ojos de Cristal with its length more than 16 km became the second longest cave in Venezuela (the longest one is the Cueva del Samán, developed in limestone).
Similar geological and biological research (including sampling) as on the Chimantá we performed on the Roraima (moreover we probably discovered new mineral species), thus we can compare two of the table mountains, also the biggest quartzite caves of the world discovered by us based on scientific data. This fact will push the knowledge forward about the origin, age and development of them, in their amazing variety. P. Barabáš is preparing a next movie about discovering and exploring of caves on the Roraima, titled „Matawí“.

Fig. 6: Entrance to Cueva Lago Gladys in Guyana part of Roraima Mountain. Photo: B. Šmída

SUMMARY OF RESULTS

During 7 expeditions performed by us since 2002 to 2007 each year or half year to the table mountains Chimantá, Roraima and Kukenán we discovered more than 30 km of quartzite caves. 16140 m long Cueva Ojos de Cristal cave on Roraima Mountain represents the longest cave in silicic rocks and simultaneously the second longest cave in Venezuela. Cueva Charles Brewer cave on Macizó Chimantá Massif is the most spacious cave in quartzite karst and one of largest caves in the world. One of the main goals is that the new genetic types of opal biospeleothems were discovered, sampled and studied.

REFERENCES

Šmída, B. – Audy, M., Vlček, L., 2003: Expedícia Roraima, Venezuela, január 2003 – Cueva Ojos de Cristal (Kryštálové oči).- Spravodaj SSS, 34, 2, 1–192, Liptovský Mikuláš.

Šmída, B. – Audy, M. & Brewer-Carías, Ch., 2004: Cueva Charles Brewer – najväčšia kvarcitová jaskyňa sveta. Speleoexpedície do masívu Chimantá 2004, Venezuela.- Spravodaj Slovenskej speleologickej spoločnosti, 36, 3 (Supplementum), 1–178, Liptovský Mikuláš.

Šmída, B. – Audy, M. & Mayoral, F., 2005a: Cueva Charles Brewer – la plus importante grotte du monde creusée dans les quartzites (massif du Chimantá, Venezuela).- Spelunca, 97, 27–35, Paris.

Šmída, B. – Audy, M. & Mayoral, F., 2005b: Cueva Charles Brewer: Larger quartzite cave in the world.- NSS News, 63, 1, 13–14, Huntsville.

Šmída, B. – Audy, M. & Mayoral, F., 2005c: Into the Lost World. Descent, 183, 36–38, Abergavenny.

Šmída, B. – Audy, M. & Mayoral, F., 2005d: Cueva Charles Brewer.- Regards, 58, 9–12, Grivengee.

Šmída, B. – Audy, M. & Mayoral, F., 2005e: Cueva Charles Brewer.- The largest quartzite cave in the world (Chimanta massif, Venezuela). Journal of the SSS, 49, 1, Sydney Speleological Society, 3–12, Sydney

Lánczos, T., – Aubrecht R., – Schlögl, J., – Šmída, B., & Brewer-Carías, Ch., 2007: Preliminary results of the Tepuy 2007 expedition to the venezuelan table mountains – water geochemistry and its relation to genesis of the quartzite karst. In.: Fľaková, R. & Ženišová, Z. (eds.): Proceedings of the Hydrogeochémia 2007 conference, Slovak Assocation of Hydrogeologists, Bratislava, 136-141, Bratislava.

SPELEOTHEMS AND THEIR HISTORICAL SACRED VALUES: TWO EXAMPLES FROM THE STATE OF MINAS GERAIS, BRAZIL

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Abstract

Compared with international karst studies, those in Brazil can be considered relatively new. Since the first studies of Peter W. Lund in 1833, Brazilian karstology developed slowly for at least 175 years. The majority of scientific papers concerning national karst areas were produced by the end of the 50's to the 90's, and continue today. Greater emphasis should be given to the pioneering work of Kohler (1989) on the Karst Geomorphology of Lagoa Santa, Minas Gerais, the first of PhD thesis on the subject in Brazil. More recently caves are studied with respect to their use as temples as religious and ritual sites. In Brazil, by the end of the 17th century (1691), the pilgrim Francisco de Mendonça Mar inhabited a cave on the banks of the São Francisco River, giving rise to the Sancturay of Bom Jesus da Lapa, the oldest registered example of religious use of a cave in Brazil. In other regions, as early as the 18th century, supposedly appearances of Our Lady occurred in the cities of Antonio Pereira and Vazante, State of Minas Gerais. In these two caves both water as well as some speleothems, are considered to be sacred. When a cave is made sacred, the fundamental opposition between good and evil, sacred and profane is established even though not all caves had experienced miraculous appearances. Some of them are just considered to be a divine work, and consequently worshiped. Even though the religious use of caves causes numerous negative environmental impacts, their cultural importance is enormous. This makes cave conservation a very difficult situation. The simple prohibition of cults is not acceptable because religious beliefs usually have positive impacts on regional economies and the pilgrims' quality of life. It's believed that what is should be done is to work towards maintaining such heritage sites that exist while discouraging the use of other caves for this purpose.

Key words: speleothems, sacred values, Our Lady of Lapa, religious tourism.

INTRODUCTION

Compared with international karst studies, those in Brazil can be considered relatively new. Since the first studies of Peter W. Lund in 1833, Brazilian karstology developed slowly for at least 175 years. The majority of scientific papers concerning national karst areas were produced by the end of the 50's to the 90's, and continue today. Greater emphasis should be given to the pioneering work of Kohler (1989) on the Karst Geomorphology of Lagoa Santa, Minas Gerais, the first of PhD thesis on the subject in Brazil. More recently caves are studied with respect to their use as temples as religious and ritual sites.

Worldwide, the duality of perceptions about the karst is visible, especially when shafts are portrayed as "portals of hell" or living places that shelter strange creatures. Sacred caves, however, have considerable historic interest. Buddhist and Hindu cave-temples are very common especially in Southeast Asia and India. Christian cave-churches, analogous to the ancient catacombs, are scattered around the world, varying very little in relation to the legends and stories associated with them.

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When a cave is made sacred, the fundamental opposition between good and evil, sacred and profane is established even though not all caves had experienced miraculous appearances. Some of them are just considered to be a divine work, and consequently worshiped.

MATERIAL AND METHODS

This work, carried out in 2007, compares two popular festivals dedicated to Our Lady of the Cave (*Nossa Senhora da Lapa*), in the State of Minas Gerais, Brazil. Although the events have a religious theme, the main focus of the research is the social importance of the caves to countryside communities and their importance to the religious tourism on a regional and a national scale.

The methodology was adapted from the work of Steil (1996, 2000) and Cervantes (2007), using documentary sources about the rise of these religious cults, as well the information provided by the pilgrims and clerical elements though interviews.

OUR LADY OF LAPA

It is believed that the cult of Our Lady of Lapa (*Lapa = cave*; *grotto; jama*) began in the Lapa Mountain Range (*Serra da Lapa*), central-northern region of Portugal. This region has an important historical value as a starting point of the cult that had spread throughout the world since the 15th century.

According to the tradition, in 1498 a mute twelve year old shepherd called Joana, was bringing back her cattle when she entered a rock shelter and saw an image of Our Lady. After finding the image, she cleaned it and made a small altar adorned with wild flowers. From that moment she started to go to the improvised shrine every day. Her mother, after discovering this obligated her to stop with the rituals.

One day, after taking the image with her, her mother threw the image on the fire. At this moment the child, who was mute, spoke: “Mother, what have you done! It is Our Lady of Lapa!”. Immediately the child took away the image from the fire without being burned. Because of her actions the mother’s arm was paralysed. After this moment they started to pray for *Our Lady of Lapa* and the mother’s arm was healed.

Soon the story of this miracle spread and from that moment on, pilgrims started to worship Our Lady of Lapa. Knowing about the miracle, a priest from the region of Quintela suggested that the image should be taken to the local church. However, the image had disappeared, appearing again in the cave where it was first discovered. When they tried to put the image again in the church the phenomenon took place again, and was considered to be a sign from the Our Lady of Lapa, that she wanted to be worshiped in the cave.

Some historians recount that the story image of Our Lady found in the cave originated in the year 982. At the time a Moorish army invaded the village of Trancoso and Lamego destroying the Sismeiro convent, and torturing many nuns. Some of them escaped and managed to take the image of Our Lady with them. During the journey they saw the Lapa Mountain Range (*Serra da Lapa*) and were able to hide the image in one of the rock shelters.

OUR LADY OF LAPA IN MINAS GERAIS, BRAZIL

In Antonio Pereira, located about 70 km from Belo Horizonte (State capital city), the cave-church (about 230 meters long) is developed in dolomite of the Paleoproterozoic Gandarela Formation (2,4 Ga). The history of the cave is linked to two apparently historical events:

The first event took place in 1722, supposedly when some children were looking for firewood in the forest when they saw a rabbit entering a cave (*lapa*). While going after the animal, they saw Our Lady surrounded by a bright light and then found an image of Her. The image was taken to the main Church of the village, but it returned by itself to the cave when an altar was constructed in its honor. This account is very similar to events that took place in Portugal, in the 15th century.

The second event which took place in 1767, tells about a young boy who was also attracted to the cave by a rabbit, also seeing the Our Lady seated on a rock. After leaving the cave to tell others

and to witness the phenomenon, he found an image of Our Lady when he returned. The image was taken to the main Church by orders from the local priest, but with the destruction of the main Church by a fire of unknown origins in 1830, the image was taken back to the cave. After this, the number of pilgrims to the cave increased. Since then, in August, about ten to fifteen thousand people visit the cave in honor of Our Lady of Lapa, where they held processions, masses and baptisms.

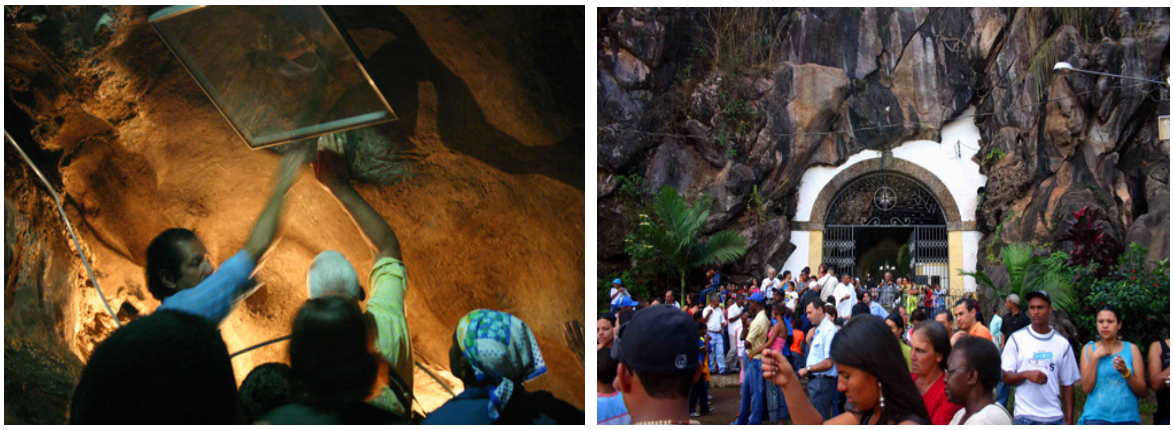

Fig. 1 – On the left, the entrance of the Sanctuary. On the right, a speleothem is perceived as an image of Our Lady of Conceição of Lapa (*Nossa Senhora da Conceição da Lapa*) (Photos: Travassos, 2007)

Fig. 2 – On the left, the altar dedicated to Our Lady of the Cave (*Nossa Senhora da Conceição da Lapa*). On the right, pilgrims laying down candles in honor to Our Lady (Photos: Travassos, 2007).

A similar event also took place in another city, about 350km away from the capital city of Minas Gerais. In Vazante, the two versions of the legend are also associated with the appearance of the Our Lady of Lapa:

The first version report that the city was founded because of the vision of the Saint in a local cave. The Cave of Pamplona was already known by plantation workers from the village that used to go inside to find fresh water. To facilitate their work, two brothers built a ranch near the cave so that they could have food and also get some rest, not wasting time while waiting for the next shift. One day, the cook, looking inside the cave saw a woman dressed in a long white dress. Because of this vision she ran out to tell the workers about it. After returning, nothing was found except a stalagmite, supposedly in the shape of Our Lady.

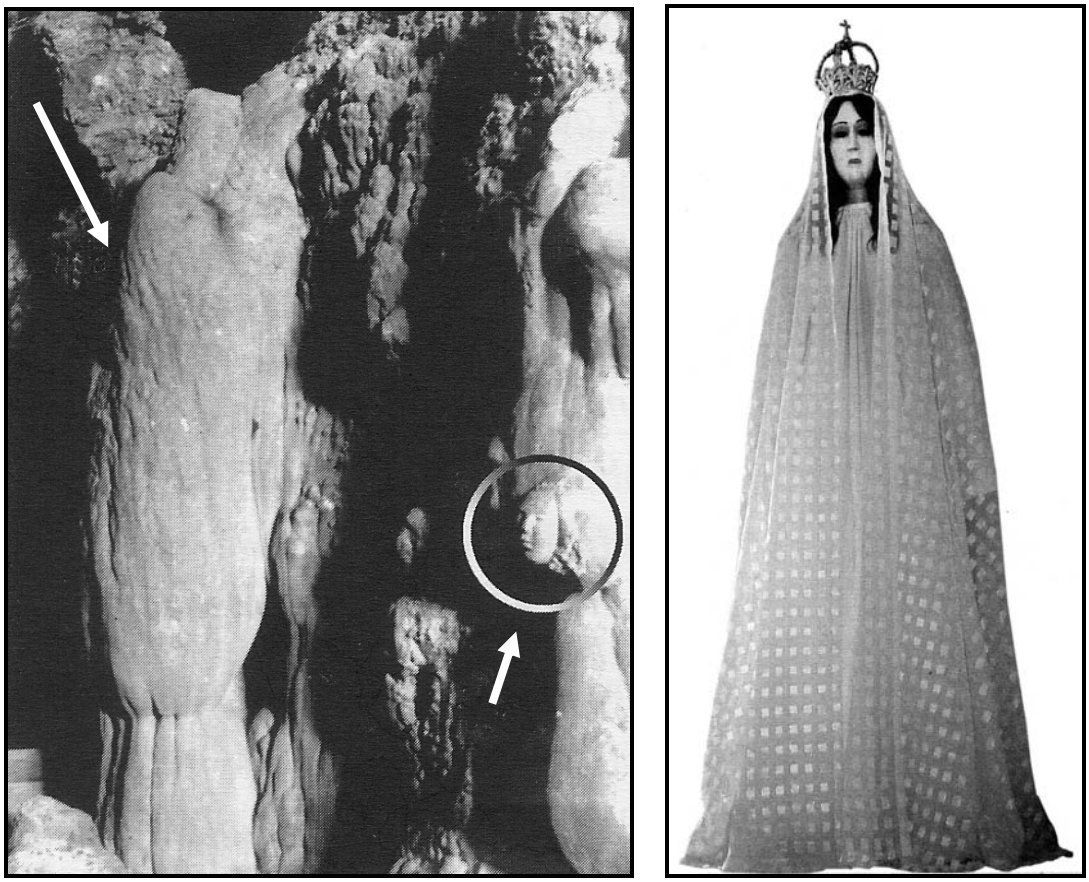

Fig. 3 – On the left, the stalagmite perceived as the image of Our Lady of Lapa. On the side of the stalagmite it's possible to notice a face of an angel artificially made in another stalagmite. Pilgrims assume that the sacred power of Our Lady made it. On the right, the image of Our Lady of the Cave. (Photo: Mello, 2003, 71;75)

The second version is similar to the first, mainly regarding the surname of the character. Due to the Paraguayan War, also known as the War of the Triple Alliance (1865 to 1870), many Brazilians feared being sent to the front. So they used to move to remote and deserted areas. The city of Vazante fitted these categories and was chosen by Manoel Ribeiro Paixao, escaping from the compulsory enlistment. He chose a cave to serve as shelter and hideout. One day, at the shelter's entrance, he spotted a tall woman dressed in white inside the cave. He went out to the city to tell everyone about it. During wartime the daily difficulties and afflictions were the impetus for the first of the processions to the "holly cave". Since then, countless numbers of pilgrims have visited the cave, especially in May. This year was the 127th Feast of Our Lady of Lapa.

DISCUSSION AND CONCLUSIONS

The landscape is not only a simple location. People convey different meanings to it depending on the social matters such as religion. Religion is one of the most important cultural elements of a Country (Norton, 2002). Religion and spirituality are still among the most common motivations for travel. Many major touristic destinations have developed largely as a result of their connections to sacred places and events. Every year millions of people travel to pilgrimage sites around the world, both ancient and modern in origin (Dallen & Olsin, 2006). Vukonić (1996) also affirms that pilgrimage has been defined as a physical journey in search of truth and of what is sacred or holly. It is also believed that religious tourism can act as an educational experience.

So if religious tourism is well directed, pilgrims or tourists may be able to learn something beyond the rituals. From the 16th to the 19th centuries, Brazil was a colony of Portugal. For this reason, the word *Lapa* to designate a cave or a rock shelter was brought with the colonizers. Although the Country was composed of a mixture of indigenous groups, Portuguese colonialists and African slaves, Catholicism was very strong among the population and so were the Iberian traditions.

Comparing the images and the names given to each example in Minas Gerais, the strong influence of Portugal can be seen in the appearances of Our Lady of Lapa in Antônio Pereira. The city is a district of Ouro Preto, an important village in the 18th century due to the discovery of gold and precious stones. The patroness of Portugal was the Our Lady of Conceição. It is believed that Our Lady who appeared in the first example described received the name from Our Lady of *Conceição* of Lapa, pointing out the strong bond between the traditions from the colonizers and colonists in this region. In Vazante, far from the strong and direct Portuguese influence, the image appears to be unique in its appearance.

Interviews with pilgrims and tourists revealed their lack of knowledge in relation to cave genesis and the connection with Portuguese traditions. For the majority, cave formation is imputed to supernatural powers and their belief is stronger than any environmental education tool. Some religious fundamentalists are also opposed to be exposed to certain ideas.

When performing a pilgrimage, participating in a collective act of celebration, an individual can exteriorize your faith through the worship of the myth in which he deposited their religious desires and life experiences. In this sense, Steil (1996) affirms that beyond the sacred, real historical characters coexist with the imagination. For this reason clerical members and spiritual leaders do not want to break with the folk traditions and myths associated with the sacred places. Instead of breaking with it, they reinterpret and incorporate them into Catholic orthodoxy.

The use of caves is tied to the people's beliefs. The folk faith goes beyond the domain of specialists from outside. It links the pilgrims with the sacred according with their customs.

Folk culture today survives mainly in rural areas, often among groups linked by a distinctive cultural background. It tends to resist change and remain attached to long-standing attitudes and behaviors being more traditional and less subject to change (Norton, 2007). Both Feasts briefly described in this paper have resisted change for more than 200 years.

Even though the religious use of caves causes numerous negative environmental impacts, their cultural importance is enormous. This makes cave conservation a very difficult situation. The simple prohibition of cults is not acceptable because religious beliefs usually have positive impacts on regional economies and the pilgrims' quality of life. It's believed that what is should be done is to work towards maintaining such heritage sites that exist while discouraging the use of other caves for this purpose.

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REFERENCES

Amorim, J., 2006. *Nossa Senhora da Lapa: Síntese histórica de uma devoção multissecular*. -Santuário da Lapa, 19p.,Viseu, Portugal.

Dallen, J.T. & Olsin, D.H., 2006: *Tourism, Religion and Spiritual Journeys*.- Routledge, *285 p.,* New York/London.

Evia Cervantes, C.A., 2007: El Mito de la Serpiente Tsukán.- Universidad Autônoma de Yukatán, Mérida/México.

Forte, J.; Madeiros, S.; Medeiros, G.; Ferreira, C.; Lemos, R.; Mendes, H.; Neves, C.; Alves,P.; Guedes, E. Barcelos., 2008: Caves, worship and religion: some portuguese case studies. (Unpublished).

Kohler, H.C., 1989: *Geomorfologia cárstica na Região de Lagoa Santa-MG.* Doctorate Dissertation.113p., University of São Paulo, Brazil.

Mello, O., 2003: *Vazante, meu bem quere*. Prefeitura Municipal/Votorantim Metais, 287p., Vazante, Brazil.

Norton, W., 2007: *Human Geography*.- Oxford University Press, 552p., New York.

Steil, C.A., 2003: Romeiros e turistas no santuário de Bom Jesus da Lapa.- Horizontes Antropológicos, 9/20, 249-261, Porto Alegre, Brazil.

Steil, C.A.,1996: *O Sertão das Romarias: um estudo antropológico sobre o Santuário de Bom Jesus da Lapa-Bahia.*- Vozes, 309p., Petrópolis.

Vukonić, B., 1996: *Tourism and religion*.- Pergamon, 200p., Oxford.

MICROBIAL ORIGIN OF OPAL SPELEOTHEMS IN VENEZUELAN QUARTZITE CAVES (RORAIMA GROUP, GUYANA HIGHLANDS)

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Abstract
The largest and longest silicate caves in the world created in arenites of the Roraima Group in Venezuela have been explored on Chimantá and Roraima plateaus (tepuis) of Guyana Highlands. Geological and geomorphological research showed that most feasible way of the caves genesis is winnowing and erosion of unlithified or poorly lithified arenites. Dissolution is also present but it probably plays neither the trigger role, nor volumetrically important role in the cave-forming processes. The strongest dissolution/reprecipitation agent is the condensed air moisture which is most likely the main agent contributing to growth of siliceous speleothems. As such, it can be active only after, not before the cave is created. Siliceous speleothems are mostly microbialites except of some normal stalactites, cobweb stalactites and flowstones which are formed inorganically. They consist of two main types: 1. fine-laminated columnar stromatolite formed by silicified filamentous microbes (either heterotrophic filamentous bacteria or cyanobacteria) and 2. a porous peloidal stromatolite formed by *Nostoc*-type cyanobacteria. The initial stages of encrusted shrubs and mats of microbes were observed, too, but the surrounding arenitic substrate was intact. This is a strong evidence for the microbial mediation of the silica precipitation.

Keywords: speleology, tepuis, Venzuela, sandstone caves, siliceous speleothems, microbialites, cyanobacteria, stromatolites. Cueva Charles Brewer. Cueva Ojos de Cristal.

INTRODUCTION

In the last time, several Works emerged which apply the term karst to silicate caves that occur either in granites (Willems et al., 2002) or, more frequently, in sandstones (see the reviews in Wray, 1999, 2003). According to these authors dissolution, although slow, is the main process that forms the caves. For sandstone rock, the term “arenization” was introduced by Martini (1979). This term involves both – the dissolution of the cements in the arenitic rocks, with subsequent erosion and winnowing of the loose sand material. If the “arenization” theory was true, most of the sandstone caves could really be attributed to karst as the dissolution is considered there to be trigger process of the cave formation. The main proof of that the dissolution is important in silicate caves are silica speleothems which occur in most of the silicate caves. They are mostly composed of opal-A, which slowly turns to opal-CT and then to microquartz. The question remains, whether the silica dissolution is so important that the silicate caves can be really ranked among the karstic ones. This paper brings one of the first results of several speleological and scientific expeditions to Venezuelan Gran Sabana, Guyana Highlands (Fig. 1), where largest caves evolved in the sandstone plateaus called tepuis. Tepuis are the key area where sandstone “karstic” phenomena can be studied and where the term “arenization” is widely used (e.g. Urbani, 1986). In our last papers (Aubrecht et al. 2007; 2008) we bring different views on the genesis of sandstone caves and of siliceous speleothems

which occur in most of them, base on our geological, geomorphological, hydrogeochemical and speleological observations.

Fig. 1: Location of the studied table mountains

MATERIAL AND METHODS

The geological and speleological observations were focused on the differential weathering of various sorts of arenites of the Matauí Formation, Roraima Group on the Macizó Chimantá and Roraima tepui surfaces and in the caves – particularly in Cueva Charles Brewer and Cueva Ojos de Cristal (Fig. 1). Four sites with different lithification and erosion phenomena in arenites were sampled in detail for petrographic analysis (thin-sections and SEM) the results of which will be published later. Equally important was sampling of siliceous speleothems. A limited number of samples was collected for study to prevent excessive damage to the speleothem decoration of the cave. They were studied in petrographic thin-sections. Fresh speleothem surfaces in growth position, as well as surfaces of broken speleothems (some etched by hydrofluoric acid), were coated by thin gold films and observed under SEM. The samples were gold coated and then observed in JEOL JXA 840 A scanning electron microscope, with an accelerating voltage of 5 kV. Mineralogical composition of the speleothems was determined optically and by X-ray diffraction analysis (XRD). Analyses were performed with a DRON-3 analyser, using CoKα of the wavelength λ: 1.79021Å, filter Fe, voltage 30 kV, intensity 15 mA, diaphragms 1;1;0.1, or CuKα of the wavelength 1.54178 Å, filter Ni, voltage 40 kV, intensity 20 mA, diaphragms 1;1;0.5.
Speleothem surfaces were also sampled for microbiological analyses. Part of the samples was fixed in agar for further cultivation (about 20 samples – results not included yet); about 40 samples were fixed in formaldehyde (for microscopic observations only).

GENESIS OF THE SILICEOUS SPELEOTHEMS

Caves formed in silicate rocks are characterized by siliceous speleothems, in which the dominant mineral is opal. Unlike in carbonate speleothems, microbial mediaition is much more common in precipitation of siliceous speleothems. Siliceous speleothems commonly represent small forms, rarely exceeding 2 cm in size. In all the examined caves, peculiar forms of speleothems were found (see also Aubrecht et al., 2008). They have various shapes

and forms and they most of them bear signs of microbial origin (Fig. 2). Many of the speleothems remind classical stalactites and stalagmites known from limestone caves but their structure and genesis are different. Apart from variable shapes, the microbial speleothems show identical principal texture, corresponding to various stages of their evolution (Fig. 3). They consist of two principal zones: 1. laminated columnar stromatolite, consisting of non-porous compact opal, forms mostly the internal zones of the speleothems, 2. strongly porous zone formed by white chalk-like opal, represents accumulation of microbial peloids and forms mostly the outer zones of the speleothems. In some speleothems, both zones may alternate.

Fig. 2: Large microbial speleothem forms called "champignons" are frequently more than 30 cm in size (Cueva Charles Brewer, Chimantá). Photo: B. Šmída

The **columnal stromatolite zone** consists of finely laminated layers of pure opal, intercalated by some zones of filamentous microbialite, with thin filaments oriented in the direction of the stromatolite growth. SEM study of the etched surfaces of the columnal stromatolite showed that it mostly consists of concentric laminae formed by dense parallel tubes representing casts after filamentous microbes. The microbes are most similar to filamentous cyanobacteria from the order Oscillatoriales (Golubic, 1976). In other places, irregular, larger-scale, doublelayered cross-sections of microbe tubes occur. They resemble casts after cyanobacterial cells of the genus *Cyanostylon* or *Entophysalis* (Golubic, 1976). The **zone of peloidal microbialites** consists of ovoidal peloids of relatively uniform shape. They are densely packed, arranged in concentric laminae. The size of peloids varies from 0.1 to about 0.3 mm. Microscopic study revealed that the peloids are formed by *Nostoc*-type cyanobacteria. Fungal hyphae, metazoan and plant remains also subordinately contribute to speleothem construction. In many places, initial colonization of the surface by *Nostoc*-type cyanobacteria was observed, forming mats and shrubs covering the underlying arenites (Fig. 4)). The microbial filaments are commonly encrusted by white silica, whereas the surrounding arenites are intact. This is a strong evidence that the microbes were not only passively encrusted by silica but the

encrustation was microbially mediated, either by their metabolism, or by changing physico-chemical conditions. This phenomenon is common in the limestones but it was not yet evident for the siliceous microbialites. Some speleothems, e.g. the cobweb stalactites (Aubrecht et al., 2008) represent mostly inorganic precipitates, encrusting various structures, such as spider threads. There are also large inorganically precipitated stalactites and flowstones. Comparing the size of the speleothems from various caves, there seem to be dependence between the cave size and speleothems size. Cueva Charles Brewer hosts the largest recorded silica speleothems (up to several dm in size) whereas those in other caves were not so large (cm to dm. size).

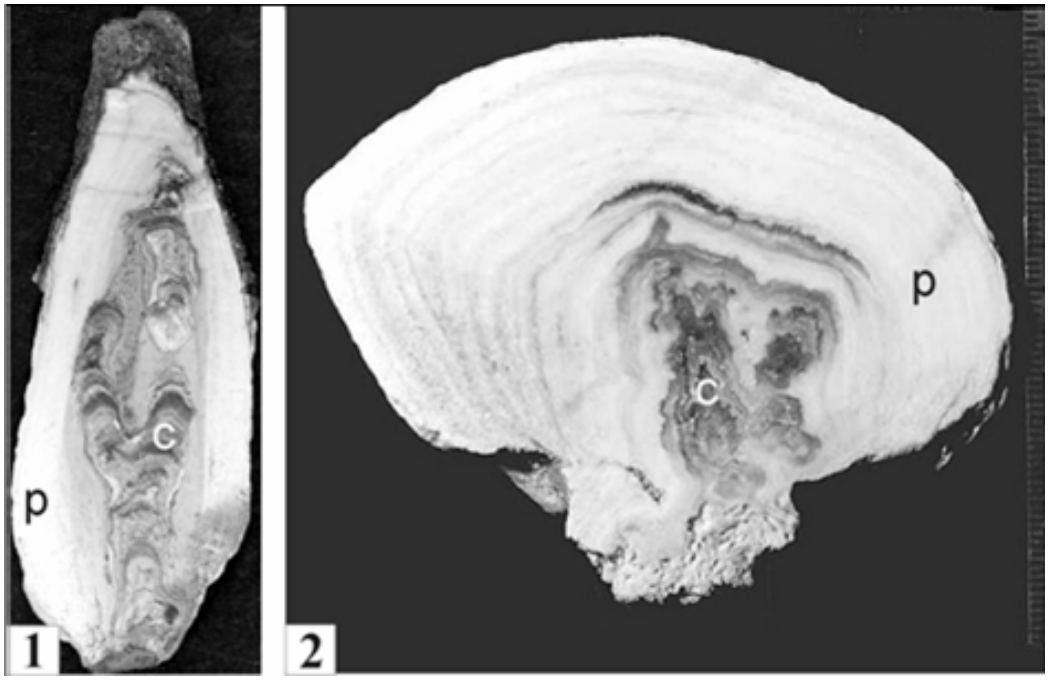

Fig. 3: Slabs of "muñeco" (1) and"champignon" (2) speleothemsfrom Cueva Charles Brewer (Chimantá) showing common principal inner structure, consisting on the columnal stromatolite (c) forming the inner zones and white, chalk-like peloidal layer (p). Photo: R. Aubrecht

Microbial origin of the siliceous speleothems was recognized by previous workers (e.g. Forti, 1994; Lévillé et al., 2000; Willems et al., 2002; Urbani et al., 2005) but very few of them attempted to make a closer description of the microbes. Siliceous microbialites of much larger forms are known from hot springs and geysers (opal sintres). These also contain abundant microbial assemblages, dominated by cyanobacteria, i.e. phototrophic organisms (Jones et al., 2001; Konhauser et al., 2001; 2003). Phototrophic organisms – diatomaceans – were also found to contribute to formation of similar speleothems in Japan and USA (Kashima et al., 1987; Kashima & Ogawa, 1995). These speleothems, however, occurred still close to the entrance, whereas speleothems presented in this paper came from the deepest parts of the cave. Therefore, it is surprising that considerable part of the central compact stromatolite of the speleothems is probably formed by cyanobacteria. Biological investigations of microbes of opal speleothems from similar sandstone cave on Sarisariñama Plateau (Cueva de los Guácharos – Kunicka-Goldfinger, 1982) showed mostly presence of heterotrophic microorganisms, the trophic life mode of which was adapted to decaying of excrements of bats and birds guarachos, as well as fruit remnants coming from their diet. What is the basis of microbe ecology in Cueva Charles Brewer is yet unclear. Presence of these otherwise phototrophic organisms in caves is not so surprising as it seems to be. Some cyanobacteria do not withstand an excess solar light that can damage their cells (Vincent & Roy, 1993; Quesada & Vincent, 1997). Some of them produce protective pigments in extracellular sheath

(e.g. *Lyngbya estuarii* produces pigment scytonemine – Kylin, 1937); others are even able to protect themselves against the excess light by boring the substrate, e.g. endolithic boring cyanobacteria *Hormathonema* and *Hyella* (Golubic, 1976). The genera *Fisherella* and *Calothrix* are even able to change their mode of life to slow heterotrophic in complete darkness (Whitton, 1987). Finally, the most convincing fact is that some cyanobacteria, e.g. *Geitleria calcarea* and *Scytonema julianum* were found to live in caves (Friedman, 1955; Bourrely & Depuy, 1973). It is obvious that the cyanobacteria in Venezuelan caves are also adapted to heterotrophic mode of life.

The reason for the size dependence between the caves and the speleothems is yet unclear. One of the possible explanations would be that the larger the cave is, the more siliceous material undergoes the dissolution/reprecipitation cycle. Larger cave corridors and galleries of the Cueva Charles Brewer have several times larger surface than other caves available for the condensed air moisture which plays the most important role in the cycle.

Fig. 4: Silica-encrusted shrubs forming an initial mat of Nostoc-type microbes on the quartzite substrate (Cueva Cañon Verde, Chimantá). Photo: B. Šmída

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REFERENCES

Aubrecht, R., Brewer-Carías, Ch., Šmída, B., Audy, M. & Kováčik, Ľ., 2008: Anatomy of biologically mediated opal speleothems in the world's largest sandstone cave Cueva Charles Brewer, Chimantá Plateau, Venezuela. – Sed. Geol., 203, 3-4, 181-195.

Aubrecht, R., Brewer-Carías, Ch., Kováčik, Ľ., Mayoral, F., Schlögl, J., Šmída, B., Vlček, L. & Lánczos, T., 2007: Microbial composition of opal stromatolites in Venezuelan sandstone caves. 9th Int. Symp. Fosil Algae, Croatia, 204-205.

Forti, P., 1994: Los depositos quimicos de la Sima Aonda Superior y de otras cavidades del Auyán-Tepui. Venezuela. Bol. SVE, 28, 1-4.

Friedman, I., 1955: *Geitleria calcarea* n.gen. et n.sp., a new atmophytic lime-encrusting bluegreen alga. – Bot. Not., 108, 439-445.

Golubic, S., 1976: Organisms that build stromatolites. In: Walter, M.R. (ed.): Stromatolites. Developments in Sedimentology 20, – Elsevier, 113-126.

Jones, B., Renaut, R.W. & Rosen, M.R., 2001: Microbial construction of siliceous stalactites at geysers and hot springs: Examples from the Whakarewarewa Geothermal Area, North Island, New Zealand. – Palaios, 16, 73-94.

Kashima, N., Teruo, I. & Kinoshita, N., 1987: Diatom, contributors of coralloid speleothems, from Togawa-Sakaidani-do Cave in Miyasaaki prefecture, Central Kyushu. – Japan Int. J. Spel., 16, 95–100.

Kashima, N. & Ogawa, T., 1995: A note on biogenic effect of coralloid speleothems in Round Mountain Lava Cave, Oregon, U.S.A. – J. Spel. Soc. Japan, 19, 8–12.

Konhauser, K.O., Phoenix, V.R., Bottrell, S.H., Adams, D.G. & Head, I.M., 2001: Microbial-silica interactions in Icelandic hot spring sinter: possible analogues for some Precambrian siliceous stromatolites. – Sedimentology, 48, 2, 415-433.

Konhauser, K.O., Jones, B., Reysenbach, A.-L. & Renaut, R.W., 2003: Hot spring sinters: keys to understanding Earth's earliest life forms. – Can. J. Earth Sci., 40, 1713-1724.

Kunicka-Goldfinger, W., 1982: Preliminary observations on the microbiology of karst caves of the Sarisariñama plateau in Venezuela. – Bol. SVE, 19, 133-136.

Kylin, H., 1937: Über die Farbstoffe und die Farbe der Cyanophyceen. – K. Fysiogr. Sällsk. Lund, Förh., 7, 131-158.

Léveillé, R.J., Fyfe, W.S. & Longstaffe, F.J., 2000: Geomicrobiology of carbonate–silicate microbialites from Hawaiian basaltic sea caves. – Chem. Geol., 169, 339-355.

Martini, J.E.J., 1979: Karst in Black Reef Quartzite near Kaapsehoop, Eastern Transvaal. – Ann. South Afr. Geol. Surv., 13, 115-128.

Quesada, A. & Vincent, W.F, 1997: Strategies of adaptation by Antarctic cyanobacteria to ultraviolet radiation. – Eur. J. Phycol., 32, 335-342.

Urbani, F., 1986: Notas sobre el orígen de las cavidades en rocas cuarcíferas precámbrias del Grupo Roraima. – Interciencia, 11, 298-300.

Urbani, F., Compère, Ph. & Willems, L., 2005: Opal-a speleothems of Wei-Assipu-Tepui, Roraima Province, Brazil. – Bol. SVE, 39, 21-26.

Vincent, W.F. & Roy, S., 1993: Solar ultraviolet-B radiation and aquatic primary production: damage, protection, and recovery. – Envir. Rev., 1, 1-12.

Whitton, B.A. (1987): The biology of *Rivulariaceae*. In: Fay, P. & van Baalen, C. (eds.): The cyanobacteria – a comparative review. – Elsevier, 513-534.

Willems, L., Compère, Ph., Hatert, F., Puclet, A., Vicat, J.P., Ek, C. & Boulvain, F. (2002): Karst in granitic rocks, South Cameron: cave genesis and silica and taranakite speleothems. – Terra Nova, 14, 355-362.

Wray, R.A.L. (1999): Opal and chalcedony speleothems on quartz sandstones in the Sydney region, southeastern Australia. – Australian J. Earth Sci., 46, 4, 623-632.

Wray, R.A.L. (2003): Quartzite dissolution: karst or pseudokarst? – Speleogen. Evol. Karst Aquif., 2, 1-9.

THE LIKA AND GACKA SINKING KARST RIVERS HYDROLOGY

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Abstract
In this paper a case of very special hydrological behaviour of two neighbouring sinking karst rivers, Lika and Gacka, (Dinaric karst of Croatia), is analysed. The Lika River has a torrential hydrological regime. At the Sklope gauging station its minimum, mean and maximum measured discharges in the 1951-2005 period were: 0 (dry) m3/s : 24.5 m3/s : 729 m3/s. During the same period the Gacka River, at the Vivoze gauging station, had the following characteristic discharges: 2.29 m3/s; 14.7 m3/s; 71.0 m3/s. While the flow regime of the Lika River is characterised by extremely and very quick changes of discharges, the Gacka River flow regime is unusually uniform. The objective of the investigations made in this paper was to analyse the extremely different hydrological behaviour of the two neighbouring sinking rivers in order to find its reasons. Master depletion curves defined for the two analysed rivers shows that the karst aquifer of the Gacka River is much more abundant than Lika's. The difference in the water temperature regime of the two neighbouring rivers is extremely high. At the Lika-Bilaj gauging station the minimum, mean and maximum measured water temperatures in the period of 1964-1991 were: 0.6 °C; 9.3 °C; 21.4 °C. During the period of 1964-2005 the Gacka River, at the Čovići gauging station had the following characteristic water temperatures: 6.4 °C : 9.1 °C : 11.6 °C. The resident time in the karst underground of water discharging from the Gacka karst springs is much longer than in the case of the Lika River. The most probable explanation for this unusual hydrological behaviour of the two neighbouring karst rivers is that water from the Lika River and its catchment recharges some karst springs of the Gacka River. It is concluded that the Lika River feeds the Gacka River with an average annual discharge of about 5.35 m3/s. This value is different during each year and depends on the hydrological situation. It is very probably higher during the wet years than during the dry ones.

Keywords: karst hydrology, sinking river, water temperature, Lika and Gacka Rivers (Croatia)

INTRODUCTION

The term "rivers system" is used for the system of connected river channels in a drainage basin (Bridge 2005). For rivers developed in ordinary conditions they are composed of three zones (Schumm 1977): the uppermost or production zone; the central or transfer zone; the downstream or deposition zone. It is well known that conditions which govern flow in karst regions strongly change karst rivers systems. They are generally very different in comparison with ordinary rivers systems which exist in non-karst regions.
Bonacci (1987) mentions that flow regime in open streamflows in karst depends mostly upon the interaction between the groundwater and the surface water. The groundwater levels in karst greatly depends upon the effective porosity of the matrix, while groundwater connections between different parts of karst massive as well as some open streamflows depend on the existence, features, and dimensions of karst conduits. Some of these conduits recharge, while some drain off water from the rivers in karst. Generally, recharging or drainage depends on the groundwater level.
In this paper the case of very special hydrological behaviour of two neighbouring sinking karst rivers Lika and Gacka will be analysed. Their catchments are located in the central part of the Dinaric karst region of Croatia. Figure 1 represents location maps indicating (a) the study area, and (b) the supposed catchment areas of the Lika and Gacka Rivers up to their swallow-hole zones where they disappear

into the karst underground. Their waters reappear on the surface about twenty kilometres away at many abundant coastal karst springs and submarine springs (vruljes) along the Adriatic Sea.

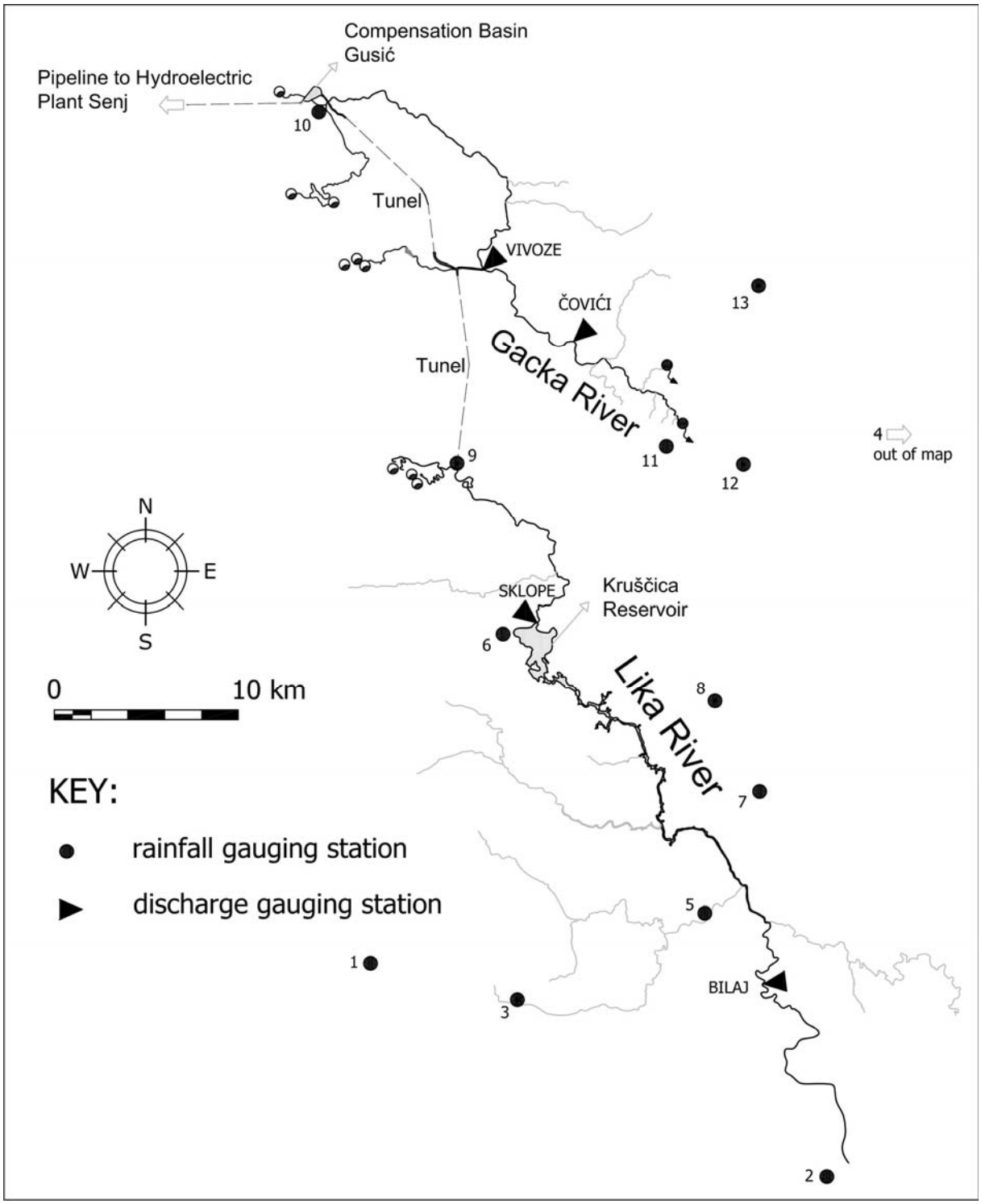

Fig. 1: Location map of the Lika and Gacka Rivers indicating the main ponor zones and karst springs, reservoirs, HEPPs, tunnels, canals, pipeline, and meteorological and hydrological gauging stations analysed in the paper

While the Lika River system is composed of three zones (Schumm 1977), the Gacka River system generally has only a downstream or deposition zone. The very different regulatory influence of karst at the closed locations could be seen from the Lika and Gacka Rivers

hydrological behaviour. The Lika River has torrential hydrological regime. At the Sklope gauging station (Figure 1) its minimum, mean and maximum measured discharges in the period of 1951-2005 were: 0 (dry) m3/s; 24.5 m3/s; 729 m3/s. During the same period the Gacka River at the Vivoze gauging station had the following characteristic discharges: 2.29 m3/s; 14.7 m3/s; 71.0 m3/s. While the flow regime of the Lika River is characterised by extremely and very quick changes of discharges, the Gacka River flow regime is unusually uniform. Due to this reason as well as due to the high quality of water, it represents an exceptionally valuable regional strategic water resource (Ožanić and Rubinić 1999). The objective of the investigations made in this paper is to analyse the extremely different hydrological behaviour of the two neighbouring sinking rivers in order to find its reasons.

MATERIAL AND METHODS

They are 13 precipitation gauging stations on Figure 1 showed that were analysed in this paper. During the analysed period (1951-2005) the average annual precipitations measured at these stations varied from a minimum of 1149 mm (at Lički Osik gauging station) to a maximum of 2270 mm (at Baške Oštarije gauging station).

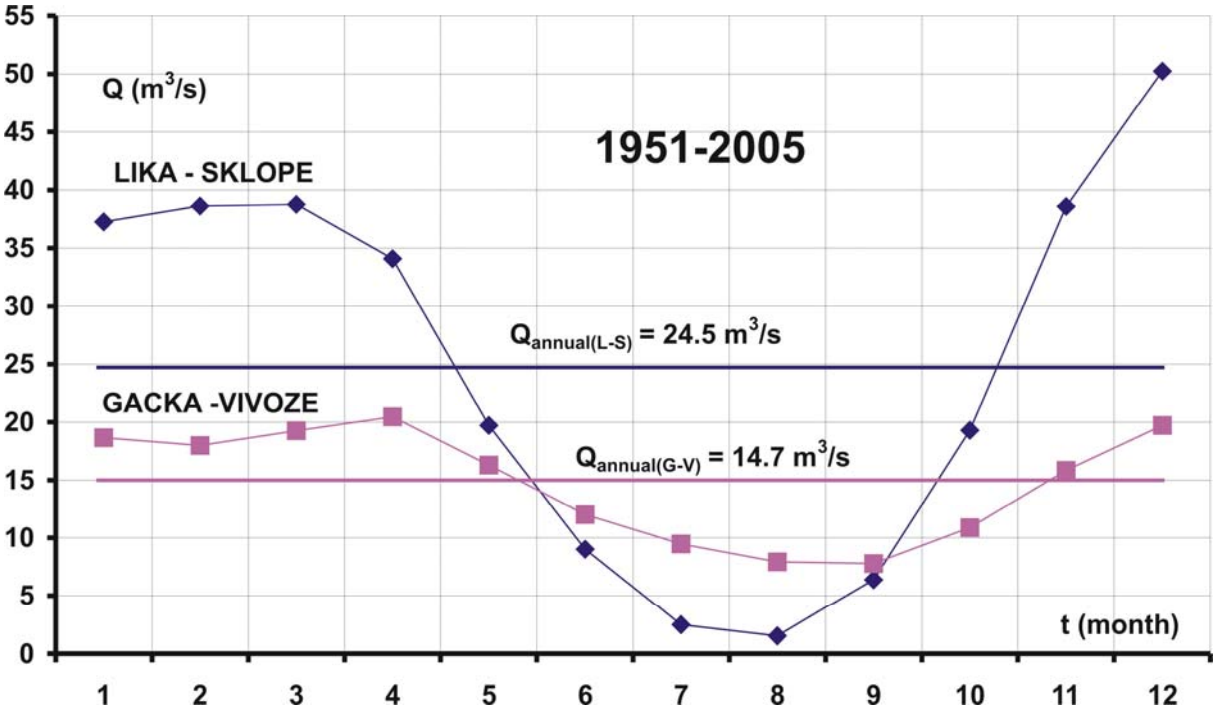

Fig. 2: Annual time series of average monthly discharges for Lika at Sklope QL-S and Gacka at Vivoze QL-S stations during the period of 1951-2006

Figure 12 represents an annual time series of average monthly discharges for Lika at Sklope QL-S and Gacka at Vivoze Q_{G-V} stations during the period of 1951-2006. The annual hydrologic regime of the Gacka at Vivoze is uniform while on the Lika at Sklope it is extremely variable. The time series of mean annual discharges of the Lika at Sklope in the period from 1930-2005 and of the Gacka at Vivoze in the period from 1951-2005 were subjected to the analysis. The RAPS analysis for the gauging station Sklope indicates that in the whole period there exist the following three sub-periods with different average annual discharges: 1) 32.04 m3/s for the first sub-period 1930-1944; 2) 25.78 m3/s for the second sub-period 1945-1981; 3) 21.68 m3/s for the third sub-period 1982-2005. The average annual discharge for the whole period (1930-2005) is 25.7 m3/s. A similar behaviour of mean annual discharges is on the profile of the Gacka River at Vivoze. The RAPS analysis indicates the

existence of two sub-periods with different average annual discharges: 1) 15.27 m3/s for the first sub-period 1951-1981; 2) 14.01 m3/s for the second sub-period 1982-2005.
Air temperature is measured only at the Gospić meteorological station. During the period of 1902-2006 (missing 1943-1945) the mean annual temperature varied between 7.0 and 10.5 °C with an average value of 8.7 °C. A maximum temperature of 38.8 °C was measured on 30 Jul. 1947, and a minimum of -33.6 °C on 17 Feb. 1956.
Water temperature is a relatively simple and inexpensive variable to monitor. At a Lika-Bilaj gauging station (Figure 1) the minimum, mean and maximum measured water temperatures in the period of 1964-1991 were: 0.6 °C; 9.3 °C; 21.4 °C. During the period of 1964-2005 the Gacka River at the Čovići gauging station had the following characteristic water temperatures: 6.4 °C; 9.1 °C; 11.6 °C. The difference in water temperature regime of the two neighbouring rivers is extremely high.
In this paper the Rescaled Adjusted Partial Sums method (RAPS) (Garbrecht and Fernandez 1994; Bonacci et al. 2008) was used for the purpose of analysing a time series, detecting and quantifying trends and fluctuations in records.

RESULTS AND DISCUSSION

All the previously mentioned analyses lead to the conclusions that the hydrological behaviour of two analysed rivers Lika and Gacka is unusual and unexpected, even for the deep and well-developed Dinaric karst terrain in which their catchments were developed. The Lika River has a completely torrential and intermittent hydrological regime. It dries up very often, during the last twenty years practically every year, while the Gacka River has a very well regulated hydrological regime and never dries up. It is very probable that their topographic catchments do not correspond to their hydrological catchments.
In accordance with the previous analyses the most probable explanation for the unusual hydrological behaviour of the two neighbouring karst rivers is that water from the Lika River and catchment recharges some karst springs of the Gacka River. This assessment could be supported by the fact that the altitude of the Lika River channel is higher than the exits of all the karst springs of the Gacka River. The investigation explained in this paper has pointed to the necessity of performing further detailed and karst-specific measurements and analyses. In order to protect extremely valuable groundwater and surface water resources of the Gacka River it is of the paramount importance to discover groundwater connections between two analysed rivers using tracing methods as well as isotopic and geochemical analyses (Pavičić 2001; Pavičić et al. 2003; Horvatinčić et al. 2007).

REFERENCES

Bahun S, Fritz F. 1972. Hidrogeologija Ličkog polja (The hydrogeology of Ličko polje). Krš Jugoslavije 8/3; 43-55.
Bojić D, Mandić M, Roller-Lutz Z, Lutz H, Kapelj S, Horvatinčić N, Krajcer-Bronić I, Sironić A. 2007. Isotopic composition of spring waters from Croatian karst regions: Gacka river area. Studia Universitatis Babeş-Bolyai, Geologia 52 (1): 9.
Bonacci O. 1987. Karst hydrology. Springer Verlag, Berlin. 184 pp.
Bonacci O. 2001. Monthly and annual effective information coefficients in Dinaric karst: example of the Gradole karst spring catchment. Hydrological Sciences Journal 46 (2): 287-299.
Bonacci O, Trninić D, Roje-Bonacci T. 2008. Analyses of the water temperature regime of the Danube and its tributaries in Croatia. Hydrological Processes 22 (7): 1014-1021.
Božičević S. 1984. Hydrogeology of the lost river Gacka in the Dinaric karst after completion of hydroelectric power plant Senj. Krš Jugoslavije 11/2: 13-70.
Bridge JS. 2005. Rivers and floodplains - forms, processes, and sedimentary record. Blackwell Publishing. Malden (USA). 491 pp.
Gajić-Čapka M, Patarčić M, Perčec-Tadić M, Srnec L, Zaninović K. 2003. Prostorna raspodjela srednjih godišnjih temperatura zraka i količina oborina u Hrvatskoj (Mean annual air temperature and precipitation spatial distribution in Croatia). Proceedings of 3. Croatian Conference of Water, Osijek (Croatia) 28 -31 May 2003:75-81.

Garbrecht J, Fernandez GP. 1994. Visualization of trends and fluctuations in climatic records. Water Resources Bulletin 30(2): 297-306.
Horvatinčić N, Kapelj S, Sironić A, Krajcar-Bronić I, Kapelj J, Marković T. 2007. Investigation of water resources and water protection in the karst area of Croatia using isotopic and geochemical analyses. Proceedings of Symposium Advances in Isotope Hydrology and its Role in Sustainable Water Resources Management, Vienna (Austria) 21 – 25 May 2007. Vol 2: 295-304.
Ožanić N, Rubinić J. 1999. Vodni resursi izvorišta Gacke (The Gacka spring water resources). Proceedings of 2nd Croatian Conference of Water, Dubrovnik (Croatia) 19 - 22 May 1999: 575-583.
Pavičić A. 2001. Hidrogeološka osnova zaštite voda izvorišta rijeke Gacke (Hydrogeologic bases for the Gacka springs water protection). Proceedings of Croatian Symposium "How protect waters in Croatia with respect to water supply and drainage", Rijeka: 229-238.
Pavičić A, Benamatić D, Pešt D, Marasović M. 2002. Water reservoir within the karst field overburden: Gusić polje, Croatia. Geologia Croatica 55 (1): 93-100.
Pavičić A, Kapelj S, Lukač J. 2003 The influence of the highway on the protected spring of Gacka river. RMZ - Materials and Geoenvironment 50 (1): 189-292.
Pavičić A, Renić A, Ivičić D. 2001. Groundwater tracing in the karst of Lika, Croatia. In: Seiler K-P & S Wohulich (eds) New Approaches Characterizing Groundwater Flow, Munich.
Ray JA. 2005. Sinking streams and losing streams. In: DC Culver, WB White (eds) Encyclopedia of Caves. Elsevier, Amsterdam: 509-513.
Schumm SA. 1977. The fluvial system. J. Willy, New York, 338 pp.

USE OF MATHEMATICAL MORPHOLOGY OF LANDSCAPE TO STUDY KARST AND THERMOKARST PROCESSES

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Abstract
The purpose of this work is to study regularity of structure and development of the morphological structures associated with karst and thermokarst processes. Within the framework of this work an attempt has been made to solve 2 problems: analyze regularity of space construction of the morphological structures associated with karst; analyze regularity of space construction of the morphological structures associated with thermokarst. In our work we use a method of mathematical morphology of a landscape - a branch of landscape science, investigating quantitative laws of landscape mosaics and methods of the mathematical analysis of these mosaics. Investigation was carried out for eight parcels in Australia, Russia and Alaska. The analysis has shown that a number of deductions of proposed mathematical model for karst depressions and thermokarst lake plains, in general are being corroborated by empirical data. The specified deviations, probably, are due to some non-uniformity of terrain.

Keywords: remote sensing, landscape pattern analysis, methods of mathematical morphology of a landscape

INTRODUCTION

The purpose of this work is to study regularity of structure and development of the morphological structures associated with karst and thermokarst processes.
Within the framework of this work an attempt has been made to solve 2 problems:
- analyze regularity of space construction of the morphological structures associated with karst;
- analyze regularity of space construction of the morphological structures associated with thermokarst.
In our work we use remote sensing data and method of mathematical morphology of a landscape. Mathematical morphology of a landscape is a branch of landscape science, investigating quantitative laws of landscape mosaics and methods of the mathematical analysis of these mosaics.
Theoretical basis of mathematical morphology of a landscape is formed by mathematical models of morphological structures – the quantitative dependences describing the basic properties of morphological structures. Canonical initial mathematical models play a special role in mathematical morphology of a landscape. They should develop in uniform conditions and under unique process.
In a nature conditions we as a rule have some combination of different processes. But basing on these models we can describe most of such combinations. And the most important thing is that with the help of those models, we can describe similar landscapes in quite different climate, geological and other conditions.

MATERIAL AND METHODS

The equations of the mathematical model of a morphological pattern for karst and thermokarst lake plains proposed by A.S. Viktorov [2, 3] were used for the analysis of data and forecast constructions. It is interesting, that mathematical models of a morphological structure associated with thermokarst and kars are similar.
They represent combination of the probabilistic mathematical relations reflecting the most essential geometrical features of the patterns. The equations include:
- Probabilistic distribution of a number of karst depressions and thermokarst lakes, which have appeared within a specified site during the given time interval (Poisson process).

$$P(\kappa, t) = \frac{(\gamma t s)^k}{k!} e^{-\gamma t s},$$

where γ – is an average of the reductions appearing on unit area for unit time; s – is a size of a test site; t – is a time.
- Probabilistic distribution of changes of karst depressions and thermokarst lakes areas (Winer random process relative to logarithms of areas)

$$F_r(x) = \frac{1}{\sqrt{2\pi}\sigma x\sqrt{t}} e^{-\frac{(\ln x - at)^2}{2\sigma^2 t}},$$

where α, σ - are distribution parameters, t - is lake age;

The first task of our work was to analyze regularity of space construction of the morphological structures associated with karst depressions and thermokarst lakes.
As it follows from the model, at the specific moment of time lake diameters should submit to lognormal distribution, given that lakes originated in comparatively short space of time and if spread in sizes of primary depressions is considered small. This deduction has been verified on series of reference parcels. Space pictures have been used as a source of information on morphological structure.
The researches were carried out on the basis of parcels, which are placed:
For karst depressions:

- in South Australia, Nullarbor plain (fig.1, fig.2)
- on East-European plain, near Kuibyshevskoe water storage (fig.3, fig.4)

For thermokarst lakes:

- in Khanty - Mansy autonomous region on Middle Ob lowland in a valley of the river (fig.5)
- on Alaska in the western part of Seward island (fig.6),
- on West Siberian plain, in area of the river Pjakupur (fig. 7) and in area of the river Vatyogan (fig. 8).

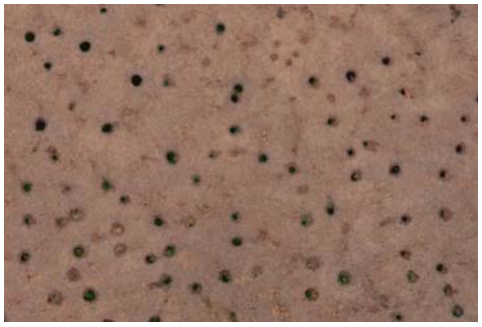

Fig.1. Fragment of a picture of the parcel 1

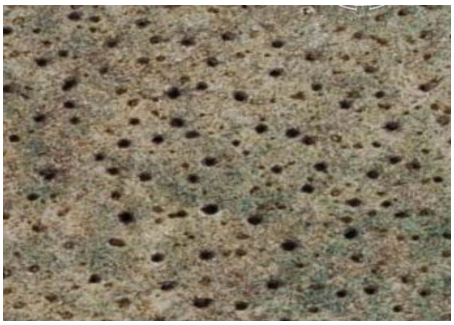

Fig. 2. Fragment of a picture of the parcel 2

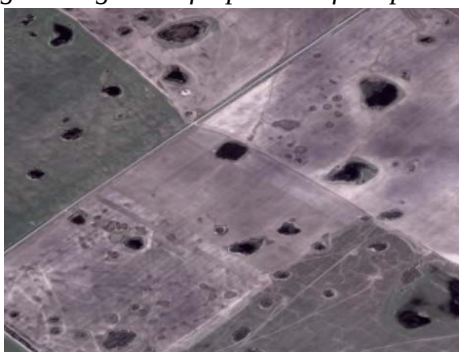

Fig.3. Fragment of a picture of the parcel 3

Fig. 4. Fragment of a picture of the parcel 4

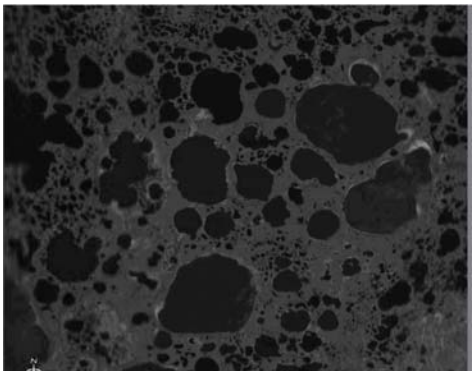

Fig.5. Fragment of a picture of the parcel 5

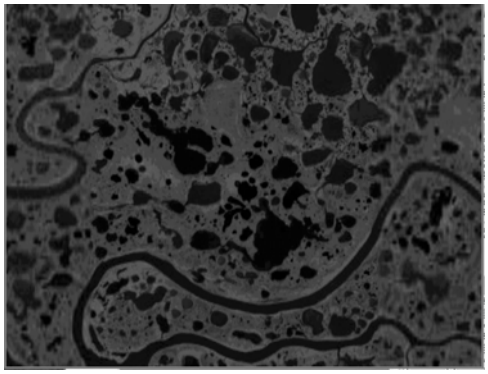

Fig. 6. Fragment of a picture of the parcel 6

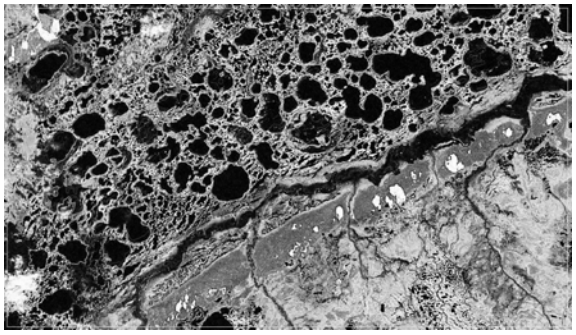

Fig. 7. Fragment of a picture of the parcel 7

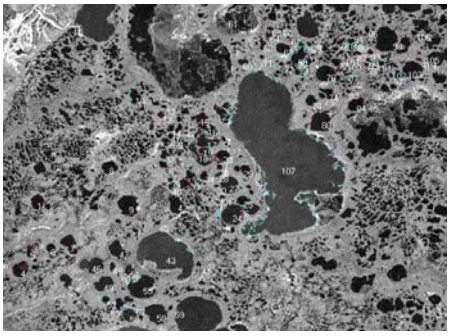

Fig. 8. Fragment of a picture of the parcel 8

These parcels numerical values were assigned using specially developed program Vektorizator and then the data of area, diameter and perimeter have been taken. After that, in the program Statistics the conformity of theoretical and empirical distributions was determined by Pirson's criterion (tab. 1).

Table 1

Parcels	χ^2	№ of degrees of freedom	Critical value χ^2 on the level 0,95 (0,99)
Parcel 1	10,82	3	7.815 (11.34)
Parcel 2	32.64	9	16.92 (21.67)
Parcel 3	2,68	1	3,84 (6,64)
Parcel 4	0,54	2	5.99 (9.21)
Parcel 5	0.09	1	3,84 (6,64)
Parcel 6	5,60	5	11,07 (15,09)
Parcel 7	4.02	4	9.49 (13.28)
Parcel 8	11,68	7	14,07 (18,48)

We have received a good conformity between theoretical and experimental data. On all the parcels value of criterion corresponds to a significance value 0,95 on one parcel – to a significance value 0, 99, and on another one parcel – haven't received conformity between theoretical and experimental data

Thus, research shows, that for the selected parcels in a whole the theoretical deduction about lognormal distribution of areas proves to be true.

The analysis of model shows also, that at the specific moment of a time the location of karst depressions and lakes should submit to Poisson distribution. On the same reference parcels the distribution of centers of dipressions and lakes was analyzed.

For this purpose in program Vektorizator a region of interest with assigned numerical values was outlined, and the quantity of the centers on a random field (in this case – a circle) of a constant size was calculated. The position of fields was defined with the help of the random-number generator, doing 100 casts. Statistical distributions of centers were obtained. For each parcel several experiments were made with circles of different area. After that, with the help of the program Statistics, distribution graphs were plotted, their parameters were obtained and the conformity to Poisson distribution (tab. 2) was determined.

Table 2

File	Field size (pixel)	Circle size (pixel)	λ	χ^2	Number of degrees of freedom	Critical value χ^2 on the level 0,95 (0,99)
Parcel 1	692x434	38	0.38	2.78	1	3,84 (6,64)
		54	0.58	5.84	1	3,84 (6,64)
		71	1.14	9.47	2	5.99 (9.21)
		100	2.21	11.28	4	9.49 (13.28)
Parcel 2	238x30	24	0.97	13.02	2	5.99 (9.21)
		34	1.79	22.17	3	7.815 (11.34)
		52	4.27	32.21	6	12.59 (16.812)
		46	3.53	21.79	5	11,07 (15,09)
Parcel 3	404x84	42	0.68	1.64	1	3,84 (6,64)
		54	0.95	0.95	2	5.99 (9.21)
		74	2.44	64.61	4	9.49 (13.28)
		96	3.05	20.58	4	9.49 (13.28)
Parcel 4	30x410	26	0.52	0.046	1	3,84 (6,64)
		41	1.53	2.77	3	7.815 (11.34)
		58	2.68	6.45	5	11,07 (15,09)
		75	4.37	6.45	6	12.59 (16.812)
		103	6.52	8.46	7	14,07 (18,48)
Parcel 5	521x580	70	1.28	1.12	2	5.99 (9.21)
		90	1.76	0.41	3	7.82 (11.34)
		119	3.25	6.35	4	9.49 (13.28)
Parcel 6	562x470	61	1.55	0.72	3	7.815 (11.34)
		79	2.3	10.03	4	9.49 (13.28)
		128	7.21	10.25	8	15.51 (20.09)
		52	1.14	6.39	2	5.99 (9.21)
		128	7.21	7.40	8	15.51 (20.09)
Parcel 7	541x77	114	19,87	12.35	11	19.68 (24.73)
		87	10,83	4,89	4	9.49 (13.28)
		68	9,15	8,25	9	16.92 (21.67)
		52	6,71	3,97	7	14.07 (18.48)
		42	3,28	10,87	4	9.49 (13.28)
		31	1,52	2,25	3	7.82 (11.34)

For parcel 1 most every values of criterion of conformity of empirical distribution to theoretical Poisson distribution do not surpass critical on a significance level 0,99. For a parcel 2 – they are no conformity, for parcel 3 – they are two values of criterion of conformity of empirical distribution to theoretical Poisson distribution do not surpass critical on a significance level 0,95. Parcels 4, 5, 6 – we have received a good conformity between theoretical and experimental data. on a significance level 0,95. And for parcel 7 two values of criterion surpass critical on a significance level 0.95, but meet a significance level 0.99.

RESULTS AND DISCUSSION

Thus, a number of deductions of proposed mathematical model for karst depressions and thermokarst lake plains, in general are being corroborated by empirical data. The specified deviations, probably, are due to some non-uniformity of terrain. The obtained conclusions have essential practical value. The researches on a whole confirm validity of the model, which, in turn, allows giving the estimated forecast of risks for linear, areal, and point objects [3].

REFERENCES

1. Viktorov A.S. 1998. Mathematical morphology of a landscape. Tratec: Moscow; 180
2. Viktorov A.S. 2006. Main problems in mathematical morphology of a landscape. Nauka: Moscow; 252.
3. Zolotarev G.S. 1983. Engineering geodynamics. Moscow University: Moscow;328.
4. Ivashutina L.I., Nikolaev V.A. 1969. About analysis of landscape structure of natural regions. Moscow University bulletin, Geography 4: 49-59.
5. Simonov Yu.G. 1972. Regional terrain analysis. Moscow University: Moscow; 251.

CALCITE MOONMILK FROM CAVES IN THE MORAVIAN KARST: MICROBIOLOGICAL AND GEOLOGICAL ASPECTS

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Abstract
Calcite moonmilk from five caves in the Moravian Karst was examined for the presence of culturable microorganisms (bacteria and fungi) and mineral composition. Sampling sites were in Sloupsko-šošůvské Caves, Císařská Cave, Suchožlebská zazděná Cave, Kateřinská Cave and Horní v Chobotu Cave. Seventy bacterial strains were isolated from the samples. Most of the strains were gram-negative non-fermenting rods. The majority of them were classified as fluorescent pseudomonads. Ten different cultures of sporulating fungi belonging to eight genera and one culture of non-sporulating fungus were isolated from four samples of moonmilk. The identified species and genera were *Beuveria bassiana*, *Isaria farinosa, Cladosporium subtilissimum, Geomyces pannorum* var. *pannorum, Mortierella alpina, Oidiodendron truncatum, Engyodontium rectidentatum* and *Mucor* sp. Moonmilk was composed of calcite and a variable content of water (-H_2O) (34–85.8 %). The amount of crystalline water (+H_2O) oscillates between 0.88 and 3.13 %. Its stucture is micritic, sparitic and fibrous. Moonmilk occurs in relatively wide range of atmospheric cave conditions.

Keywords: bacteria, calcite moonmilk, cave mycobiota, fibrous calcite, Moravian Karst, *Pseudomonas*

INTRODUCTION

Moonmilk is a kind of cave deposit. Its basic features are a microcrystalline structure and a relatively high water content (40-80%). Mineral composition of this speleothem is variable. Moonmilk consists predominantly of calcite in the limestone caves. It can also consist of other carbonate and non-carbonate minerals. Macroscopically, moonmilk appears to be soft and plastic in the wet form. It is crumbly and powdery after desiccation and mostly white but it can be coloured too. Moonmilk forms coatings on the walls, speleothems and sediments, or it constitutes speleothems itself. Moonmilk occurs in a wide range of geographical latitudes and altitudes from tropical to high alpine karst (Hill & Forti 1997).

The mechanism of formation has not been sufficiently explained. The origin of moonmilk is a frequently discussed topic. There are hyphotheses proposing a microbial or non–microbial origin or both (Borsato *et al.* 2000, Gradziński *et al.* 1997, Hill & Forti 1997, Northup *et al.* 2000, Onac 1995, Richter *et al.* 2007). Abiogenic precipitation from supersaturated seepage water is taken into consideration as microorganisms are not always present (Borsato *et al*. 2000) or their presence does not necessarily have to take part in the moonmilk genesis. The microbial origin of moonmilk may consist in active or passive role of microorganisms.

The Moravian Karst is an area formed by devonian and lower carbonian limestones (upper eifel – lower visé). There are two complexes of strata – shallow-water limestones (eifel–frasn/famen) and deeper-water limestones with shale layers (frasn/famen-lower visé). The samples of moonmilk were collected in caves in the nothern part of the Moravian Karst. They were formed in two facies of shallow-water limestones (Lažánecké limestones and Vilémovické limestones). The entrance parts of the caves are between 345 and 464 meters above see level (Přibyl 1984). The parameters of the studied caves are shown in Figure 1. The Moravian Karst has a temperate climate.

Fig. 1: Parameters of studied caves.

	Altitude (m asl.)	Host rock	Underground stream	Number of entries	Lenght of galleries	Denivelation
Sloupsko-šošůvské Caves	464	VL	Yes	5	6000 m	94 m
Císařská Cave	461	VL	Yes	2	250 m	21 m
Suchožlebská zazděná Cave	366	LL	No	1	135 m	10–15 m
Kateřinská Cave	345	LL	No	1	950 m	63 m
Horní v Chobotu Cave	396	LL	No	1	90 m	10 m

Host rock- LL lažánecké limestones, VL- vilémovické limestones

MATERIAL AND METHODS

Microbiology

Four samples of moonmilk for microbiological analysis were collected in four caves in the Moravian Karst. The sampling was conducted in two periods.

In the first period, the samples were collected aseptically and on the same day transferred to laboratory for the

analysis which was aimed at the isolation of strains (bacteria and fungi). The samples were screened by using the dilution-plating method. Macromonas medium (MM), NWRI-agar and King B medium (selective medium for fluorescent pseudomonads) were used for the bacteria isolation. The agar plates were inoculated with the volume of 0.1 ml of the suspension and incubated at 10°C for 7 days. Randomly chosen colonies (on MM, NWRI-agar) were picked up and pure cultures were analysed. On the King B medium only fluorescent colonies were picked up. After the gram staining, the isolated strains were characterized by biotyping. After that, all the gram-negative strains were characterized by whole-cell protein analysis by SDS-PAGE (Pot *et. al.*1994). Protein profiles were obtained from cultures cultivated on NA at room temperature. The normalization of patterns was performed with BioNumerics software. The cluster analysis was conducted on the matrix of correlation values by the unweighted pair group method using arithmetic averages (UPGMA). A selected group of gram-negative strains was also characterized by ribotyping (Popovic *et al.* 1993).

Malt Extract Agar (2%) was used for the isolation of fungal strains. The agar plates were inoculated with 0.2 ml suspension and incubated at 16°C for two weeks. Colonies of different species of microscopic fungi were isolated and transferred on an appropriate diagnostic medium. The isolates of filamentous fungi were observed under the light microscope and their determination to species or genera level was based upon microscopic and macroscopic morphological characteristics.

In the second period, additional sampling was conducted to determine the total cell number of cultivable bacteria in 1g of wet moonmilk. Trypton-soya agar, NWRI-agar and Nutrient agar (NA) were used for this enumeration method. The moonmilk was aseptically homogenized with glass beads in the volume of 35 ml of physiological solution and diluted (10x, 100x). The volume of 0.1 ml of accordant dilution was spread on the plates and incubated at 15°C. After 5 and 10 days the colonies were counted and the number of CFU per 1g of the moonmilk was determined.

Geology

Eight samples of moonmilk were collected from 5 caves for geological analyses. Two samples were taken from Sloupsko-šošůvské Caves *(from Moonmilk Cave and Elizabeth´s Cave).* One sample was taken from Suchožlebská zazděná Cave *(entrance part),* Kateřinská Cave *(Main Chamber,)* Horní v Chobotu Cave *(entrance part)* and three samples from Císařská Cave *(White Chamber, Nagel´s Chamber)*. The temperature (^{o}C) and relative humidity (%) of cave atmosphere were measured by the digital device GFTH 200 (Greisinger electronic GmbH) at the same time. These characteristics were repeatedly measured in an interval of 3 months. The partial pressure of CO_2 in the cave atmosphere was once measured by the device ALMEMO 2290-4 with the infrared detector FYA600CO2H, Ahlborn GmbH.

Water content ($-H_2O$) was determined by comparing the weights of the moonmilk samples before and after dehydratation at 110°C. Content of crystalline water ($+H_2O$) was determined by Penfield method at 900°C with Pb_3O_4. The microstructure was observed using the polarizing microscope JENALAB (ZEISS). Mineralogy was examined by the X-ray diffractometer STOE Stadi P. The chemical composition and microstructure were investigated by the Electron Micro Probe Analyser Cameca SX 100 on the dehydrated samples coated with graphite film.

RESULTS AND DISCUSSION

Microbiology

Bacteriology Altogether 70 psychrotrophic bacterial strains were isolated from the samples of moonmilk. Out of these, 60 strains were isolated on MM and NWRI-agar and additional 10 gram-negative fluorescent strains on selective King B medium. All of the 60 strains were gram-negative non-fermenting rods except for 2 gram-positive isolates. Out of 58 gram-negative non-fermenting rods, 39 strains represented fluorescent pseudomonads. The number of fluorescent pseudomonads isolated from samples from a particular cave and the distribution of the groups mentioned above are given in Figure 2. The results of biochemical tests revealed some atypical strains among the pseudomonads (decarboxylation of lysine together with negative decarboxylation of arginine - 11 strains from Kateřinská Cave, 4 strains from Suchožlebská zazděná Cave; positive aesculine hydrolysis - 1 strain from Císařská Cave, 2 strains from Suchožlevská zazděná Cave). The remaining gram-negative rods were not identified by biotyping.

Fig. 2: Groups of isolated strains and their distribution.

	Caves				Total
	Císařská	**Horní v Chobotu**	**Kateřinská**	**Suchožlebská zazděná**	
Isolated strains on MM and NWRI-agar	12	18	11	19	60
Gram-negative strains	11	17	11	19	58
Gram-positive strains	1	1	0	0	2
Fluorescent pseudomonads	4	9	10	16	39
Fluorescent pseudomonads (%)	**36.36**	**52.94**	**90.9**	**84.21**	/

Furthermore, two dendrograms were obtained after the numerical analysis of protein electrophoregrams of gram-

negative strains. The first dendrogram represented grouping of all gram-negative strains (58), including strains isolated on King B medium (10). Thereafter, the second of 148 entries showed similarities of isolated fluorescent and some non-fluorescent strains of presumptive pseudomonads with pseudomonads deposited at CCM. The dendrogram clusters correlate with the biochemical profiles and the origin of the samples. There were e.g. homogenous clusters of nitrate reducing strains, nitrate and nitrite reducing strains, and decarboxylation of lysine positive strains. One aesculine positive fluorescent strain was even clustered together with other aesculine positive CCM strains of pseudomonads, which were published by Švec *et. al* (2004). This finding also correlated with the results of ribotyping. Generally, the results of ribotyping verified the equivalence among previous findings. In most cases, there were analogous groupings. In conclusion, pseudomonads from Kateřinská Cave and Suchožlebská zazděná were very similar by whole-cell protein analysis and ribotyping and there were also similarities in their biochemical profiles.

The results of the enumeration method are showed in Figure 3. Although there were no considerable differences in the numbers of colony forming units (CFU), considering the media used and the origin of the samples, the best numbers were obtained on the TSA. Generally, there were 10^3 to 10^6 CFU in 1g of wet moonmilk. Similar data were published by Mulec *et al.* (2002).

Fig. 3: Number of CFU per 1 gram in wet moonmilk considering used media and origin of the sample.

Caves	NWRI-agar	TSA	NA
Císařská Cave	$6.3x10^3$ CFU/g	$4.8x10^4$ CFU/g	$7.4x10^3$ CFU/g
Horní v Chobotu Cave	$2.8x10^6$ CFU/g	$3.5x10^6$ CFU/g	$1.5x10^5$ CFU/g
Kateřinská Cave	$1.3x10^6$ CFU/g	$9.6x10^5$ CFU/g	$5.9x10^5$ CFU/g
Suchožlebská zazděná Cave	$9.1x10^3$ CFU/g	$1.2x10^4$ CFU/g	$1.9x10^4$ CFU/g

Mycology Ten different cultures of sporulating fungi belonging to eight genera and one type of sterile mycelium were isolated from four samples of moonmilk. Most species were found in Suchožlebská zazděná Cave. The identified genera and species were *Beuveria bassiana*, *Isaria farinosa, Cladosporium subtilissimum, Geomyces pannorum* var. *pannorum, Mortierella alpina* and *Mucor* sp. *B. bassiana* and *I. farinosa* are entomogenous fungi on troglobiotic insects (Samson *et al.* 1984) and were found on aragonite in Zbrašov Aragonite Caves as well (Bosák *et al.* 2001). Other isolated species are common in soil or plant material. *Mucor* species are regarded as true coprophilous fungi. They were isolated directly from colonies on bat guano in the caves of the Slovakian and Moravian Karst (Nováková 2004, 2006) as well as from aragonite, atmosphere and soil in the caves of the Moravian Karst (Bosák *et al.* 2001). The occurrence of one unidentified *Mucor* species was detected in Horní v Chobotu Cave. The other unidentified species of the genus *Mucor* and *Mortierella, G. pannorum* var. *pannorum* and *Oidiodendron truncatum* were isolated from moonmilk in Kateřinská Cave. *O. truncatum* is a common inhabitant of humus layers in forest soil. Species of *Mortierella* are generally capable of decomposing chitin and were found on insects although they are not typical insect parasites (Kubátová 2005). Only one microscopic fungus *Engyodontium rectidentatum* was obtained from Císařská Cave. This species was described from plant material and insects as well as from aragonite and air in caves (Bosák *et al.* 2001). Regarding microscopic fungi, no relation between the substrate (moonmilk) and a particular group of fungal species was proved. The species diversity in each sample is affected by many factors of caves environment (temperature, humidity, availability of light, substrate for fungal growth, speleomicrofauna, visitors).

Geology

The moonmilk in the five selected caves forms white, 0.5–8 cm thick coatings on the walls. It occurs near the entrances or near the ground surface. The temperature of the cave atmosphere varied in the range of 3.9–12.5 °C. The lowest average temperature was detected in Suchožlebská zazděná Cave (7.8 °C) and the highest in White Chamber in Císařská Cave (10.1°C). The relative humidity varied from 69.5 to 91.2 %. The lowest average relative humidity was in White Chamber in Císařská Cave (80.4 %) and the highest in Suchožlebská zazděná Cave (89.6 %). The content of CO_2 ranged in the cave atmosphere from 700 to 1190 ppm. The content of water in moonmilk oscillated from approximately 34 to 85.8 wt. %. The proportion of crystalline water in the samples was in the range of 0.88 to 3.13 wt. %. A relatively high content of crystalline water indicated that the samples may also contain hydrated minerals (for example monohydrocalcite).

Analyses of the mineral composition by using the X-ray diffractometer revealed that the specimens consisted only of calcite. There were no differences in outcomes between wet and dry samples. Hydrated minerals were not detected probably because of low content and high detection limits of the X-ray device.

Fine needle-shaped fibres, nanofiber veils, rods and polycrystals (probably calcite) in micritic and sparitic matter were observed in the microstructure of moonmilk. The surface of fibres was either smooth or with serrated edges (parallel growth of rhombohedra). Mineral grains were observed in extremely rare cases (calcite or dolomite, silica and aggregations Fe oxides). The structure of moonmilk appears to be recrystalized in some cases. Chemical analyses by

EMPA revealed that moonmilk was mainly composed of near pure calcium carbonate $CaCO_3$ (about 98%). In the sample from Horní v Chobotu Cave a higher content of Mg (0.077–0.256 wt. %) was detected. A very low content of other elements was detected in some samples (Si 0.03–0.445 wt. %, S 0.033–0.078 wt. % and P 0.031–0.063 wt. %).

From the occurence of moonmilk in caves with different atmospheric conditions can be assumed that the formation of moonmilk was not directly related to the distinctive temperature and humidity of the cave atmosphere. Probably, the main factor managing the formation of moonmilk was the saturation of source water with respect to calcite and its input to moonmilk coatings.

Biotic compound (bacteria and microscopic fungi) in moonmilk samples of mentioned caves was surprisingly proved by common methods of cultivation. The genus *Pseudomonas* was the dominant bacterial taxon in all studied environments which represented in two cases even more than 80% of isolated strains. The pseudomonads are commonly known for their genetical heterogenity and considerable adaptability. Their presence in the cave environment and also moonmilk was mentioned by Mulec *et al.*(2002). The biochemical activity of both microbial members might be inconsiderable in the formation of moonmilk.

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References

Borsato, A., Frisia, S., Jones, B. & van der Borg, K. 2000: Calcite moonmilk: crystal morphology and environment of formation in caves in the Italian Alps.—Journal of Sedimentary Research, 70, 5, 1171-1182.

Bosák, P., Vašátko, J., Cílek, V., Dumnická, E., Hanuláková, D., Horáček, I., Jeník, J., Kopecký J., Marvanová, L., Mlejnek, R., Růžička, V. & M. Zacharda, 2001: Czech Republic. – In: Juberthie C. and Decu V. (eds.), Encyclopaedia Biospeleologica, Tom III, 1405–1426, Moulis and Bucarest.

Gradziński, M., Szulc, J. & Smyk, B., 1997: Microbial agents of moonmilk precipitation. - In: Jeannin P.Y.(ed) Proceedings 12th International Congress of Speleology, vol. 1. Swiss Speleological Society, La Chaux-de-Fonds, 275-278.

Hill, C.A. & Forti, P., 1997: Cave Minerals of the World (2nd edition). - National Speleological Society, Huntsville, Alabama.

Kubátová, A. & L. Dvořák, 2005: Entomopathogenic fungi associated with insect hibernating in underground shelters. - Czech Mycol., 57 (3-4), 221 – 237, Praha.

Mulec, J., Zalar, P., Hajna, N. Z, & Rupnik, M., 2002: Screening for culturable microorganisms from cave environments (Slovenia). Acta Carsologica. 31/2, p. 177-187.

Northup, D. E., Dahm, C. N. & Melim, L. A., 2000: Evidence for geomicrobiological interactions in Guadulpe Caves. - Journal of Cave and Karst Studies, 62, 2, 80-90.

Nováková, A., 2004: Saprotrophic microscopis fungi in caves of the Slovak Karst National Park. - In: Bella, P. (Ed.), Investigation, Exploatation and Preservation of Caves, 4th Scientific Conference with International Participation, 162-168, Liptovský Mikuláš.

Nováková, A., 2006: Microscopic fungi of Chýnov Caves and the Na Turoldu Cave (Czech Republic). - In: Bella, P. (Ed.): Research, Exploitation and Protection of Caves 5. 26. - 29.9. 2005, 211-213, Demänovská Dolina.

Onac B. P., 1995: Mineralogical data concerning moonmilk speleothems in few caves from Nothern Norway. - Acta Carsologica, 24, 429-437.

Popovic, T., Bopp, C.A., Olsvik, O. & Kiehlbauch, J.A., 1993: Ribotyping in molecular epidemiology. In: D.H. Persing, T.F. Smith, F.C. Tenover, T.J. White (eds.), Diagnostic molecular microbiology: principles and applications. pp. 573-583. ASM Press, Washington, USA.

Pot, B., Vandamme, P. & Kersters, K., 1994: Analysis of electrophoretic whole-organism protein fingerprints. In: Chemical Methods in prokaryotic Systematics, pp. 493-521. Edited by M. Goodfellow and A.G.O´Donnell. Chichester: Wiley.

Přibyl J., Vodička J., Kuzdasová Z., Hofírková S., 1984: Přehled údajů o jeskyních Moravského krasu, textová část 1. - ČSAV, Brno.

Richter D.K., Immenhauser A., Neuser R.D. 2007: Electron backscatter diffraction documents randomly orientated c-axes in moonmilk calcit fibres: evidence for biologically induced precipitation. - Geophysical Research Abstracts, 9, 02714, 1-11.

Samson, A. R., Rombach, C. M. & A. K. Seifert, 1984: *Hirsutella guignardii* and *Stilbella kervillei*, two troglobiotic entomogenous hyphomycetes. – Persoonia, 12, 123-134, Leiden.

Švec, P., Štegnerová, H., Durnová, E. & Sedláček I., 2004: Characterization of esculinpositive *Pseudomonas fluorescens* strains isolated from an underground brook. Folia Microbiol. (Praha). 49(6): 725-30.

GENERATIONS OF TECTONIC EVENTS AND THEIR INFLUENCE ON GENESIS OF THE CAVES (SLOVAK REPUBLIC, HIGH TATRA MTS., ÚPLAZ MASSIF)

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Abstract
Cave-related data was collected during the structural field mapping. From the measured data we were able to separate six monogenetic groups of discontinuities. We divided the complex of these groups into two populations of discontinuities. As the compare criterion we used the tectonic tilting of the High Tatra Mts. Via the back-rotation of this tilted group we obtained their original orientation. Individual generations of these monogenetic groups were further timed be means of orientation of paleostress axis and tectonic regimes, based on the general knowledge of the studied area. All the mentioned groups controlled both the development and orientation of caves.

Keywords: High Tatra Mts, speleology, tectonic structures, discontinuities, structural analyse.

INTRODUCTION

The studied area is located in north region in the High Tatra Mts. within the Úplaz massif, which is the NW ridge of the Mt. Kolovy štít. This study area is rich on the forms of karst (Pavlarčík, 1976, 1981, 1984). Caves Verných, Čiernohorská Nižná, Veterná, Kamenné oči, Suchá diera, Mokrá diera a Javorinka are situated in Gutenstein member and massive organogene limestones of tomanova formation (Matějka & Andrusov in Nemčok et al., 1993). During the structural field mapping of the presented caves the collected cave-related data were completed with the surface-measured data (Pavlarčík, 1983).

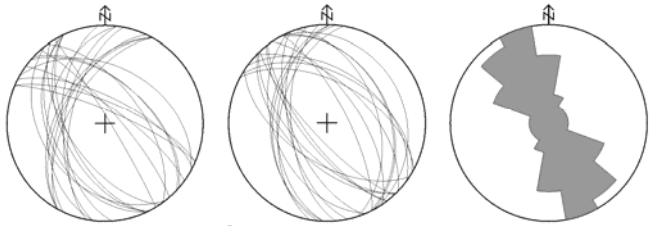
METHODS AND ESTABLISHED DATA

For the measured data was used structural field mapping in presented caves. The measured values we were able to separate from polygenetic population of discontinuities be means of structural analyse to six monogenetic groups (Kučera, 2005, 2007). The complex of six monogenetic groups we have divided into two groups, based on their compared orientation to the paleostress axes. As the comparation criterion we used the tectonic tilting of the High Tatras Mts., dated from Sarmatian to Pannonian age. The High Tatras Mts tectonic tilting was given based on bedding of paleogene sediments on mountainside with S0 0/25 – 0/35º, axis of rotation is horizontal E-W direction (ρ 90/0°) and measurement of rotation is positive value 27º. Via the back-rotation of the group of tectonic failures affected by the measured tilting (0/27°) we have obtained their original orientation.

Individual generations of failures were further timed, based on the general knowledge of the studied area (Kováč, 2000; Lukniš, 1973).

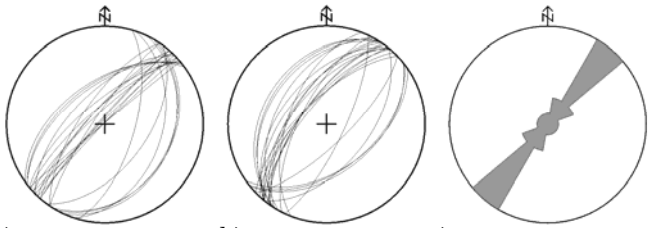
The Ottnangian to early Badenian failures are supposed to belong to the lower generation, representing the early stage of the Tatras upheaval (Kráľ, 1977; Kováč et al., 1994). This stage was characterized by the extensional tectonic failures of NE – SW direction and 30 to 70° angle of dipping (Fig. 1). The second group, affected by tilting, generated under extensional regime, is timed to late Badenian. The direction of failures was measured as NW – SE with 55 - 60° angle of dipping (Fig. 2). The third generation of the failures originated under compressional tectonic regime. It`s paleostress axis is oriented NE – SW, while these failures can be regarded as a conjugated strike-slip system of

Sarmatian age (Fig. 3). After this time the High Tatras Mts. block rotated horizontally and the later generations of failures were generated under normal orientation of the paleostress axes. As the oldest monogenetic group we regard those which were generated under N - S extension and have dipping 60°. The conjugated system of discontinuities mirrors an extensional normal-slip system, generated probably during the final stages of the Tatras tilting (Fig 4). After this stage, there started since Pleistocene a compressional tectonic regime with NNW – SSE axis, coincident with the present orientation of the principal stress axes (Fig. 5). As the youngest failures we can regard the discontinuities, connected with gravitational sliding. These failures were generated by gravitational collapse of the massif stability, due to a deep erosion generate by a glacier of Rissian, and later of Wurmian age (Fig.6). The motion along the sliding planes was enabled also by a proper orientation of a significant mylonite zone.



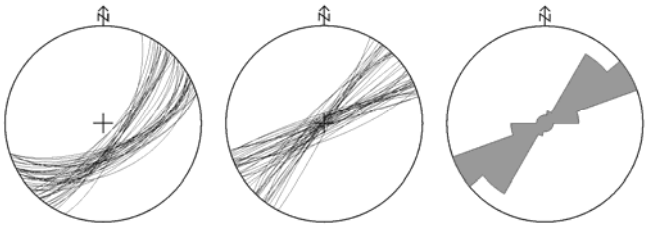
a) *b)* *c)*

Fig. 1) Ottnangian - early Badenian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



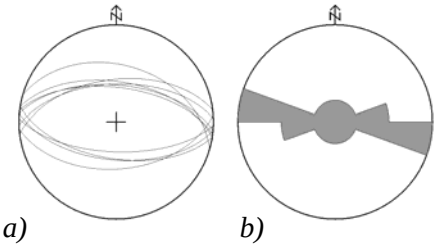
a) *b)* *c)*

Fig. 2) late Badenian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



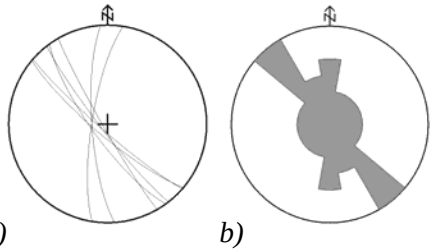
a) *b)* *c)*

Fig. 3) Sarmatian
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Equal area projection lower hemisphere – back-rotation discontinuities by the measured tilting (0/27°). The monogenetic group of discontinuities gained by this operation a normal paleostress axes situation.
c) Rose diagram of the monogenetic group.



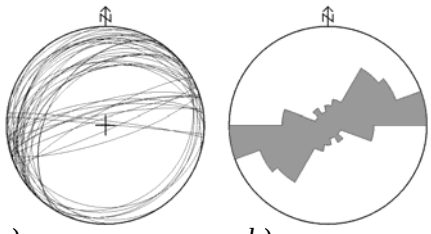
a) *b)*

Fig. 4) Late Miocene
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.



a) *b)*

Fig. 5) since Pleistocene
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.



a) *b)*

Fig. 6) late Rissian - recent
a) Equal area projection lower hemisphere – real orientation of discontinuities.
b) Rose diagram of the monogenetic group.

RESULTS

The measured values we were able to separate to six tectonic events and timed it.

Monogenetic group conjugate discontinuities generated under extensional tectonic regime. Extension regime is in tendency NE-SW. Population of discontinuities is timed to Otnang – lower Badenian.

Monogenetic group conjugate discontinuities generated under extensional tectonic regime. Extension regime is in tendency NW-SE. Population of discontinuities is timed to late Badenian.

Monogenetic group of the conjugated discontinuities with a very good orthorombic symmetry generated under extensional tectonic regime. It`s paleostress axis is oriented NE – SW, while these failures can be regarded as a conjugated strike-slip system of Sarmatian age.

Monogenetic group of the conjugated discontinuities with a good orthorombic symmetry generated under extensional tectonic regime. Extension regime is in tendency N-S. Population of discontinuities is timed to Sarmatian - ? Panonian.

Monogenetic group of the conjugated discontinuities with a good orthorombic symmetry generated under compressional tectonic regime. Compressional regime is in tendency NNW-SSE. Population of discontinuities is timed since Pleistocene to recent.

Monogenetic group conjugated with gravity sliding. The discontinuities are represented by shallow sliding surfaces with gentle NW tilting and vertical tear off fractures with NE-SW orientation. The mentioned group of discontinuities come to existence as consequence of gravity movement caused by collapse of rock massif disturbed by deep glacial erosion.

All the mentioned groups of discontinuities controlled both the development and orientation of caves.

REFERENCES

Kováč, M., Kráľ, J., Márton, E., Plašienka, D. & Uher, P., 1994: Alpine uplift history of the Central Western Carpathians: Geochronological, paleomagnetic, sedimentary and structural data. Geol. Carpath., 45, 2, pp. 83-96.

Kováč, M., 2000: Geodinamický, paleogeografický a štruktúrny vývoj karpatsko-panonskeho regionu v miocéne: Nový pohľad na neogénne panvy Slovenska. Vyd. Slov. Akad. Vied, Bratislava, 204 s.

Kráľ, J., 1977: Fission track ages of apatites from somegranitoid rocks in West Carpathians. Geol. Zbor. Geol. Carpath. 28, 2, 269-276.

Kučera, M., 2005: Analýza tektonických štruktúr jaskýň v masíve Úplazu vo Vysokých Tatrách a ich vplyv na vývoj jaskynných priestorov. Mineralia Slov., 37, 230-233.

Kučera, M., 2007: New data on tectonic behaviour of High Tatras caves. 13th International Cave Bear Symposium, pp 20.

Lukniš, M., 1973: Reliéf Vysokých Tatier a ich predpolia. Vyd. Slov. Akad. Vied, Bratislava 1975 s.

Nemčok, J., Bezák, V., Janák, M., Kahan, Š., Ryka, W., Kohút, M., Lehotský, I, Wieczorek, J., Zelman, J., Mello, J., Halouzka, R., Raczkowski, W., Reichwalder, P., 1993:Vysvetlivky ku geologickej mape Tatier 1: 50 000. Bratislava, GÚDŠ, 135s.

Pavlarčík, S., 1976: Vplyv základných geologických štruktúr na vývoj krasu mädzi Kolovou a Sirokou dolinou vo Vysokých Tatrách. Diplomová práca, Katedra geologie a paleontologie, Prírodovedecká fakulta UK. Bratislava. 68 s.

Pavlarčík, S., 1981:Geologický a geomorfologický výskum krasu v širšej oblasti javorovej doliny vo Vysokých Tatrách. Záverečná správa. Manuskript, Správa Slovenských jaskýň – Múzeum Slovenského krasu. Liptovský Mikuláš 97 s.

Pavlarčík, S., 1983: Použitie geologických metod pri mapovaní jaskýň. Spravodaj SSS. 14, 4, 4-11.

Pavlarčík, S., 1984: Speleologický výskum krasových javov obalovej jednotky severnej strany Vysokých Tatier. Slovenský kras, 17, 41-67.

PALEOKARST AND ASSOCIATED SEDIMENTS AT DUBCI GEOSITE IN DALMATIA, SOUTHERN CROATIA

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Abstract
This short paper brings preliminary results of sedimentological study of Dubci bone-breccia site as an update to former research. The study site is located on the saddle between the mountains Omiška Dinara and Biokovo 404m a.s.l. The site was discovered already at the end of 19th century during road construction between Makarska and Zadvarje. The road cut exposed a cross section through a paleocave covered with coarse clastic sediments in alternation with paleosols. The Dubci site is of Cromerian age (Malez, 1967), one of several Lower Pleistocene sites in Dalmatia with bone breccias rich in fossil skeletal elements of macr mammals and micro mammals. Detailed geological context of the Dubci site was first described by Malez (1967). More recent study of the site indicates even more complex origin of this paleocave and associated sediments, which comprise three sedimentary units. New sediment samples revealed presence of well preserved ostracod fauna, glass spherules and microtectites of probable impact origin, black glass shards, rare microscopic fish bones, benthic and pelagic foraminifers, and particles of various allochthonous lithologies, which all give new input for interpretation of the Dubci site.

Keywords: Croatia, Early Pleistocene, paleocave, cave sediments, coarse clastic sediments, paleosol, spherules, shards, foraminifers, ostracods, geosite

INTRODUCTION

The study site Dubci is located 404 m above modern sea level, on the saddle between the mountains Omiška Dinara and Biokovo. It became exposed by the road construction between Makarska town at the coast and Zadvarje in the hinterland of Biokovo. The road cut opened two subvertical crossections, NW and SE, about 50 m long and 8 m high, which transected a paleocave covered with Pleistocene sediments. Near the end of the 19th century, at the time of road construction works, bone breccia rich in fossil fauna was discovered. Paleontological determinations were done by Gasperini (1885, 1887), Toula (1907) and Thenius (1958). In 1964 Malez (1965a, 1965, 1967) collected new fossil material, performed detail paleontological study and described geological context of the site. He determined the Early Pleistocene - Cromerian age of the sediments based on fossil fauna (Malez 1965b, 1967).
Recently, due to the road cut widening, additional geological study, conducted by the Institute of Quaternary paleontology and geology, was carried out for the purpose of geosite conservation, since the site Dubci is on the rim of the Nature park Biokovo. Special conditions for the road widening were given, and during construction works, all the waste material was collected for separation of bone breccia. Refreshed and clean road sections were then studied in detail, and new samples of sediments were collected for sedimentary and paleontological analyses.

MATERIAL AND METHODS

The filed work comprised detailed mapping of the sections in scale 1:100, detailed description of sediments and sampling. In sediment layers containing large debris, diameter of ten largest clasts was measured, and the mean clast size was calculated. Sediment samples were prepared for analysis by standard method of dissolving and wet sieving (Kummel and Raup, 1965). Preliminary microscopic analysis of silt to fine gravel fractions were done to obtain particle composition. Glass spherules and some mineral grains, found in sand fraction (sieve 0.90mm), were analyzed by SEM coupled with EDAX in the electron microscopy lab of the Geological Department of the Faculty of Science in Zagreb. Further analyses are in process.

RESULTS AND DISCUSSION

The paleokarst (paleocave) and associated Pleistocene sediments are found in the reverse fault zone within the Upper Cretaceous limestones which dip at 40˚ northeastwards (Marin□i□ et al, 1969). Three sedimentary units have been recognized: 1 - paleocave unit, 2 - lacustrine unit, 3 - alluvial unit. All three units are observable on the NW section, whereas on the SE section only the unit 3 is present (Fig. 1). The Units 1 and 2 were studied at NW section, and the Unit 3 at SE section. The Unit 1 was formerly described as Eocene clastics - flysch (Malez, 1967).

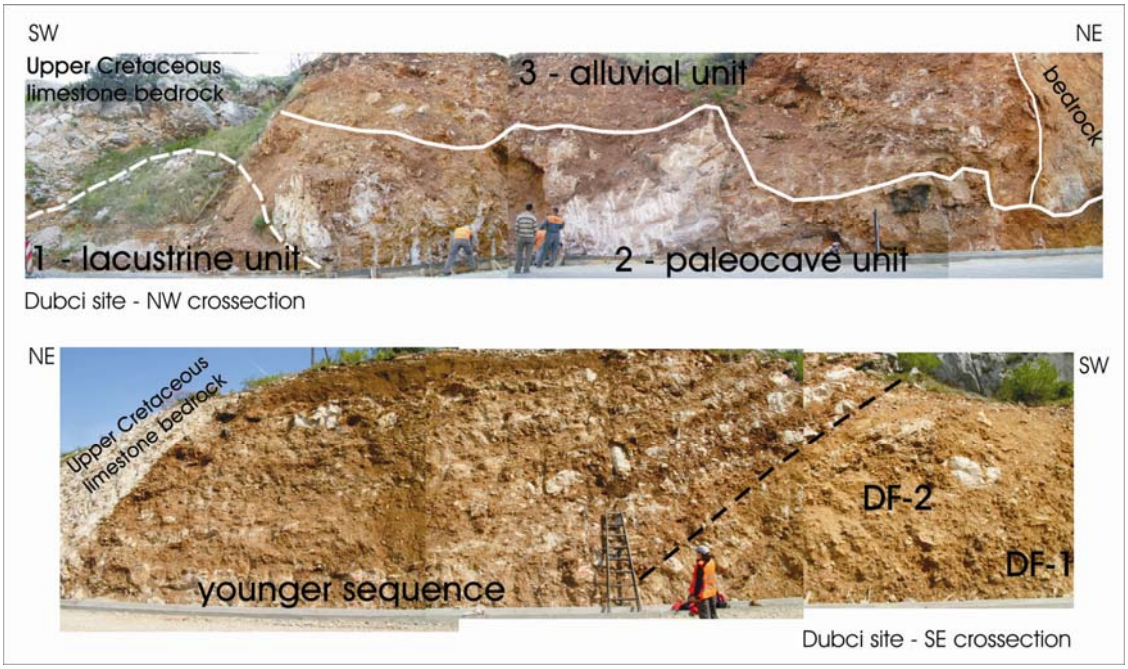

Figure 1. Dubci geosite.

Unit 1. There is a massive stalagmite in growth position, 10 m across and 6 m high, which represents a relict of a big cave, which must have had at least 50 m hanging wall during its active period in post-Cretaceous time. On the left side of the massive stalagmite there are variously oriented limestone blocks overgrown with speleotheme, which seams to be contemporaneous with the massive stalagmite. On the right side of this stalagmite there are limestone cobbles and boulders, and collapsed and broken thin columnar stalactites/stalagmites, which are partly overgrown by younger

tabular speleotheme and partly buried under rock debris. There are two locations of yellowish to red-brown sandy clay accumulations, which probably represent remnants of cave sediments filling large hollows. The sand fraction of clays contains calcite and quartz grains, opaque mineral grains, rock particles and juvenile ostracods *Candona* sp., *Cypridopsis* sp., *Mixtacandona* sp., and adult species *Eucypris* cf. *pigra* (Fischer), the later two indicating shallow fresh water pond environment. A limestone boulder on the left side (2 x 5 m) is a part of rock debris accumulation and is in direct contact with slightly contorted fine grained lacustrine sediments of Unit 2.

Unit 2. A sequence consists of coarse gravel layer, composed of predominantly well rounded gravel of quartz, quartzite and other metamorphic rocks, and an alternation of clay laminae, clayey silt and clayey sand laminae or thin layers, some composed only of quarts sand. Fine grained sediments contain rare, probably resedimented benthic and planktic foraminifers, juvenile ostracods, mica, opaque minerals, black glass shards, quartz and calcite crystal grains, limestone, quartzite and other metamorphic rock particles. Juvenile ostracods *Candona* sp., *Cypridopsis* sp. and *Heterocypris* sp. are indicative of shallow, fresh water (maximum oligohaline) environment, and occur from the beginning of Pleistocene until present. Transparent glass spherules and high temperature bipyramide quartz crystals were found in sand fraction of the gravel layer. They are probably of impact origin, but not resedimented from the Eocene clastics, which also contain transparent glass spherules but of different chemical composition (Marjanac et al, 2004, 2006a, 2006b).

Unit 3. This alluvial unit comprises an alternation of coarse clastic sediments and more-or-less preserved paleosols. They lay over steep and tectonized Upper Cretaceous limestones. Their bedding dip is 40° northeastwards, decreasing to subhorizontal at sharp contact with Upper Cretaceous limestones in the front. As visible on the NW section, these sediments buried the paleocave after it had been destroyed probably by erosion and collapse, possibly in pre-Pleistocene time. These sediments are well exposed on SE section. Ten coarse clastic layers are differentiated. All coarse clastic layers consist of around 70% rock debris - cobbles and boulders of the mean clast size in span from 56,3 cm to 94,7 cm. Sorting is very poor. Clasts are sharp-edged or subrounded. Rarely occur well rounded pebbles. Rounded gravel and sand is common. Clast imbrication indicating downslope transport is recorded in all layers. The first two layers are four meters thick each, and are debris flow (DF) sediments with very low matrix content. Matrix is clayey silt of yellowish light brown color. Matrix of DF-1 layer contains rare small bone fragments, planktic and benthic foraminifers, ostracods, glauconite grains, mica, opaque minerals, quartz grains and bipyramide quartz crystals, transparent glass spherules, microtectites, sulphur and carbon particles, rare microscopic fish bones. Abundant glauconite grains occur as nodules or have shape of planktic foraminifers without tests, probably all resedimented from the Upper Eocene glauconitic limestones and marls. Rare planktic foraminifers with hollow tests were found, which indicates they are contemporaneous to the sediment. Besides resedimented ostracods from Eocene sediments, there are Pleistocene ostracods *Candona* cf. *neglecta* Sars, *Mixtacandona* sp. and *Potamocypris* sp. indicative of a close spring fresh water coming to a ponded water basin. Glass spherules, the same as those in the Unit 1, togeather with microtectites, black glass shards, sulphur and carbon particles, planktic foraminifers, fish bones and bipyramide quartz crystals, make a group of particles indicative of an impact event that might have occurred in the Lower Pleistocene.
The other layers of a younger sequence above DF layers, originated probably by rock avalanches or even debris saturated snow avalanches, which is indicated by nearly vertical position of a boulder in one of them, and concentration of large debris in the zone of low angle dip. Paleosol formed on every coarse clastic layer, after it was filled and covered by fine grained material. The paleosol was than completely or partially eroded by the following rock avalanche. Paleosols are reddish-darkbrown (5YR 5/6). This younger succession of sediments contains fossil bones and bone fragments of macromamals, micromamals and birds. They occur as localized accumulations, and are

found in clayey matrix or mixed with rock debris and cemented, forming bone breccia. According to findings of Malez (1967) this fossil fauna should also belong to Chromerian group. The sand size fractions contain black glass shards and abundant mica flakes, which may indicate on influence of volcanic activitiy during Middle Pleistoncene as documented in central Italy for the period between 350ky and 560ky (Marcolini et al, 2003).

Considering the new data it is likely that sedimentation and events occured in much longer time span than just Cromerian, which equates to only Günz-Mindel Interglacial of the European Alpine region. Sediment characteristics indicate on both cold and snowy, and warm climate periods.
Threafter, the aim of further studies of the Dubci site is to reviel its event stratigraphy, and to define source areas especially of metamorphic rocks, which are not found today in the closer surroundings.

REFERENCES

Gasperini, R., 1885: Contributo alla conoscenza geologica del diluviale Dalmato, *Ann. Dalmatico*, 2, Zara.

Gasperini, R., 1887: Secondo contributo alla conoscenza geologica del diluviale Dalmato, *Progr. dell Scuola Reale Sup. di Spalato* a 1886-87, Split

Kummel, B. & Raup, D., 1965: *Handbook of Paleontological Techniques*, W. H. Freeman and Company, San Francisco, pp. XIII + 852.

Malez, M., 1965a: Paleontološka istra⟩ivanja kvartara u 1963. godini, *Ljetopis JAZU* 70, Zagreb.

Malez, M., 1965b: Der altpleistozäne Fundort Dubci in Mitteldalmatien, *Bull. scient., Sec. A,* 10, 12, Zagreb.

Malez, M., 1967: Donjopleistocenska fauna koštane bre□e kod sela Dubci u Dalmaciji, *Rad Jugoslavenske akademije znanosti i umjetnosti*, 345, 55-100.

Marcolini, F., Bigazzi, G., Bonadonna, F. P., Centamore, E, Cioni, R. & Zanchtta, G., 2003: Tephrochronology and tephrostratigraphy of two Pleistocene continental fossiliferous successions from Italy. Journal of Quaternary Science, 18/6, 545-556.

Marin□i□, S., Korolija, B., Mamu⟩i□, P., Magaš, N., Majcen, □., Brki□, M. & Ben□ek, Đ., 1969: *Tuma□ OGK List Omiš K 33-22*, Savezni geološki zavod, Beograd, pp. 51.

Marjanac T., Bermanec V. & Premec-Fu□ek V., 2004: Late Eocene megabed with glass sphaerules and microtectites in eastern Adriatic flysch (Croatia). 32th International geological congress, Florence 2004, Abstracts 1, 542

Marjanac T., Bermanec V., Premec-Fu□ek V., Marjanac Lj. & Tomša A.M., 2006a: Eocene glass spherule-bearing turbidites in eastern Adriatic flysch - evidence of multiple impacts into sedimentary targets? 40th ESLAB 1st International Conference on Impact Cratering in the Solar System. 8-12. May 2006, Noordwijk, Abstract Book, 135

Marjanac T., Bermanec V., Premec-Fu□ek V., Marjanac Lj. & Tomša A.M., 2006b: Glass spherules in Upper Uocene flysch of Croatian Adriatic - evidence of an impact into carbonate target? ESLAB-40. First International Conference on Impact Cratering in the Solar System. 8-12 May 2006 ESTEC, Noordwijk ESA CD WPP-266.

Thenius, E., 1958: Über einen Kleinbären aus dem Pleistozän von Slowenien nebst Bemerkungen zur Phylogenese der plio-pleistozänen Kleinbären, *Razpr. SAZU, Cl.* 4, 4, Ljubljana.

Toula, F., 1907: Rhinoceras Mercki Jäger Österreich, *Jahrb. d. k. k. geol. R. A.*, 57, Wien.

GLACIAL SEDIMENTS IN DINARIC KARST

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Abstract
Dinaric karst in Croatia hosts, among other, rather extensive sediments of Pleistocene age, some of which are interpreted as of glacial, proglacial and periglacial origin. The detailed field study of northern Adriatic islands and Croatian eastern Adriatic coast, as well as southern Velebit Mt. revealed presence of ice derived sediments, sediments reworked by glacial meltwaters, glaciolacustrine sediments, as well as glacial, periglacial and glaciotectonic features. The age of these sediments is so far constrained only by ostracod fauna found in associated lacustrine sediments which yield an Early Pleistocene age. More precise age determination may become available by dating of tillite cements, which at the moment of writing were not completed.

Keywords: Adriatic, Dinarides, glaciation, Pleistocene sediments, diamictons, moraine, kame-terrace, eratics

INTRODUCTION

The continuous study of glaciation of Croatian Dinarides progressively provides more data on its extent and variety of facies. So far, glacial deposits were recognized at several localities in rather large area, on the Risnjak Mt. (Bognar & Prugove□ki 1997), Northern Velebit Mt. (Bognar et al. 1991), Kvarner, Southern Velebit Mt., Dalmatia, and Knin and Drniš area. There are probably many other localities with glacial sediments, but are not recognized as such due to insufficient research.
The key questions in recognition of glacial sediments are: a) could these sediments originate by other non-glacial processes, b) what can be concluded on grounds of sediment geometry and facies, c) where is provenance of debris found in studied sediments and what is their most likely transport avenue. Skeptics= major argument is that the studied sediments, interpreted as moraines, were deposited from debris-flows. However, it is important to note that interpretation must be a result of extensive study of whole sediment succession, and must take into account the whole set of observational data such as deposit (sedimentary body) geometry, its structure and texture, relationship with other depositional units, sediment composition and provenance of debris.
The presented results and interpretations have accumulated during 20 years of our research in coastal Dinarides and are partly published elsewhere (Marjanac et al. 1990, Marjanac & Marjanac 1994, 1999, 2004 a, b), but a large number of presented data has not been published yet. Some of the ideas, like Dinaric model of glaciation are still Aunder construction@. Key sections (Fig. 1) are located on Krk (A) and Pag (B) islands, in Senjska Draga (C), on Veliko Rujno (D), in Velika Paklenica (E), in Seline (F), □rilo (G), at the coast of Novigradsko (H) and Krinsko (I) more, in Obrovac (J) and □egar (K). This study was part of the research projects 1-09-084, 119-303, 0119-401 and 119-0000000-1164 funded by the Croatian Ministry of Science.

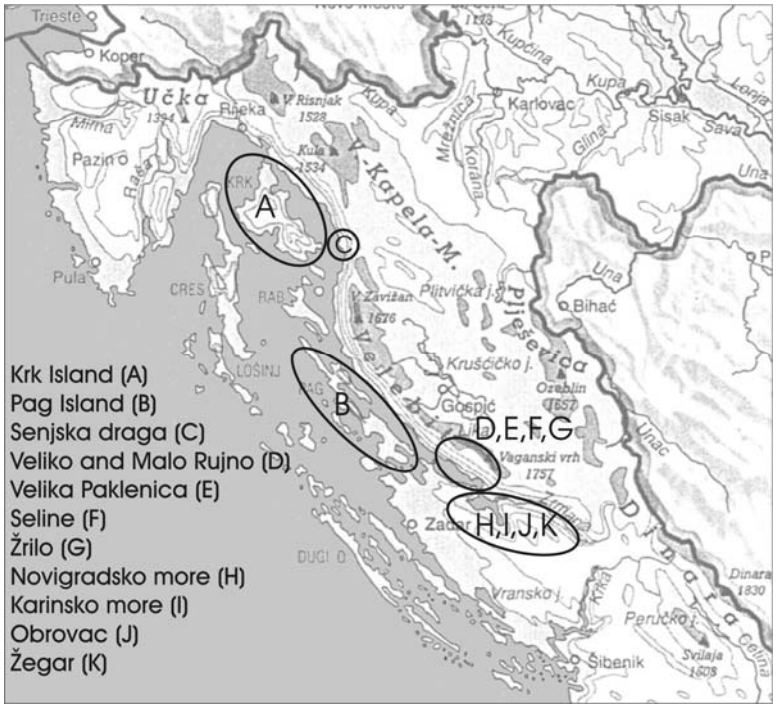

Figure 1. Study areas.

RESULTS AND DISCUSSION

A set of sediment types and sedimentary bodies are recognized in the studeid areas, which document ice-contact and periglacial depositional environments, as well as several phases of ice advance and retreat.

Fine-grained sediments herein comprise silty clay, clayey silt, silt, sand and gravel deposits. Except for silt and finest-grained sand, which may be also of aeolian origin, all of the lithologies indicate deposition in aquatic environment by stream flow and suspension deposition, in other words lacustrian and fluvial environments.

Lacustrian sediments are represented by alternation of silty clay-clayey silt-silt to very fine sand - varved sediments deposited in proglacial lakes which were occupying southern part of the Velebit Channel. Proximal facies occur in Seline, at Novigradsko more, Karinsko more, and near □egar. Many dropstones are found in sediments at Seline section and Novigradsko More coastal section. Distal facies is well exposed at key section □rilo. At well visible contact (Fig. 2), large rip-up clasts incorporated in the overlying ground moraine document a large-scale erosion of the underlying glaciolacustrine sediments. Erosion of glaciolacustrine sediments by younger moraine is also visible at Novigradsko more coastal section. There also occur ice-wedge casts in glaciolacustrine sediments.

Calcareous sands/sandstones and gravel deposits represent a variety of fluvial environments. Meandering fluvial channels are exposed on Krk and Pag islands, and Novigradsko more. These large fluvial channels (5-15 m deep and 25-100 m wide) have originally been ice-marginal rivers flowing between ice tongue and valley slope. There drainage basin and tributary system is missing today. Sediments left by those rivers built parts kame-terraces charcteristic for the ice-marginal zone, and their erosional remnants are found on Krk and Pag islands between 50 and 200 m a. s. l.. Sand and gravel deposits also represent breaded stream deposits and are interpreted as sandur - the periglacial outwash plane sediments (northern Dalmatia study area).

Figure 2. Key section Žrilo. Ground-moraine overlying deformed glaciolacustrine varved sediments.

Coarse-grained sediments comprise pebble-cobble-boulder deposits. They are matrix-supported to grain-supported diamictons containing angular to rounded rock debris, or occur as isolated boulders. Diamictons are commonly unsorted to poorly sorted, poorly- to well cemented, unorganized sediments with the largest clasts commonly around 1 m, exceptionally larger thyn 25 m in diameter (Velika Paklenica).

The matrix-supported diamictons are interpreted as tills or tillites, and form sedimentary bodies which locally occur as valley-marginal bodies (Krk island latteral moraines associated with kame-terraces), valley-longitudinal ridges (Veliko Rujno medial moraine, previously interpreted as terminal moraine, Nikler 1973), valley-normal walls (Velika Paklenica De Geer moraines), and valley-bottom sheets (Velika Paklenica ground-moraines). Glacial striae were found on some cobbles and boulders at several study sites (Veliko Rujno, Novigradsko more, Velika Paklenica, rilo, Obrovac).

Diamictons are composed of "local" lithologies, which are common throughout the Dinaric mountains, so it is difficult to decipher their provenance. However, clasts of Permian siltstones, and Lower Triassic micaceous sandstones give some idea of provenance because their occurrence is limited to two areas, upper reaches of the Velika Paklenica valley and the hinterland of the Knin city in Dalmatia.

Taking into consideration that these diamictons might be debris- or mud-flow deposits, it must be noted that matrix content of these diamictons is insufficient to suspend the largest clasts. Taking also into account their position in the field, the flow must have been of enormous size, and should have climbed the far side of Novigradsko More, after crossing its 30 m deep basin and suffering significant flow expansion. In the case of Novigradsko More, the closest high mountainous relief as a possible source of this hypothetical mud flow, is located ca. 20 km away.

The grain-supported sediments are interpreted as breccia or conglomerate, and locally matrix filled interspaces between clasts, whereas locally the sediment is open-work and the interspaces are filled with calcite cement. They can be organized, normal or inverse graded, clasts imbricated, or on the contrary can have chaotic fabric. These sediments commonly built valley-marginal terraces. They are interpreted as kame-terraces with characteristic slopeward bedding dip, the ice-contact sedimentary bodies, whose erosional remnants occur on Krk and Pag islands. Breccias and conglomerates aslo occur as subvertical valley walls - Krk island and Velika Paklenica lateral moraines.

Clast-supported openwork sediments with chaotic fabric are recognized as snow and ice avalanche deposits. These sediments occur in valley-normal fashion and probably form small avalanche cones (Krk island, Velika Paklenica, but also on Biokovo Mt.).

Sediment wedges filled with clast-supported chaotic debris, sometimes with clasts lining the walls, occur

in variety of sizes; from ca. 2 m up to ca. 10 m in depth, and 1 m to 6 m wide, and are interpreted as filled ice-wedge casts (Krk Island, Rab Island, Pag Island, Velika Paklenica, Novigradsko More).
Isolated boulders (extraclasts) occur scattered in the studied areas. Some are obviously rockfall and rock-failure sediment, but some like on the Pag island and Southern Velebit lithologically do not match nearby topographic sources and some stand on topographic highs. These extraclasts are interpreted in terms of eratic blocks which have been ice-driven and left at their present position after glacier retreat. Eratic blocks on Bojinac on the Southern Velebit Mt. occur above 800 m a.s.l. and stand on karstified (fluted) rock surfaces on topographic highes, which they could not reach by gravity. They are 8 - 25 m across.

AGE

The glaciation in Dinarides certainly post-dates karstification, because moraines locally comprise large clasts of fluted limestones, and eratic blocks stand on the fluted bedrock. However, the only direct evidence of its age are just poorly preserved ostracods recovered from the lacustrine sediments in Ravni Kotari (Malez & Soka 1969), which indicate generally Middle Pleistocene age. Independent research in Montenegro (Phil Hughes, personal communication) showed that the age of cements in tillites reaches ca. 350.000 years BC, what is broadly consistent with the available palaeontological age.

CONCLUSION

Study of the Pleistocene sediments in the coastal Dinarides and eastern Adriatic islands revealed their glacial or periglacial origin. It was possible to approximate limits of Pleistocene glacial extent at key sections on Krk and Pag islands, rilo and Novigradsko More. We assume that the glacial history in the Eastern Adriatic was dominated by at least two major glacial episodes, with one warm (? interglacial) period between, as documented by paleosol and traces of higher vegetation, although not discussed in this paper. Each glacial episode, however, comprised several pulses of glacial advance followed by retreat, as documented by succession of studeid sediments, de Geer moraines and glaciotectonic deformations. The glaciation was very extensive and the valley glaciers crossed the present Velebit channel, after descending from the high mountains down to 30 and maybe more metres below the modern sea-level.

REFERENCES

Bognar A., Faivre S. & Paveli J., 1991: Tragovi oledbe na Sjevernom Velebitu. (Glaciation traces on the Northern Velebit). *Geografski glasnik 53,* 27-39. Zagreb

Bognar A. & Prugove ki I., 1997: Glaciation Traces in the Area of the Risnjak Mountain Massif. *Geologia Croatica 50/2,* 269-278, Zagreb.

Malez M. & Soka A., 1969: O starosti slatkovodnih naslaga Erveni kog i egarskog polja. *III Simpozij dinarske asocijacije 1,* 81-93 Zagreb

Marjanac Lj. & Marjanac T., 1999: Polyphase kame terraces on the Island of Pag (Eastern Adriatic, Croatia). Field Symposium on Pleistocene Stratigraphy and Glacial Chronology, Southern Estonia 1999, Abstract volume, 34-35, Tartu 1999

Marjanac L. & Marjanac T., 1994: Slopeward-dipping terraces on NE Adriatic islands, Pleistocene low altitude kame-terraces? Abstracts 15th Regional Meeting IAS Ischia, 271-272.

Marjanac Lj. & Marjanac T., 2004a: Glacial history of Croatian Adriatic and Coastal Dinarides. In: Quaternary Glaciations - Extent and Chronology (ed. by J. Ehlers & P.L. Gibbard). Developments in Quaternary Science, 2a, Elsevier. 19-26.

Marjanac Lj. & Marjanac T., 2004b: Quaternary glacial and associated deposits of Velika Paklenica and Rujno (Southern Velebit Mt., Croatia). In: Adriatic-Dinaric Mesozoic carbonate platform, environments and facies from Permian to recent time. 32th International geological congress, Florence - Italy, August 20-28, 2004, Field-trip guidebook - P53, 27-29.

Marjanac T., Marjanac Lj. & Oreški E., 1990: Glacijalni i periglacijalni sedimenti u Novigradskom moru. *Geol. vjesnik 43, 35-42,* Zagreb.

Nikler L., 1973: Nov prilog poznavanju oledbe Velebita. *Geol. vjesnik 25 (1971), 109-112,* Zagreb.

THE IMPACT OF BLASTING ON CAVE VELIKA PEĆA

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Abstract
Cave Velika Peća is situated near Grabovac village, which is positioned in the background of mountain Biokovo on the part of Šestanovac-Zagvozd motorway. The cave is a natural speleological object which is an important archeological site too. Velika Peća consists of limestones, upper Cretaceous.
On the part of motorway route above the cave test blasting was made with the purpose of evaluating the possibility of damage beginning in limestones in the cave and measuring seismological impacts of blasting with calculation of permitted mass of explosive charge.
The route of Šestanovac-Zagvozd motorway which is under construction passes close to the cave. The technology of excavation includes drilling and blasting. The nearest distance of final slope from the cave is 10 m. The impact blasting and propose drilling blasting parametars for the future were determinated towards execute measuring of oscillation velocities on the occasion of test blasting. On the occasion of blasting oscillation velocities of the ground were measured with transport seismographs and deformations with LVDT sensors. Six points of monitoring for a test blasting field MP-1 were placed and eight points for a test blasting field MP-2. Mass of the explosive charge of blasting field MP-1 was 25,5 kg and for a MP-2 36,0 kg with the sequence of milisecond delay blasting. During the both blasting measuring oscillation velocities of the ground in points of monitoring in the cave were under the permitted standard DIN 4150. LVDT sensors did not record any deformations on the measured points on the limestones of Cave Velika Peća. Intensity of shaking caused by blasting was determinated by measuring the oscillation velocities of the ground in points of monitoring. Permitted oscillation velocities of the ground for the cave is middle value of a permission velocities between the historical monument and the apartament v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for a continuation of blasting works on the part of motorway route above the cave. Applied standard is DIN 4150 with frontier permission of oscillation velocities from v_{per}=1,0 cm/s.

Keywords: limestones, blasting, seismological impacts of blasting, deformations, archeological site

INTRODUCTION

Cave Velika Peća is situated near Grabovac village, which is positioned in the background of mountain Biokovo on the part of Šestanovac-Zagvozd motorway *(Fig. 1)*. The cave is a natural speleological object which is important archeological site. The object was blessed and dedicated to religous aims *(Fig. 2)*. The entrance of the cave is on 414 m a.s.l. between tops Lisača 576 m a.s.l. and Velika Orljača 909 m a.s.l.

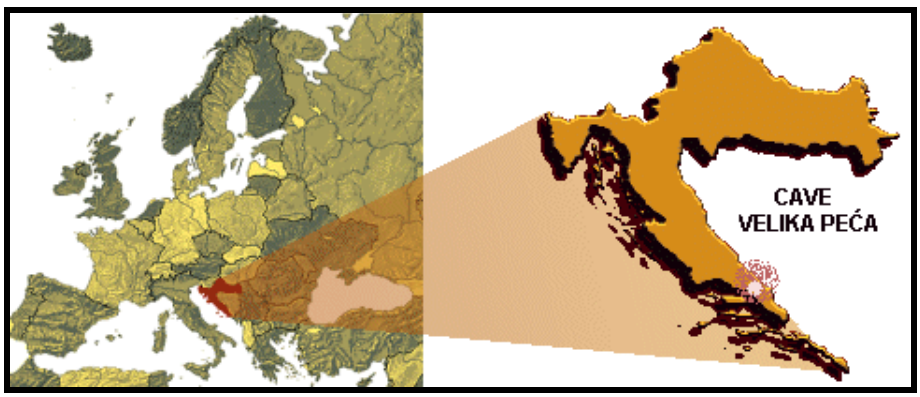

Fig. 1: Location map with regional view

Velika Peća is the cave in formation what is obvious for a numerous stalactites and stalagmites *(Fig. 3).* Speleological prospect have established a fact that the cave is a ramify type. Space of the cave is in the Dinaric zone with typical karst landscape, specific surface, underground and solution shapes. The cave consists of limestones upper Cretaceous. Shabbing of limestones rocks take its rise sediments in form of pebbles and clay.

Fig. 2: Entrance in Cave Velika Peća

Fig. 3: Inside Cave Velika Peća

The route of Šestanovac-Zagvozd motorway which is under construction passes close to the cave. The original route of motorway was moved 10 m towards N because it was necessity to preserve site Velika Peća. On the part of motorway route above the cave test blasting was made with the purpose of evaluating the possibility of damage beginning in limestones in the cave and measuring seismological impact of blasting including the calculation of permitted mass of expolosive charge.

MATERIAL AND METHODS

Measuring the oscillation velocities of the ground and deformations

Two test blasting field MP-1 from st. 44+625 m to st. 44+645 m and MP-2 from st. 44+400 m to st. 44+410 m were exploded. MP-1 contain 120 wells and MP-2 contain 60 wells which was main explosive charge amonal-patron Ø 60 mm. Initiation was with nonelectric system initiation with conectors slowless 25 i 42 ms. Maximum mass of the explosive charge of blasting field MP-1 was 25,5 kg and for a MP-2 36,0 kg with the sequence of milisecond delay blasting. On the occasion of blasting oscillation velocities of the ground were measured by transport seismographs type Instantel Minimate, Instantel Minimate plus, Instantel Minimate plus 8 i Instantel Blastmate Series III *(Fig. 4)* which are applied by ISO 9001 standard.

Fig. 4: Seismograph Instantel Blastmate Series III

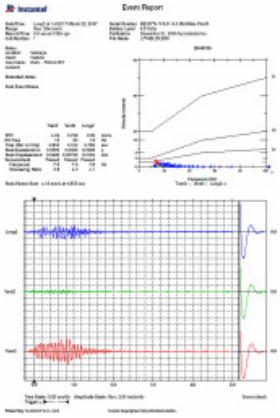

Fig. 5: Trajectories of oscillation velocities

Six points of monitoring for a test blasting field MP-1 were placed and eight points for a test blasting field MP-2. Trajectories of the oscillation velocities were recived *(Fig. 5)*. On the occasion of blasting, deformations were measured by LVDT sensors in two points inside Cave Velika Peća *(Fig. 6)*.

Fig. 6: Measured deformations with LVDT senzors inside Cave Velika Peća

Establish a fact about intensity of shaking

Intensity of shaking caused by blasting was determined by measuring the oscillation velocities of the ground in a points of monitoring. On the occasion of seismological impacts of blasting at the test blasting on the part of motorway route above the cave instruments were used to evidence frequency oscillations of the ground automatically for every measured value and for a three components of oscillation velocities. After that DIN 4150 standard results diagram was drawn.

Estimate permitted mass of the explosive charge

Within several years of monitoring and measuring the dependance between oscillation velocities, mass of the explosive charge and distance between motorway and blasting field were established by M. A. Sadovski equation *Eq. (1)*:

$$v = k\left(\frac{\sqrt[3]{Q}}{R}\right)^{n} \qquad \textit{Eq. (1)}$$

Where are: $\boldsymbol{v}$ – oscillation velocities of the ground (cm/s), $\boldsymbol{Q}$ – mass of the explosive charge (kg), $\boldsymbol{k}$ – coefficient of blasting way, $\boldsymbol{R}$ – distance between place of monitoring and blasting field (m), $\boldsymbol{n}$- smother coefficient of seismic waves and $\frac{\sqrt[3]{Q}}{R} = \rho$ represent mass of explosive charge.

$$v_{r1} = k\,\rho_1^n \qquad \textit{Eq. (2)} \qquad \text{and} \qquad v_{r2} = k\,\rho_2^n \qquad \textit{Eq. (3)}$$

At the blasting time $\boldsymbol{Q}$ and $\boldsymbol{R}$ were known. Coefficients $\boldsymbol{k}$ and $\boldsymbol{n}$ were calculated from the system of equation *Eq. (2)* and *Eq. (3)*.

$$n = \frac{\log\frac{v_{r1}}{v_{r2}}}{\log\frac{\rho_1}{\rho_2}} = \frac{\log\frac{v_{r1}}{v_{r2}}}{\log\frac{R_2}{R_1}} \qquad \textit{Eq. (4)} \qquad \text{and} \qquad k = \frac{v_{r1}}{\rho_1^n} = \frac{v_{r2}}{\rho_2^n} \qquad \textit{Eq. (5)}$$

Computer programme calculates coefficients $\boldsymbol{n}$ *Eq. (4)*, $\boldsymbol{k}$ *Eq. (5)* and permitted mass of explosive charge with the sequence of milisecond delay blasting. Measured oscillation velocities of the ground applied DIN 4150 standard and the criteria for some type of buildings was determined: 0,5 cm/s for the buildings and the historical monument, 1,5 cm/s for the apartaments and 4 cm/s for the industrial buildings.

Permitted oscillation velocities of the ground for the cave is middle value of a permission velocities between the historical monument and the apartaments v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for the continuation of blasting works on the part of motorway route above the cave. Permitted mass of the explosive charge of blasting with the sequence of milisecond delay blasting for eastern direction (Ploče) was taken from measured point MO-1>MO-2 at the blasting field MP-1. For the western direction (Split) permitted mass of the explosive charge of the blasting with the sequence of milisecond delay blasting was taken from measured point MO-V/1>MO-V/2 for the blasting field MP-2.

RESULTS AND DISCUSSION

On the basis of test blasting, tests gave parameters for maximum values of explosive charge for a distant blasting work. Results of test blasting are in *Table 1* and *Table 2* and were under the permitted DIN 4150 standard.

Points of monitoring	Distance from the MP-1 m	Max mass of the explosive charge kg	Oscillation velocities of the ground cm/s			
			v_l	v_v	v_t	v_{rez}
MO-1-way - MM+8-1	36,0	25,5	2,41	2,86	2,98	3,74
MO-2-way - MM+8-2	60,0	25,5	1,69	1,46	1,69	2,23
MO-3- way - MM 5421	88,0	25,5	1,14	0,483	1,45	1,55
MO-4- way - BM II	111,0	25,5	0,864	0,622	0,559	1,02
MO-5-cave - MM +	86,0	25,5	<0,1	<0,1	<0,1	<0,1
MO-6-cave - BM III	102,0	25,5	<0,1	<0,1	<0,1	<0,1
Deformations – LVDT sensors (mm)						
MO-5-cave - LVDT-1	under the sensitiveness of instrument (0.0396 mm)					
MO-6-cave – LVDT-2	under the sensitiveness of instrument (0.0396 mm)					

Table 1. Results of measuring test blasting field MP-1 from st. 44+625 to st. 44+645

Points of monitoring	Distance from the MP-2 m	Max mass of the explosive charge kg	Oscillation velocities of the ground cm/s			
			v_l	v_v	v_t	v_{rez}
MO-1-way - MM+8-1	31,0	36,0	3,25	1,75	4,53	4,56
MO-V/1-way - V-1, MB	41,0	36,0	1,36	1,42	1,87	2,19
MO-2-way - MM+8-2	58,0	36,0	1,37	0,952	1,30	1,79
MO-V/2-way - V-2, MB	73,0	36,0	1,65	0,914	1,60	2,34
MO-3-way - MM 5421	78,0	36,0	1,07	0,914	1,63	1,69
MO-4 - BM II	102,0	36,0	0,0127	0,483	0,787	0,87
MO-6-cave - BM III	111,0	36,0	0,343	0,203	0,178	0,436
MO-5-cave - MM +	127,0	36,0	0,0254	0,127	0,165	0,209
Deformations – LVDT sensors (mm)						
MO-5 - LVDT-1	under the sensitiveness of instrument (0.0396 mm)					
MO-6 - LVDT-2	under the sensitiveness of instrument (0.0396 mm)					

Table 2. Results of measuring test blasting field MP-2 from st. 44+400 to st. 44+410

Location:		**Cave Velika Peća**		
Type of explosive:		**Amonal Ø 60**		
No. blasting field:		MP	1	2
No. points of monitoring:		MO=	2	2
Explosive charge (kg)		Q=	25,5	36
Velocities in MO-1 (cm/s)		v_{r1}=	3,740	4,560
Velocities in MO-2 (cm/s)		v_{r2}=	2,230	2,190
Distance MP to MO-1 (m)		R1	36,00	31,00
Distance MP to MO-2 (m)		R2	60,00	41,00
Permitted oscilation velocities (cm/s)		v_{per}=	1,00	1,00
Distance for MP-1 and MP-2				
min	Rmin	18	m	
max	Rmax	100	m	
interval	Rz	1	m	
CALCULATE INFORMATIONS				
R for MP-1	Q for MP-1	R for MP-2	Q for MP-2	
18	0,06	18	1,24	
19	0,08	19	1,46	
20	0,09	20	1,70	
25	0,17	25	3,33	
30	0,30	30	5,75	
35	0,47	35	9,14	
40	0,70	40	13,64	
45	1,00	45	19,42	
50	1,37	50	26,64	
55	1,82	55	35,46	
60	2,37	60	46,03	
65	3,01	65	58,53	
70	3,76	70	73,10	
75	4,62			
80	5,61			

Table 3. Permitted mass of the explosive charge of the blasting with the sequence of milisecond delay

During the both blasting measuring oscillation velocities of the ground in a points of monitoring in the cave were under the permitted DIN 4150 standard. LVDT sensors did not record any deformations on the measured points on the limestones of Cave Velika Peća *(Table 1, Table 2)*.

Intensity of shaking, caused by blasting, was determined by measuring the oscillation velocities of the ground in a point of monitoring. Permitted oscillation velocities of the ground for the cave is a middle value of a permission velocities between the historical monument and the apartament v_{per}=1,0 cm/s. Mass of explosive charge was determined according to permitted oscillation velocities of the ground v_{per}=1,0 cm/s for a continuation of blasting works on the part of motorway route above the cave. Applied standard is DIN 4150 with frontier permission of oscillation velocities from v_{per}=1,0 cm/s. Results of the measuring during test blasting field MP-1 and MP-2 eliminated possibility of initiating damage in Cave Velika Peća.

In SE direction towards Ploče oscillation velocities from 1 cm/s on the bedrock of the cave were accomplished. In the cave the oscillation velocities were twice smaller. Maximum mass of the explosive charge of blasting with the sequence of milisecond delay blasting can not be more then 15 kg. In NW direction towards Split maximum mass of the explosive charge of blasting with the sequence of milisecond delay blasting can not be more then 36 kg *(Table 3)*.

This documented data provided and described the importance of blasting, measuring seismological impacts of blasting and any deformations in limestones and other karst sediments. Blasting should be the top priority for all local and regional planning process in karst areas specially when we work on or near the caves, archeological sites, industrial buildings and historical monument in karst region.

REFERENCES

Ester, Z., 2005: Miniranje I, Eksplozivne tvari, svojstva i metode ispitivanja. Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 176 pp.

Ester, Z. & Dobrilović, M., 2007: Izvještaj o mjerenjima seizmičkih utjecaja miniranja i proračun dozvoljenih količina ekspolozivnog punjenja na djelu trase iznad Velike Peći, pokusna miniranja 22.03.2007. Arhiv Rudarsko-geološko-naftnog fakulteta, Zagreb.

Ester, Z. & Dobrilović, M., 2007: Izvještaj o mjerenjima seizmičkih utjecaja miniranja i proračun dozvoljenih količina ekspolozivnog punjenja na djelu trase iznad Velike Peći, miniranja 03.04.2007. Arhiv Rudarsko-geološko-naftnog fakulteta, Zagreb.

Garašić, M., 1991: Morphological and hydrogeological classification of speleological structures (caves and pits) in the Croatian karst area. (Morfološka i hidrogeološka klasifikacija speleoloških objekata (spilja i jama u krškom području). Geol. vjesnik, 44, Zagreb.

Garašić, M. & Cvijanović, D., 1984: Uzročna veza između pojave lokalnih potresa i speleoloških objekata u kršu. (Rapport de cause a effet entre les seismes et les phenomenes speleologique dans le karst localises). Zbornik predavanja 9. jugosl. Speleol. Kong. Karlovac (1974), Zagreb, 431-441 pp.

Krsnik, J., 1989: Miniranje. Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 180 pp.

Raić, V., Ahac, A. & Papeš, J., 1976: Osnovna geološka karta SFRJ 1:100.000. List Imotski K 33-23. Inst. geol. istraž. Sarajevo (1962-1967). Savezni geol. zavod, Beograd.

Raić, V. & Papeš, J., 1978: Osnovna geološka karta 1:100.000. Tumač za list Imotski K 33-23. Inst. geol. istraž. Sarajevo (1968). Savezni geol. zavod, Beograd.

SPECIES RICHNESS FROM POOLS AND DRIPS IN SELECTED ROMANIAN CAVES

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Abstract
The epikarst fauna was studied in two caves of Padurea Craiului Mountains (NW Romania) during the period November 2005 – May 2006. Sampling of two drips and one pool in each cave was performed with a procedure which allowed continuous collecting. The dominant component in terms of abundance and species richness within the faunal assemblage was copepods. In the focus of this study was the estimation of cyclopoid copepods richness from dripping water and pools with clay and calcite bottom. Sampling completeness was examined from a local point of view. Statistical analyses were performed using EstimateS version 7.5 software. Based on species accumulation curves and Chao estimates of total diversity it was determined that seven months of sampling period was not sufficient to identify all expected species in drips and pools from Ungurului cave. In the case of Vântului cave three months of sampling from two drips and one pool were proved to be enough to reach the plato of all expected species. This work represents the first Romanian study of fauna from percolation water which contributes to the understanding of ecology and biogeography of cyclopoid copepods in subterranean habitats. Results are in accordance with the recent study from Slovenia which showed that epikarst is a rich habitat for a wide variety of animals.

Keywords: Specie richness, caves, Romania, epikarst, Copepoda, accumulation curves, biospeleology

INTRODUCTION

The epikarst is the zone which is above the cave and it is the most upper layer of the rock beneath the soil. For invertebrates this habitat has already been established as a biodiversity hotspot (Pipan, 2005). A potential to find specialized troglobiotic organisms in such environments is very high (Pipan & Culver, 2007) The inaccessibility of epikarst makes direct faunal examination impossible that is why communities inhabiting epikarst should be sampled indirectly by collecting and filtering dripping water in caves from trickles and pools. From percolating water numerous groups of animals have been collected: Nematoda, Copepoda, Oligochaeta, Ostracoda, Isopoda, Acarina, Diplopoda, Collembola, Araneae, Coleoptera, Insects larvae, Bathynellaceae (Pipan, 2005, Pipan & Culver, 2005a). The most common and the most abundant group of animals in the epikarst is Copepoda (Crustacea). Pipan (2005) made in Slovenia up-to date the most extensive research of epikarst copepods, by sampling continuously thirty-five drips in six caves for more than one year. The species richness of cave fauna, which was obligated to adapt aphotic and food-scarce conditions was difficult to quantify, especially in the terms of regional patterns (Pipan & Culver, 2007).
The aim of this study was the investigation of the regional diversity patterns of Cyclopoidea (Copepoda, Crustacea) from drips and pools, copepod richness and sampling completeness in two caves in Romania. Further in the paper, the sampling sufficiency in the two caves was studied.

MATERIAL AND METHODS

This study was conducted in two caves, Ungurului cave and Vântului cave from Padurea Craiului Mountains (NW Romania, Fig. 1). Ungurului cave and Vântului cave are part of the Crisul- Repede karst basin and are both developed in Ladinian (middle Triassic) limestone. Caves are geographically close to each other and are equipped for tourist visit as show caves. Vântului cave is the longest cave in Romania (50 km). Ungurului cave is a well known show cave in Transilvania, the cave is long 1.5 km with a large entrance (dimension of the entrance 22 by 32 m). In each cave two drips and one pool were selected for the study. Sampling sites in Vântului cave were near to the entrance, 30 and 40 m

respectively along the subterranean river. In Ungurului cave one drip was situated near to the entrance (25 m), the second drip and pool were deep in the cave (500 m). Sampling was conducted in the period from October 2005 till May 2006.
The sampling of percolating water was performed by taking samples from drips using a continuous sampling technique (for reference see Pipan, 2005), and by filtering water from pools filled with seeping water from the walls. For water filtering a net of mesh size 60 µm was used. Samples were preserved in 90 % alcohol.
For computation of abundance-based and incidence-based statistical analyses EstimateS software, version 7.5 (Colwell, 2005) was applied. For analyses four drips and two pools were used; two drips and one pool from Ungurului cave and two drips and one pool from Vântului cave. Data on abundance were summed over the sampling season. Accumulation curves were based on Mao-Tau estimates of species richness (Colwell et al., 2004), and total expected number of species on Chao's and ACE abundance-based estimator.

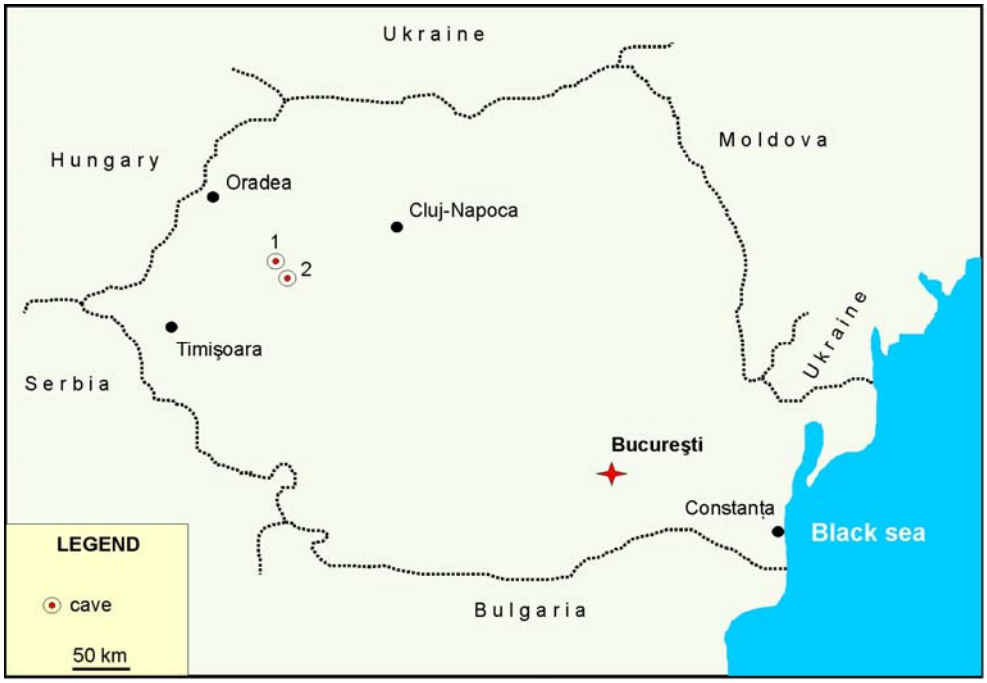

Fig. 1: Map of the study area in Romania (1- Ungurului cave, 2- Vântului cave).

RESULTS AND DISCUSSION

In Ungurului cave and Vântului cave 10 groups of invertebrates were identified what indicated high level of biodiversity (Table 1). This can be annotated to the heterogeneity of microhabitats in the karst unsaturated zone (Oarga, 2006).
In both studied habitats, drips and pools, the most abundant faunal group was Copepoda (Cyclopoida and Harpacticoida). Interestingly, in both caves in the same habitat the presence of various species was noticed. More evidently in Ungurului cave in one sampled pool four species of cyclopoids were identified (*Acanthocyclops reductus reductus*, *Speocyclops troglodytes*, *Eucyclops* sp, and *Megacyclops* sp.; Table 2). This can be attributed to large quantity of organic matter in sampled pools with clay sediment at the bottom and to the presence of guano which was observed in the immediate vicinity of the sites. Biodiversity and its patterns at local and, to some degree, at regional scales are controlled by productivity (Gibert and Deharveng, 2002).

Table 1: Invertebrate groups found in Ungurului and Vântului cave in November 2005-May 2006

Animal groups/ Caves	Pestera Vântului	Pestera Ungurului
Nematoda	+	+
Gastropoda	+	+
Oligochaeta	+	+
Aranae		+
Acarina	+	+
Ostracoda	+	+
Copepoda	+	+
nauplia	+	+
Amphipoda		+
Colembolla		+
Insecta- larvae	+	+

From five species collected from drips and pools in Ungurului cave and Vântului cave, two were stigobionts (*Speocyclops troglodytes* and *Acanthocyclops reductus reductus*). *Acanthocyclops reductus reductus* was found for the first time in Ungurului cave and Padurea Craiului Mountain (Oarga, 2006; Iepure et al., in preparation).

Table 2: Cyclopoid species from trickles and pools in Ungurului and Vântului caves

Cyclopoida	Pestera Vantului		Pestera Ungurului	
	trickles	pools	trickles	pools
Acanthocyclops reductus reductus (Chappuis, 1925)	+		+	
Acanthocyclops sp.			+	+
Speocyclops troglodites (Chapuis, 1925)	+	+		+
Eucyclops sp.				+
Megacyclops viridis (Jurine, 1921)				+

Species accumulation curves for sampled drips and pools for both caves are shown in Fig. 2 and Fig. 3. If the species accumulation curves reach an asymptote the sampling should be complete (Pipan and Culver, 2007). For Ungurului cave (Fig. 2) there was no indication that the specie accumulation curve (Mao-Tau) reached the asymptote. Chao 1 estimates of total species-richness were higher than the observed number of species. At the scale of this particular cave and sampled habitats (two drips and one pool) sampling was not sufficient to capture most of the species. In the case of Vântului cave, the species accumulation curve appeared to reach the asymptote (Fig. 3). Based on the results we can conclude that three months sampling was probably sufficient to find the majority of present species from epikarst habitat. The fact that *Eucyclops* sp., and *Megacyclops* sp. were found only once in Ungurului cave (Table 2) in the same pool can be explained with incomplete sampling or these two organisms can be considered accidental dwellers for this cave. Results of statistical analysis showed that in the case of Ungurului cave continuous sampling should be performed to reach the asymptote value of total species richness.

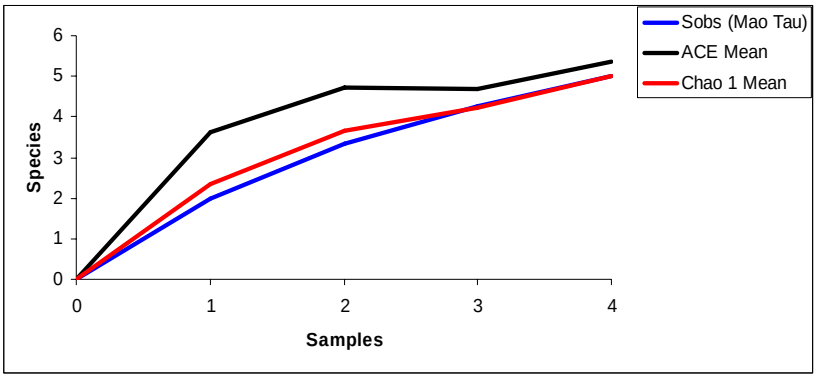

Fig. 2: The species accumulation curves for Ungurului cave.

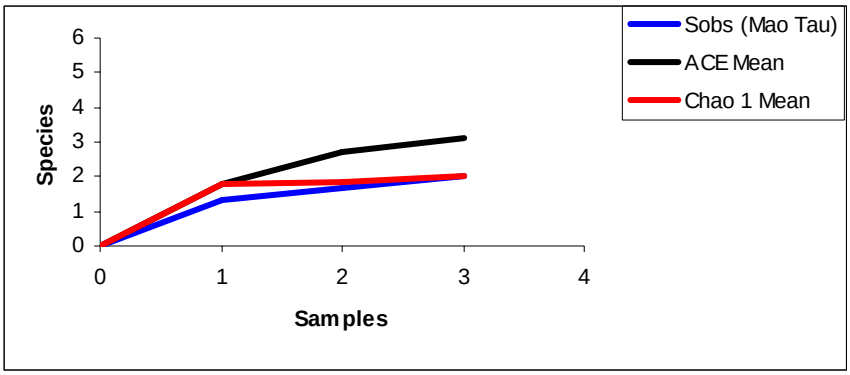

Fig. 3: The species accumulation curves in Vântului cave

This work represents the first Romanian study on epikarstic fauna with the method developed by Pipan (2005) which contributed to understanding of ecology and biogeography of cyclopoid copepods in subterranean habitats.

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REFERENCES

Colwell, R.K., Mao, C.X., Chang, J., 2004: Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85: 2717-2727.

Colwell, R.K., 2005: EstimateS: statistical estimation of species richness and shared species from samples version 7.5. User's Guide and application published at http://purl.oclc.org/estimates.

Gibert, J., Deharveng, L., 2002: Subterranean ecosystems: a truncated functional biodivesity. Bioscience 52, 6: 473-481.

Oarga, A., 2006: Groundwater Faunal Assemblages in Different Habitats of Padurea Craiului Mountains (NW Romania). Unpublished M. Sc. Thesis. Babes-Bolyai Univesity, Cluj-Napoca, 63 p.

Iepure S., Pipan T., Oarga A., in preparation: On subterranean species of the genus *Acanthocyclops* (Copepoda, Cyclopoida) from central and south-eastern Europe, with re-description of three species.

Pipan T., 2005: Epikarst- a Promising Habitat. Ljubljana, ZRC Publishing, 101 p.

Pipan, T., Culver, D.C., 2005a: Estimating biodiversity in the epikarstic zone of a West Virginia cave. Journal of Cave and Karst Studies, 67: 103-109.

Pipan, T., Culver D.C., 2007: Regional species richness in an obligate subterranean dweling fauna-epikarst copepods. Journal of BioGeography 34: 854-861.

FROM STABLE ISOTOPIC RECORD TO PALEOCLIMATE RECONSTRUCTION

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Abstract
This short paper presents results of test of a correlation method based on MC-simulations. From one speleoterm two analytical profiles are made, these two profiles (testing data) represent the same records but they have different density of sampling. The results of this experiment show that the method works and it could be useful for correlating profiles with different sampling density.

Keywords: MC-methods, correlation, stable isotopes, palaeoclimate reconstruction.

INTRODUCTION

The first two steps in a way to palaeoclimate reconstruction are field and analytical investigations. As a result usually many analytical profiles are created. The first question on this stage is. - How we could correlate these profiles?

The first real problem which we have to overcome in the correlation process - is a time scale construction. Very precise, high density stable isotope records are used usua1ly as a palaeoclimatic tools. As a time scale estimator a series of numerical dating resu1ts is used. The samples for dating are collected with less density then for stable isotope analyses. But for stable isotope record presentation an age of all analyzed points is needed. Age-depth model construction is necessary for precise and reliable time scale of any stable isotope record. After this step we can arrange the isotopic data in a time scale.

What are the next problems? - Is time scale accuracy good enough for precise correlations? What is the final record confidence bends?

Firstly, usually every profile is based on a different number of analyses. It means that any isotopic curve uses different number of points. Basic question is how we can test if record changes reflect climatic or sampling density/position changes.

Secondly, every measurement is characterized by some uncertainty. Our analytical points have two kinds of uncertainties: first from time scale and second from stable isotopes measurements. The question is how measurement uncertainties affect correlation process.

MATERIAL AND METHODS

We take two sampling profiles from one speleoterm. (*Fig.1)* It was sampled in two sides. On first side 92 samples (N-points curve), on second side only 37 samples were taken (n- points curve). For this two sampling profiles the analyses of carbon stable isotopic ratio were made. We know that these two analytical profiles are represented by the same palaeoclimatic record. The questions arises here how sampling density influences the palaeoclimatic records interpretation? To answer this question we use monte-carlo simulations. Our algorithm reflects non-uniformity of sampling, stable isotopic ratio measurement uncertainties and uncertainty of time scale model.

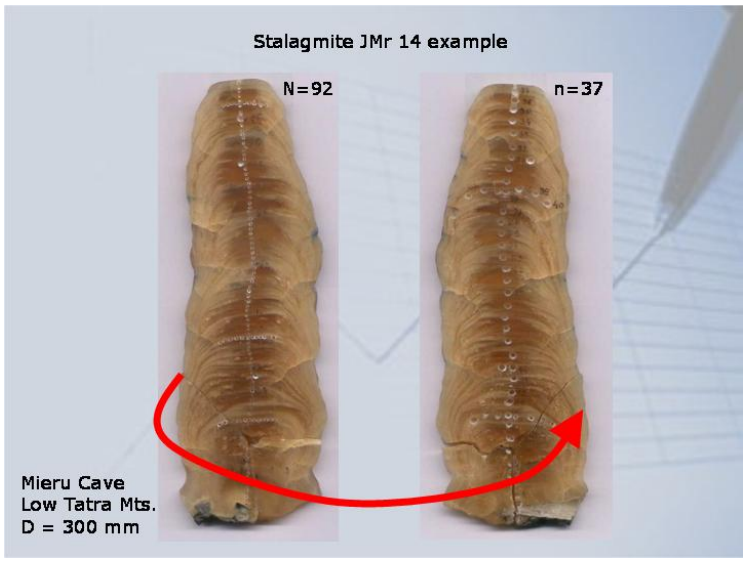

Fig 1: Sampling material.

RESULTS AND DISCUSSION

This data is good for testing of this method. Tests show that this method of correlation work property, and could be useful for correlation profiles with different sampling density.
Our two profiles have been well correlated. *(Fig.2)* Almost 80% of 37-points curve is in 65% confidence interval.
Why we use mc-simulations for answer to this problem?
-nonparametric.
-no specific assumptions.
-easy to transform algorithms for new applications.

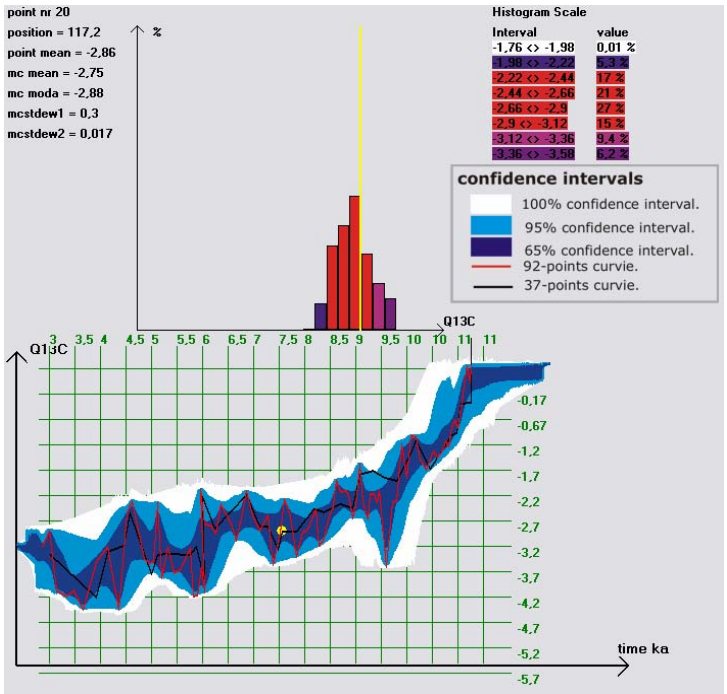

Fig.2: Results for carbon curves.

PALAEOMAGNETIC RESEARCH OF CAVE SEDIMENTS IN SLOVENIA IN 2007

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In 2007, sampling of cave fill for palaeomagnetic analysis was performed in several caves in the Classical Karst (SW Slovenia). Standard palaeomagnetic analyses were used (thermal and alternating field demagnetisation, magnetic susceptibility measurements, etc.). Paleomagnetic parameters (inclination, declination) indicate that the respective tectonic block has rotated since the deposition of karst sediments (Tabs. 1 to 3). The rotation differs in different time intervals of the infilling of cave passages and in different karst areas. Repeated sampling in some profiles, especially Divaška jama, Trhlovca, Markov Spodmol, confirmed that only high-resolution approach can ensure reliable results.

Divaška jama is situated near village of Divača, Classical Karst. It represents horizontal 700 m long cave with phreatic loops. About 2 m of laminated clays and silty and sandy clays are covered by flowstone layer and clays at about 370 m a.s.l. (about 2 m deep pit). Sampling was performed in 1997 (22 samples), 1998 (22 samples) and 2004 (60 samples). Sediments are characterized by a large scatter of the NRM intensities (0.7–301 $mA.m^{-1}$) and MS values (74–3,435 x 10^{-6} SI units).

Table 1: Mean palaeomagnetic directions, Divaška jama.

	Polarity	Mean palaeomagnetic Directions		A_{95} [°]	k	n
		D [°]	I [°]			
Divaška jama	N	354.36	58.15	5.57	24.26	26
	R	183.64	-46.78	4.7	15.3	58

Note – explanations for Tables 1 to 3: N – normal polarity, R- reverse polarity; D, I - declination and inclination of the remanent magnetization after dip correction; α_{95} - semi-vertical angle of the cone of confidence calculated according to Fischer (1953) at the 95% probability level; k - precision parameter; n - number of analyzed samples

The original analysis with relatively large distance between sampling points resulted in geometry of magnetozones which was interpreted as straddling the Brunhes/Matuyama boundary (0.78 Ma) and Jaramillo subzone (0.99–1.07 Ma; Bosák, Pruner & Zupan Hajna 1998). The magnetostratigraphy obtained from high-resolution analysis shows more complicated picture. The upper part of the profile is N polarized but with two R polarized magnetozones, the lower part of the section is R polarized. The new high-resolution results offer quite uncertain interpretation, with clear possibility of age greater than both 1.25 Ma (Th/U dates from speleothems within the profile) and 1.77 Ma (base of Olduvai subchron), i.e. identical to the Trhlovca Cave – a part of the same cave system – and some other sites situated in the Kras.

The fill of Divaška jama represents one of clear examples of temporary interruption of speleogenetic and cave-forming processes. After an infilling phase dated to more than 1.2 and/or 1.77 Ma, the cave was inactive for a long time. Deposition was renewed only after 540 ka, i.e. after a break lasting 0.7 to 1 Ma. This time-span is documented by erosion of old cave fill and by deposition of morphologically rich speleothems.

The palaeomagnetic research of clay/silt coatings of speleothems in distant part of the cave was performed too, but without any detailed results (only detected polarity of individual

samples). Calcite crust above clay coatings was dated to about 107 (+17/-15 ka) limits the time of deposition of laminites above speleothem horizon (top dated to 270-540 ka) to about 92-540 ka. The reason for the renewed filling of the cave by water is not clear, but it may be connected with a change of the hydrological system such as rise of the water table, blockage of outflow routes, etc.).

Trhlovca Cave is 142 m long and 22 deep, situated on the south-western side of the planated surface of Divaški kras. The main part of the cave is an approximately 15 m high, about 3 m wide and 60 m long meandering canyon following a N–S direction at 404–419 m a.s.l. We sampled sedimentary profile at 420 m a.s.l. and from overlying laminated flowstones several times (1997, 1998, 2004, 2005 and 2006), taking a total of 246 samples for paleomagnetic analyses. Sediments are characterized by a large scatter of the NRM intensities (0.02–302 $mA.m^{-1}$) and MS values (-15–3,710 x 10^{-6} SI units).

Table 2: Mean palaeomagnetic directions, Trhlovca.

	Polarity	Mean palaeomagnetic Directions		α_{95} [°]	k	n
Trhlovca		D [°]	I [°]			
	N	346.4	51.15	3.18	14.86	130
	R	148.87	-59.19	7.37	5.31	68

The laminated sediments from Trhlovca were expected to be younger than Jaramillo normal polarity event within the Matuyama reverse epoch. Preliminary results of palaeomagnetic research (Bosák, Pruner & Zupan Hajna 1998; Bosák et al. 2000b) suggested a substantially older age for sediments in the cave. The arrangement of the detected magnetozones was interpreted as Brunhes/Matuyama boundary (0.78 Ma) and Jaramillo subchron (0.99–1.07 Ma). The high-resolution re-sampling of the whole profile has changed this interpretation. The arrangement of R and N polarized magnetozones, starting with the flowstone crust and continuing through the sedimentary profile is clearly older than 1.77 Ma (base of the Olduvai subchron).

Markov spodmol Cave is 868 m long horizontal cave formed on the S edge of the blind valley on the southern rim of Pivka basin. The profile is situated about 150 m from the entrance is preserved in side passage or large niche of the main corridor. The section of fluvial sediments studied is about 4 m thick; the true depth is greater but the lower part is below the level of the permanent lake. Profile is composed of inter-bedding of clays and silts with some sand lenses at the base. Thick flowstone covers sediments. The site was sampled during several visits (2004, 2005, 2007), resulting in four palaeomagnetic profiles. Palaeomagnetic profile B overlaps the lower part of the profile A. The profile C is part of profile A (duplication 0.13-1.10 m) and the profile D is the duplication including deep-well of profile B (2.50-3.60 m). A total of 140 oriented laboratory samples were studied for their palaeomagnetic properties from profiles (A, B, C and D). Sediments from profiles A and C (0.075–2.865 m) are characterized by an NRM intensity from 0.5 to 167 $mA.m^{-1}$ and MS values from 79 to 1,070x10^{-6} SI units. Sediments from profiles B and D (2.5–3.6 m) are characterized by an NRM intensity from 0.3 to 7 $mA.m^{-1}$ and MS values from 63 to 247 x 10^{-6} SI units.

Table 3: Mean palaeomagnetic directions, Markov spodmol.

Markov spodmol A	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	352.26	41.38	5.17	13.12	56
	R	159.63	-53.72	30.12	4.32	5
Markov spodmol B	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	328.53	37.87	6.94	23.97	17
Markov spodmol C	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	1.61	52.81	4.14	52.01	22
	R	-	-	-	-	-
Markov spodmol D	**Polarity**	**Mean palaeomagnetic directions**		**α_{95} [°]**	**K**	**n**
		D [°]	I [°]			
	N	332.95	38.69	11.2	8.23	19
	R	139.91	-68.13	20.37	15.75	3
	R?	344.74	-25.78	16.52	10.27	7

The profiles A and C showed N palaeomagnetic direction. There are also shorter excursions (R) or transient polarized zones (N–R) in the long N magnetozone. The profiles B and D showed only N palaeomagnetic direction.

The age of the fill can be interpreted as follows: the upper laminated clay was deposited within the normal Brunhes chron, the multi-colored clays and sands/gravels were deposited in Matuyama or Gauss chrons, and the lower laminated clay is older than the middle sequence. Traces of *in situ* weathering in the lower part of the profile indicate a quite prolonged hiatus in deposition. The creation of a weathered zone under subsurface conditions needs prolonged time and warm/humid external climate. The weathering supports a rather higher age of the profile.

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KARSTIC HYDROLOGICAL ECOSYSTEM OF CEMERNICA MOUNTAIN, WESTERN SERBIA

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Abstract
The territory of the Republic of Serbia is characterised by vast karst terrains (30% of its total territory). Sets of various ecosystems have been formed on such significant areas, representing almost untouched "pearls of nature". Abundance in water, hundreds of distinctive sorts of flora and fauna, fresh air and other climatic factors arouse growing interest in these terrains, not only from scientific point of view, but even more from economic, and tourist industry view, as well. Bearing in mind that more than 70 karst springs are used for the water supply of towns in Serbia the sustainable development of karst hydrological ecosystems is a high priority in further development. One of such karst terrains is Cemernica Mountain in Western Serbia.

The complete Cemernica mountain karst aquifer is dealt with in this paper. Hydrogeological investigations and the clarification of hydrological ecosystem, water flows across and through Cemernica mountain represent a fundamental element both in the further development of ecology and environmental protection on this mountain.

Keywords: hydrogeoecology, water balance, water quality, karst

THE APPLIED METHODOLOGY

The evaluation of quantitative and qualitative features of Cemernica Mouintain groundwater, the knowledge of geological and tectonic relations on the terrain, and the sustainability of the unique karst hydrogeological Cemernica mountain ecosystem have caused using a fully complex methodological approach to the system. Cause-effect relations among investigated parameters caused the application of various methodogolical procedures, often multidisciplinary ones.The general and schematized model of the applied exploration concept is shown in Table 1.

Table 1: The Applied Methodology of Hydrogeological Explorations along Cemernica Mountain.

HG Recon.	Isotopic	Capacity monitoring of wells & springs	Baseflow analises + same as in flow		Balance methods	Field sampling	MAC lists Chemical analyses	MAC standards Vulnerab. mapping
Geophysics	Chemistry							
Aerial ph.	Hydrology				Non-balance methods	Physical		
GIS	Climate					Chemical	Temperature	
Methods				**Cemernica karst aquifer**	methods			
Delineation	**Recharge**	**Flow**	**Discharge**		**Reserves**	**Quality**	**Use**	**Vulnerab.**
Parameters					parameters			
Horizontal	Rainfall	Transm-issivity	Natural discharge		Aq. volume	Bacteriolog.	Water supply	Illegal dumping
Vertical	Percolation				GW storage	Physical		
Depth of Karstificat.	Other aq. inflow	Effective porosity	Artficial discharge		Reserved	Chemical	GW bottling	Farming
					Av. yield	Isotopic	Wellness	Fertilisation
Volume	Surf. water interaction	Groundwat. direction	Baseflow calculation		Max. yield	GW origin	Recreation	Diary industry
Geometry					Min. yield	Gen. coeff.	Sport	

BASIC GEOLOGY AND TECTONICS

The Cemernica montain massif is made of limestone mass of Triassic age (karst aquifer) surrounded by Carboniferous, Permian and Jurassic deposits (hydrogeological barrier). From spatial pont of view, as the height grows, from periferial to central, heighest parts of the massif, the age of geological units goes from older to younger ones. Triassic rock masses-collectors occupy central parts of the massif and like a limestone "island" rise above water impermeable parts of the terrain. Rock formations of

Lower Cretaceous of Seis and Campil beds as aureoles close the limestones of Anisian and farther grade into the oldest geological formations on the terrain- of the Carboiferous and Permian ages. The Triassic island is made of massive limestones of a complex rupture composition with abrupt changes of the terrain inclination.Young tectonic movements occurring at the end of the Tertiary and in the Quarternary affected significantly the formimg of faults and joints. Neotectonic activity has been recorded through morphologic forms of recognized ruptures. The area of Cemernica mountain is intensively faulted, where two fault systems of hectameter and kilometer dimensions, with clear marks in the relief in the form of elongation of corries and dry valleys, dominate. The Tectonic setting, the systems of fault formations, their orientation, size and mutual intersections cause groundwater movement and their discharge.

AQUIFER DELINEATION

Northern part of the Cemernica area differs in height from southern part with highly pronounced hypsometric difference pointing out the block structure of the terrain. The depths of occurence of Triassic formations can be followed from west to east, the change of which is directed to the reducing of thickness of Anisian sediments, which corresponds to the direction of the terrain inclination. Central part of the massif is singled out by height as elongation hearth west-east, with differently oriented line distribution of plate and well shape corries. The total area of the karst aquifer amounts 21km^2.

RECHARGE, FLOW AND DISCHARGE

The aquifer recharges through precipitation, open hydrogeological structure and the high level of karstification of the terrain intensify the process additionally. The complexity of the geological setting and tectonic features hinder the delineation of the watershed for all four spring, while the disagreement.of topografic drainage divide with the hydrogeological one, makes the process of delineation of the recharge area for all four springs even more complex (Fig.1). Mutual relations of groundwater collectors and their communication and quantitative relations in case of karst system are caused by hydrogeological barriers, fault zones with an active function or without it. The mountain massif is drained in four main springs, of different yield, distributed in an arrow from south west to south east part of the terrain. The yield drops from west to east, as well as the thickness of Middle Triassic limestones. The uniqueness of Cemernica karst ecosystem water balance is caused additionally by mountain climate, relief, the area covered by forest and unequal degree of karstification of the terrain.

WATER QUALITY AND PROTECTION

The groundwaters of the Cemernica karst massif are of an exceptional quality. Similar chemical composition characterises all four springs with minor fluctuating in mineralization and pH value. The groundwaters are hydrocarbonate-calcium type (HCO_3-Ca), the mineralization of 225-290mg/l, and pH values 7.5-7.7, while temperatures fluctuate between 8 and 10^o C. The muddiness of water has the value lower than 5°Co-Pt scale during the whole hydrologic cycle on three springs except the one where in the period of high waters periodical muddiness occur. The openness of the hydrogeological structure increases vulnerability of groundwaters and opens the way to bacterial and other pollutions. The emphasis is on the protection of the natural regime of the Cemernica environment, with established zones of sanitary protection as safety measures for insurance from undesirable consequences of pollution and disturbance of natural balance.

GROUNDWATER USE

The possibility of utilization of the Cemernica karst system as to groundwater exploiting is varied. First of all, it can be seen in the possibility for the water supply of surrounding towns, groundwater bottling, for the needs of sports and wellness centres,etc..

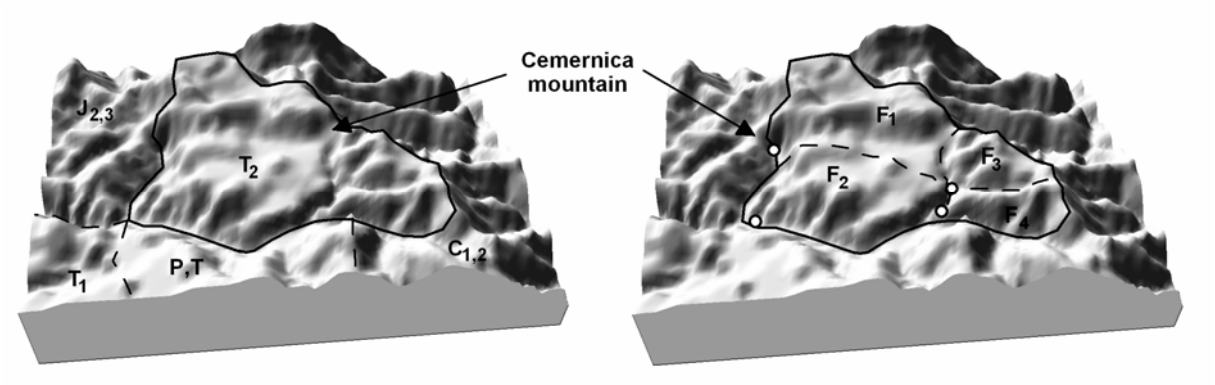

Fig.1: Investigated model of Cemernica Mountain, western Serbia.
Legend to left model: geological setting – $C_{1,2}$-Carboniferous graywacke; P,T-Perm-Triassic quartz conglomerate;T_1-Marl and shale;T_2-Massive limestone;$J_{2,3}$-Ophiolithes
Legend to right model – the surface catchment areas of the investigated springs: F_1-Curcica spring; F_2-Stitkovo spring; F_3-Bursac spring; F_1-Kusica spring

Table 2: Calculated water balance parameters of the Cemernica Mountain karst aquifer.

Area No.	Spring Name	Min/Max Yield	Average yield	Precipi-tation	Surface catchment	Evapo transpiration	Surface run-off	Effective infiltration
		$Q_{max.}/Q_{min.}$	$Q_{av.}$	P	F	E	Q	$i_{ef.}$
		m^3/s	m^3/s	mm/a	km^2	mm/a	%	mm/%P
F_1	Curcica spring	0.05-0.35	0.120	1009	12.3	342	36	300/30
F_2	Stitkovo spring	0.02-0.11	0.048	1009	5.2	342	37	293/29
F_3	Bursac spring	0.004-0.02	0.008	1009	2.3	342	56	101/10
F_4	Kusica spring	0.008-0.03	0.011	1009	1.5	342	43	232/23

CAVES OF MACIZÓ CHIMANTÁ AND RORAIMA TEPUY IN LA GRAN SABANA AREA (ESTADO BOLÍVAR, VENEZUELA)

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Abstract
The paper describes the speleological discoveries of several international expeditions to the table mountains in Gyana Highland, in the border area of Venezuela, Brasil and Guyana. Three table mountains (tepuis) were attended – Macizó Chimantá, Kukenán, Roraima and we discovered more than 30 caves in total length of more than 30 km. After the last expedition, "Tepuy 2007", which scientific tasks were geological, geochemical and biological field research, the longest one – Cueva Ojos de Cristal is 16 140 m long and it is the longest cave in silicious rocks in the world. Nowadays, the 4.8 km long cave Cueva Charles Brewer with the hall "Gran Galería Karren y Fanny" (400 000 m3) and the passages of average 30 × 60 m, is the largest cave in quartzites in the world.

Keywords: caves, Venezuela, Cueva Charles Brewer, Cueva Ojos de Cristal, Chimantá, Roraima, speleology, tepuis, quartzite karst.

INTRODUCTION

In february 2007, four experts for Venezuelan table-mountain caves, Charles Brewer-Carías, Branislav Šmída, Federico Mayoral and Marek Audy organized an expedition with duration of one month, to the underground of the Chimantá and Roraima massifs in Guyana Highlands of northern South America – southeastern Venezuela, State Bolívar (Fig. 1). The team of speleologists and scientists consisted of 16 persons from Venezuela (SVCN/Grupo Espeleológico de la Sociedad Venezolana de Ciencias Naturales, Caracas), from Slovakia (SSS/Slovak Speleological Society and Commenius University, Faculty of Natural Sciences, Bratislava), from the Czech Republic (ČSS/Czech Speleological Society), Croatia (KS HPS/SO PD Željezničar Zagreb) and also three journalists (TV, press). The longest and biggest quartzite caves of the world where again explored during the stay, discovered by us in 2002 and 2004 (Cueva Charles Brewer, nowadays its known length is 4.8 km and the Cueva Ojos de Cristal cave system with known length by now more than 16 km). Beside standard speleological exploration, topography, photodocumentation also focusing on complex evaluation of natural phenomenons, survey, measurement, sampling (rock material, biospeleothems, water, minerals, microbiological and biospeleological material) also new big cave sites where discovered.

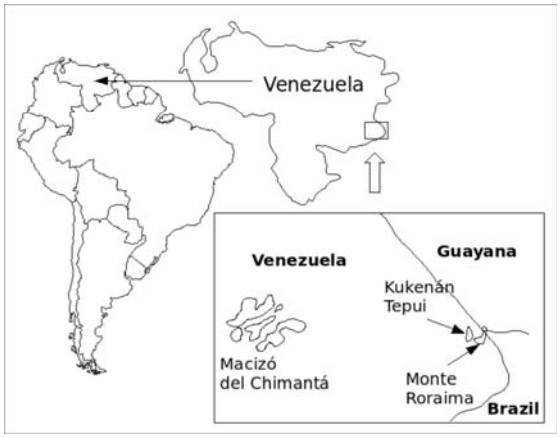

Fig. 1: Location of the studied table mountains

EXPEDITION "TEPUY 2007" – EXPLORATION AND RESEARCH

On the one of the 10 partial mesetas (tepuis) of the Chimantá massif with areal extent of 1470 km^2 the Czech subgroup discovered new cave Sistema de la Araña in length 2.5 km and the central Slovak-Venezuelan-Croatian team accomplished mapping of the cave Cueva Cañon Verde in length 1.2 km, discovered and partially explored by Slovak-Venezuelan team in the year 2005. Both of the cave sites, which have several cave entrances located in megadepressions (e.g. the Cueva Cañon Verde have a southern entrance located in depression with extent of 80 × 150 m and approx. 60 m of depth) consist of extensive fossil corridors (to the 50 m of width and 20 m of height), as well as a little bit lower situated canyon-like galleries with heights 10 to 15 m and widths 10 to 30 m, with rivers in their bottoms. In the first above mentioned cave is well developed including also the lowest situated, juvenile and probably periodically flooded zone of corridors with hundreds of sandstone pillars (Fig. 2), in the second one is situated a big dome with dimensions 50 × 100 m and also numerous dangerous collapses (chokes) and labyrinths. In both caves numerous clusters of young ("alive") and older, already opalized "Champignones" (special speleothems, built up by cyanobacterias, first time recognized by us in the Cueva Charles Brewer cave; Šmída et al. 2004) as well as other unique speleothem forms, e.g. the "muñeco" type, in enormous clusters built up on the bottom by thousands of individual pieces, or curtain-like gypsum speleothems so-called "crepe paper" type. New attitude to genesis of those speleothems, base on our geological, geomorphological, hydrogeochemical and speleological observations, brings the papers Aubrecht et al. (2007; 2008)


Fig. 2: The sandstone pillars – the key to genesis of the caves in karst on table mountains – Cueva de la Araña, Macizó Chimantá. Photo: M. Audy – R. Tásler & R. Bouda

The next of the new discovered caves, the Cueva Juliana (Fig. 3) at length 1 km having smaller height, maximum to 5 m and 10 – 20 m wide corridor, is a young karst spring, active during flooding events, with numerous lakes. This site is situated approx. 70 m below the active river in the Cueva Charles Brewer, aside from attractive, 30 m high waterfall. This cave was not explored to the end, because lack of time – is continued further. The next two caves (Cueva Croatia and Cueva de Bautizo de Fuego) are forming cascade-abyssal systems, with length 200 m and 400 m and depth -50 m. They are younger caves, very similar to caves recognized on the plateau of the Auyantepuy. The first one of them was explored by the Croatian team, the next one, with more extensive horizontal gallery near the bottom and smaller river was discovered by the Slovak-Venezuelan team.

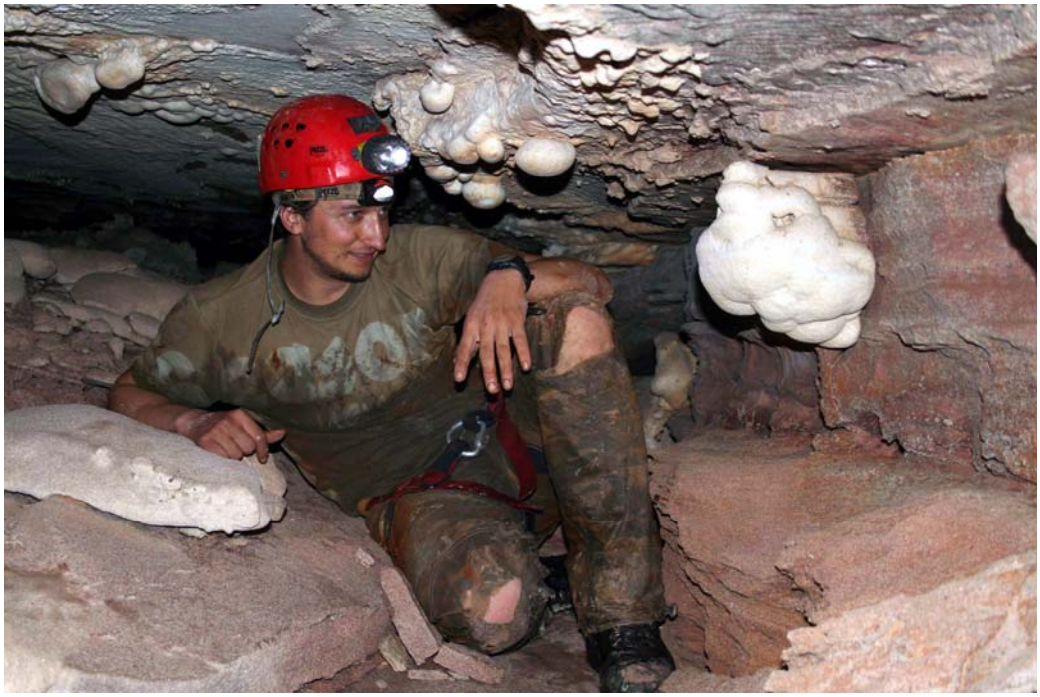

Fig. 3: Biospeleothems of "champignones" type in Cueva Juliana, Macizó Chimantá. Photo: L. Vlček

The Cueva Zuna is formed by 300 m long, relatively straight, 30 m wide fossil gallery. Slovak-Croatian team took together also an extensive half-open -100 m deep abyss (dimensions of the entrance are 80 x 100 m). However it leads through its bottom, among collapses and jungle only to the 150 m long cave fragment named Tetris. Within other newly mapped and known sites the remarkably one is the almost 150 wide cave portal, temporarily named as "Cueva el Diente", localized only from the air, during helicopter flight. The continuation behind the portal is collapsed (approx. 100 m of smaller cracked areas), on the opposite direction is eroded to the amazing, luminous, approximately 50 m wide bridge (Puente de Diana).

Now the third longest cave of the Chimantá massif remains the Cueva del Diablo (2.3 km long and -80 m deep), with corridor width in some places up to 50 m and two more than 80 m wide domes, discovered and explored in 2005. The deepest known and explored site remains the Sima Noroeste (-130 m), with crack collapse by dimensions of 60 × 400 m. It is remarkable that this site is continuation down at least next 30 m and we assume that it is connection to the big horizontal cave.

During expedition repeatedly tried to break through the end collapses of the monstrous cave of Cueva Charles Brewer, against the river current (the length of the cave lengthened up to 4782 m, the vertical distance remain +110 m), but without remarkable progress. This cave with commonly 50 – 80 m wide corridors (Fig. 4) and the monumental hall of "Gran Galería Karen y Fanny" by volume approximately 400000 m^3 remains further the biggest quartzite cave in the world. Cueva Charles Brewer was localized first time in 2002 and explored in 2004 under the leadership of Charles Brewer-Carías and friends (e. g. Šmída et al. 2005a; b; c; d; e).

Fig. 4: The waterfall Cascada Vanessa in Cueva Charles Brewer – the picture shows the common size of corridors in this cave. Photo: M. Audy.

During the "Tepuy 2007" expedition more than 5 km of cave spaces was documented on the Chimantá, further exploration perspectives are more then promising. Remarkably, that since the year 2004 during several stays we explored almost 15 km of caves on this plateau (Fig. 5).
During our last stay a numerous geological documentation was done, as well as rock samples for thin sections (investigations in microscope) and geochemical analyses were taken, from different positions and layers in quartzites in the walls of the Cueva Charles Brewer itself as well as from the surface. Moreover water samples were taken from the underground river from this and other caves, also from creeks and swamps on the plateau and field measurement were performed: pH, conductivity, water and air temperature, discharge. The same day spectrophotometrical analyses of the water samples were performed, the following items were measured: Fe, SiO_4^{4-}, PO_4^{3-}, Al, NO_3^-, Cl^- and total acid capacity, analyses of stable isotopes of H and O will be done later using the taken samples (Lánczos et al. 2007).
The expert for herpetofauna of tepuis, C. Barrio, catched and identified small endemic frogs (Ecaudata), lizards (Sauria) and snakes (Serpentes). Ethological observation and extensive cave fauna collecting were performed by all members of the team: e.g. flatworms (Turbellaria), miniature snails (Gastropoda), numerous species of spiders and harvestmans (Araneida, Opilionidea), millipedes (Diplopoda) and centipedes (Chilopoda), colossal cave cicadas from the Hydrolutos sp. family, two species of scorpions, within insects e.g. troglobiontic ground beetle-like beetles or white flies. Finally, expert for speleothemes, geologist R. Aubrecht further explored in details and sampled different types of speleothems, organic red mud (so-called barro rojo), various opal-sinters, microbiocoatings and biomaterials (also alive materials in agar), as well as cyanobacteria from the surface of the plateau and creeks (in identification of these we will continue) and together from Ch. Brewer-Carías continued in elaboration of typological system of the spelethems occuring locally. Samples taken in caves and and the surface which were transported to Europe will be further investigated in laboratories by the participants of the expedition "Tepuy 2007", scientists of the Faculty of Natural Sciences, Comenius

University in Bratislava, as well as other invited experts in natural sciences, apparently with international participations. The well-known Slovak film-maker P. Barabáš prepared an adventorous-documentary movie dedicated to discoveries and exploration in the caves of the Chimantá mountain titled as „Tepuy“ (K2 Studio, Bratislava). This movie is presented on several world festivals dedicated to mountain themes.

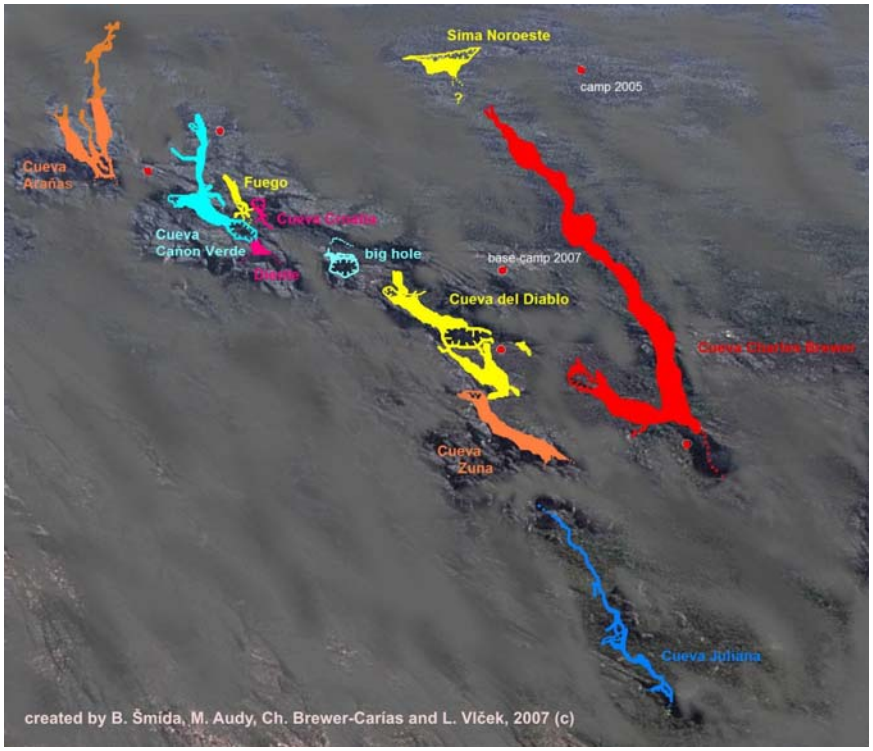

Fig. 5: Schematic location of the new-discovered caves on Chimantá table mountain. Created by B. Šmída, M. Audy, Ch. Brewer-Carías & L. Vlček

The second part of the exploration programme of the expedition was again dedicated to the Roraima Mountain, where the Slovak-Czech couple M. Audy and Z. Ágh discovered in the 2002 year up-today the longest cave system of the world developed in sandstones, names as Cueva Ojos de Cristal (Kryštálové oči in Slovak, Crystal Eyes Cave in English). This action, 5th in row expedition (with Slovak, Croatian and Venezuelan participants) in the second half of February 2007 elongated this cave to 16 140 m, by connecting with two other caves – Cueva de Gilberto and Cueva Fragmento Marginal. The labyrinth-like cave system of originally independently discovered and explored, today connected parts consist of lower (max. 5 to 8 m of height, in average only 2 m), in some places only 30 – 40 cm up to 15 – 20 m wide corridors, which are densely interconnected to each other. Today are known several entrances to the cave, they are standard cave entrances, some of them located in closed hole basins, in vertical walls of the mountain and also as 20 – 30 deep abysses, genetically named by us as “pokemon” (e. g. Šmída et al., 2003). The biggest room of the cave is the “Hall of Mother SSS”, with dimensions of 40 × 50 m. The essential progress was reached here during our expedition Kukenán/Roraima 2006, when a team of Slovak speleologists by 6 members under leadership of B. Šmída discovered and mapped more than 4 km of new corridors. This year we explored more in details also a 100 m long cave Cueva Lago Gladys (Fig. 6), discovered in the past by Ch. Brewer-Carías. The Cueva Ojos de Cristal with its length more than 16 km became the second longest cave in Venezuela (the longest one is the Cueva del Samán, developed in limestone).
Similar geological and biological research (including sampling) as on the Chimantá we performed on the Roraima (moreover we probably discovered new mineral species), thus we can compare two of the table mountains, also the biggest quartzite caves of the world discovered by us based on scientific data. This fact will push the knowledge forward about the origin, age and development of them, in their amazing variety. P. Barabáš is preparing a next movie about discovering and exploring of caves on the Roraima, titled „Matawí“.

Fig. 6: Entrance to Cueva Lago Gladys in Guyana part of Roraima Mountain. Photo: B. Šmída

SUMMARY OF RESULTS

During 7 expeditions performed by us since 2002 to 2007 each year or half year to the table mountains Chimantá, Roraima and Kukenán we discovered more than 30 km of quartzite caves. 16140 m long Cueva Ojos de Cristal cave on Roraima Mountain represents the longest cave in silicic rocks and simultaneously the second longest cave in Venezuela. Cueva Charles Brewer cave on Macizó Chimantá Massif is the most spacious cave in quartzite karst and one of largest caves in the world. One of the main goals is that the new genetic types of opal biospeleothems were discovered, sampled and studied.

REFERENCES

Šmída, B. – Audy, M., Vlček, L., 2003: Expedícia Roraima, Venezuela, január 2003 – Cueva Ojos de Cristal (Kryštálové oči).- Spravodaj SSS, 34, 2, 1–192, Liptovský Mikuláš.

Šmída, B. – Audy, M. & Brewer-Carías, Ch., 2004: Cueva Charles Brewer – najväčšia kvarcitová jaskyňa sveta. Speleoexpedície do masívu Chimantá 2004, Venezuela.- Spravodaj Slovenskej speleologickej spoločnosti, 36, 3 (Supplementum), 1–178, Liptovský Mikuláš.

Šmída, B. – Audy, M. & Mayoral, F., 2005a: Cueva Charles Brewer – la plus importante grotte du monde creusée dans les quartzites (massif du Chimantá, Venezuela).- Spelunca, 97, 27–35, Paris.

Šmída, B. – Audy, M. & Mayoral, F., 2005b: Cueva Charles Brewer: Larger quartzite cave in the world.- NSS News, 63, 1, 13–14, Huntsville.

Šmída, B. – Audy, M. & Mayoral, F., 2005c: Into the Lost World. Descent, 183, 36–38, Abergavenny.

Šmída, B. – Audy, M. & Mayoral, F., 2005d: Cueva Charles Brewer.- Regards, 58, 9–12, Grivengee.

Šmída, B. – Audy, M. & Mayoral, F., 2005e: Cueva Charles Brewer.- The largest quartzite cave in the world (Chimanta massif, Venezuela). Journal of the SSS, 49, 1, Sydney Speleological Society, 3–12, Sydney

Lánczos, T., – Aubrecht R., – Schlögl, J., – Šmída, B., & Brewer-Carías, Ch., 2007: Preliminary results of the Tepuy 2007 expedition to the venezuelan table mountains – water geochemistry and its relation to genesis of the quartzite karst. In.: Fľaková, R. & Ženišová, Z. (eds.): Proceedings of the Hydrogeochémia 2007 conference, Slovak Assocation of Hydrogeologists, Bratislava, 136-141, Bratislava.

SPELEOTHEMS AND THEIR HISTORICAL SACRED VALUES: TWO EXAMPLES FROM THE STATE OF MINAS GERAIS, BRAZIL

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Abstract

Compared with international karst studies, those in Brazil can be considered relatively new. Since the first studies of Peter W. Lund in 1833, Brazilian karstology developed slowly for at least 175 years. The majority of scientific papers concerning national karst areas were produced by the end of the 50's to the 90's, and continue today. Greater emphasis should be given to the pioneering work of Kohler (1989) on the Karst Geomorphology of Lagoa Santa, Minas Gerais, the first of PhD thesis on the subject in Brazil. More recently caves are studied with respect to their use as temples as religious and ritual sites. In Brazil, by the end of the 17th century (1691), the pilgrim Francisco de Mendonça Mar inhabited a cave on the banks of the São Francisco River, giving rise to the Sancturay of Bom Jesus da Lapa, the oldest registered example of religious use of a cave in Brazil. In other regions, as early as the 18th century, supposedly appearances of Our Lady occurred in the cities of Antonio Pereira and Vazante, State of Minas Gerais. In these two caves both water as well as some speleothems, are considered to be sacred. When a cave is made sacred, the fundamental opposition between good and evil, sacred and profane is established even though not all caves had experienced miraculous appearances. Some of them are just considered to be a divine work, and consequently worshiped. Even though the religious use of caves causes numerous negative environmental impacts, their cultural importance is enormous. This makes cave conservation a very difficult situation. The simple prohibition of cults is not acceptable because religious beliefs usually have positive impacts on regional economies and the pilgrims' quality of life. It's believed that what is should be done is to work towards maintaining such heritage sites that exist while discouraging the use of other caves for this purpose.

Key words: speleothems, sacred values, Our Lady of Lapa, religious tourism.

INTRODUCTION

Compared with international karst studies, those in Brazil can be considered relatively new. Since the first studies of Peter W. Lund in 1833, Brazilian karstology developed slowly for at least 175 years. The majority of scientific papers concerning national karst areas were produced by the end of the 50's to the 90's, and continue today. Greater emphasis should be given to the pioneering work of Kohler (1989) on the Karst Geomorphology of Lagoa Santa, Minas Gerais, the first of PhD thesis on the subject in Brazil. More recently caves are studied with respect to their use as temples as religious and ritual sites.

Worldwide, the duality of perceptions about the karst is visible, especially when shafts are portrayed as "portals of hell" or living places that shelter strange creatures. Sacred caves, however, have considerable historic interest. Buddhist and Hindu cave-temples are very common especially in Southeast Asia and India. Christian cave-churches, analogous to the ancient catacombs, are scattered around the world, varying very little in relation to the legends and stories associated with them.

In Brazil, by the end of the 17th century (1691), the pilgrim Francisco de Mendonça Mar inhabited a cave on the banks of the São Francisco River, giving rise to the Sancturay of Bom Jesus da Lapa, the oldest registered example of religious use of a cave in Brazil. In other regions, as early as the 18th century, supposedly appearances of Our Lady occurred in the cities of Antonio Pereira and Vazante, State of Minas Gerais. In these two caves both water as well as some speleothems, are considered to be sacred.

When a cave is made sacred, the fundamental opposition between good and evil, sacred and profane is established even though not all caves had experienced miraculous appearances. Some of them are just considered to be a divine work, and consequently worshiped.

MATERIAL AND METHODS

This work, carried out in 2007, compares two popular festivals dedicated to Our Lady of the Cave (*Nossa Senhora da Lapa*), in the State of Minas Gerais, Brazil. Although the events have a religious theme, the main focus of the research is the social importance of the caves to countryside communities and their importance to the religious tourism on a regional and a national scale.

The methodology was adapted from the work of Steil (1996, 2000) and Cervantes (2007), using documentary sources about the rise of these religious cults, as well the information provided by the pilgrims and clerical elements though interviews.

OUR LADY OF LAPA

It is believed that the cult of Our Lady of Lapa (*Lapa = cave*; *grotto; jama*) began in the Lapa Mountain Range (*Serra da Lapa*), central-northern region of Portugal. This region has an important historical value as a starting point of the cult that had spread throughout the world since the 15th century.

According to the tradition, in 1498 a mute twelve year old shepherd called Joana, was bringing back her cattle when she entered a rock shelter and saw an image of Our Lady. After finding the image, she cleaned it and made a small altar adorned with wild flowers. From that moment she started to go to the improvised shrine every day. Her mother, after discovering this obligated her to stop with the rituals.

One day, after taking the image with her, her mother threw the image on the fire. At this moment the child, who was mute, spoke: “Mother, what have you done! It is Our Lady of Lapa!”. Immediately the child took away the image from the fire without being burned. Because of her actions the mother’s arm was paralysed. After this moment they started to pray for *Our Lady of Lapa* and the mother’s arm was healed.

Soon the story of this miracle spread and from that moment on, pilgrims started to worship Our Lady of Lapa. Knowing about the miracle, a priest from the region of Quintela suggested that the image should be taken to the local church. However, the image had disappeared, appearing again in the cave where it was first discovered. When they tried to put the image again in the church the phenomenon took place again, and was considered to be a sign from the Our Lady of Lapa, that she wanted to be worshiped in the cave.

Some historians recount that the story image of Our Lady found in the cave originated in the year 982. At the time a Moorish army invaded the village of Trancoso and Lamego destroying the Sismeiro convent, and torturing many nuns. Some of them escaped and managed to take the image of Our Lady with them. During the journey they saw the Lapa Mountain Range (*Serra da Lapa*) and were able to hide the image in one of the rock shelters.

OUR LADY OF LAPA IN MINAS GERAIS, BRAZIL

In Antonio Pereira, located about 70 km from Belo Horizonte (State capital city), the cave-church (about 230 meters long) is developed in dolomite of the Paleoproterozoic Gandarela Formation (2,4 Ga). The history of the cave is linked to two apparently historical events:

The first event took place in 1722, supposedly when some children were looking for firewood in the forest when they saw a rabbit entering a cave (*lapa*). While going after the animal, they saw Our Lady surrounded by a bright light and then found an image of Her. The image was taken to the main Church of the village, but it returned by itself to the cave when an altar was constructed in its honor. This account is very similar to events that took place in Portugal, in the 15th century.

The second event which took place in 1767, tells about a young boy who was also attracted to the cave by a rabbit, also seeing the Our Lady seated on a rock. After leaving the cave to tell others

and to witness the phenomenon, he found an image of Our Lady when he returned. The image was taken to the main Church by orders from the local priest, but with the destruction of the main Church by a fire of unknown origins in 1830, the image was taken back to the cave. After this, the number of pilgrims to the cave increased. Since then, in August, about ten to fifteen thousand people visit the cave in honor of Our Lady of Lapa, where they held processions, masses and baptisms.

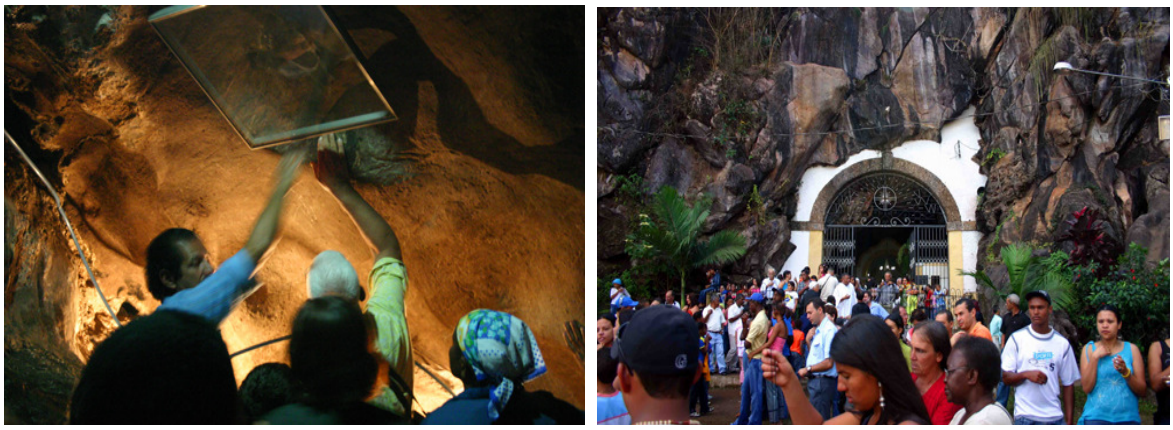

Fig. 1 – On the left, the entrance of the Sanctuary. On the right, a speleothem is perceived as an image of Our Lady of Conceição of Lapa (*Nossa Senhora da Conceição da Lapa*) (Photos: Travassos, 2007)

Fig. 2 – On the left, the altar dedicated to Our Lady of the Cave (*Nossa Senhora da Conceição da Lapa*). On the right, pilgrims laying down candles in honor to Our Lady (Photos: Travassos, 2007).

A similar event also took place in another city, about 350km away from the capital city of Minas Gerais. In Vazante, the two versions of the legend are also associated with the appearance of the Our Lady of Lapa:

The first version report that the city was founded because of the vision of the Saint in a local cave. The Cave of Pamplona was already known by plantation workers from the village that used to go inside to find fresh water. To facilitate their work, two brothers built a ranch near the cave so that they could have food and also get some rest, not wasting time while waiting for the next shift. One day, the cook, looking inside the cave saw a woman dressed in a long white dress. Because of this vision she ran out to tell the workers about it. After returning, nothing was found except a stalagmite, supposedly in the shape of Our Lady.

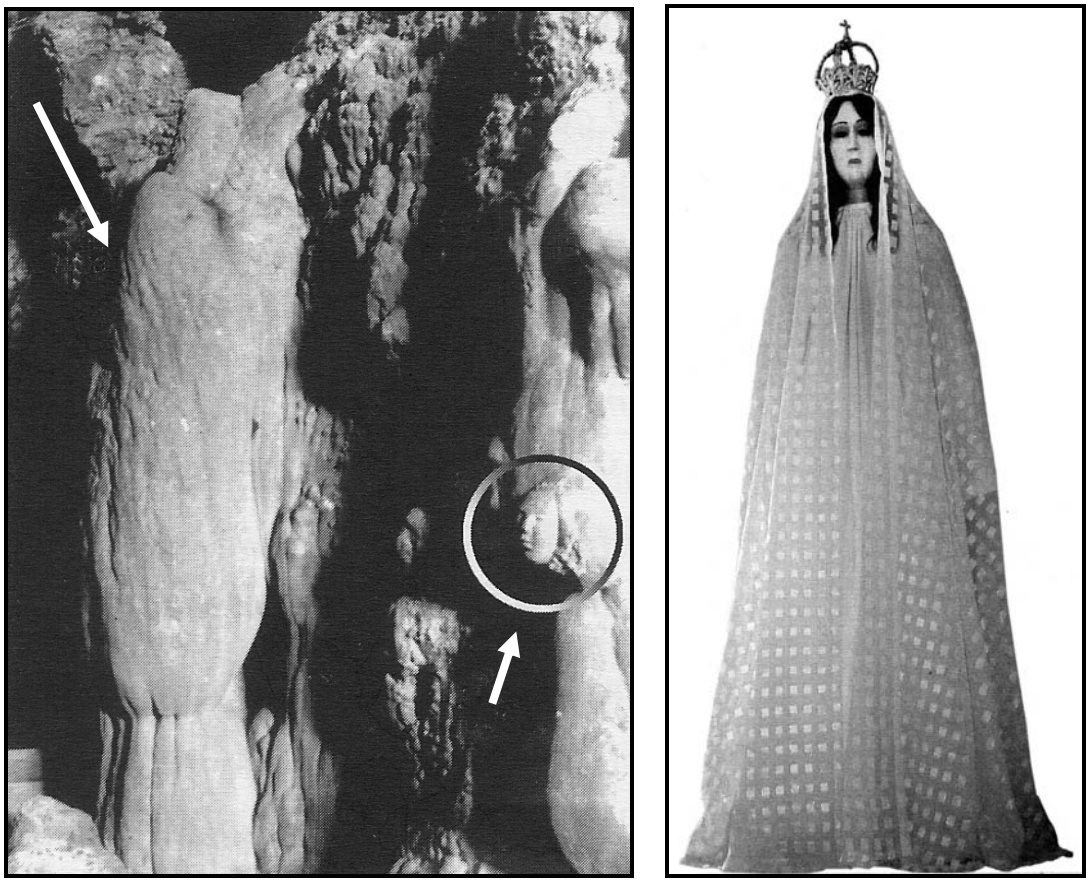

Fig. 3 – On the left, the stalagmite perceived as the image of Our Lady of Lapa. On the side of the stalagmite it's possible to notice a face of an angel artificially made in another stalagmite. Pilgrims assume that the sacred power of Our Lady made it. On the right, the image of Our Lady of the Cave. (Photo: Mello, 2003, 71;75)

The second version is similar to the first, mainly regarding the surname of the character. Due to the Paraguayan War, also known as the War of the Triple Alliance (1865 to 1870), many Brazilians feared being sent to the front. So they used to move to remote and deserted areas. The city of Vazante fitted these categories and was chosen by Manoel Ribeiro Paixao, escaping from the compulsory enlistment. He chose a cave to serve as shelter and hideout. One day, at the shelter's entrance, he spotted a tall woman dressed in white inside the cave. He went out to the city to tell everyone about it. During wartime the daily difficulties and afflictions were the impetus for the first of the processions to the "holly cave". Since then, countless numbers of pilgrims have visited the cave, especially in May. This year was the 127th Feast of Our Lady of Lapa.

DISCUSSION AND CONCLUSIONS

The landscape is not only a simple location. People convey different meanings to it depending on the social matters such as religion. Religion is one of the most important cultural elements of a Country (Norton, 2002). Religion and spirituality are still among the most common motivations for travel. Many major touristic destinations have developed largely as a result of their connections to sacred places and events. Every year millions of people travel to pilgrimage sites around the world, both ancient and modern in origin (Dallen & Olsin, 2006). Vukonić (1996) also affirms that pilgrimage has been defined as a physical journey in search of truth and of what is sacred or holly. It is also believed that religious tourism can act as an educational experience.

So if religious tourism is well directed, pilgrims or tourists may be able to learn something beyond the rituals. From the 16th to the 19th centuries, Brazil was a colony of Portugal. For this reason, the word *Lapa* to designate a cave or a rock shelter was brought with the colonizers. Although the Country was composed of a mixture of indigenous groups, Portuguese colonialists and African slaves, Catholicism was very strong among the population and so were the Iberian traditions.

Comparing the images and the names given to each example in Minas Gerais, the strong influence of Portugal can be seen in the appearances of Our Lady of Lapa in Antônio Pereira. The city is a district of Ouro Preto, an important village in the 18th century due to the discovery of gold and precious stones. The patroness of Portugal was the Our Lady of Conceição. It is believed that Our Lady who appeared in the first example described received the name from Our Lady of *Conceição* of Lapa, pointing out the strong bond between the traditions from the colonizers and colonists in this region. In Vazante, far from the strong and direct Portuguese influence, the image appears to be unique in its appearance.

Interviews with pilgrims and tourists revealed their lack of knowledge in relation to cave genesis and the connection with Portuguese traditions. For the majority, cave formation is imputed to supernatural powers and their belief is stronger than any environmental education tool. Some religious fundamentalists are also opposed to be exposed to certain ideas.

When performing a pilgrimage, participating in a collective act of celebration, an individual can exteriorize your faith through the worship of the myth in which he deposited their religious desires and life experiences. In this sense, Steil (1996) affirms that beyond the sacred, real historical characters coexist with the imagination. For this reason clerical members and spiritual leaders do not want to break with the folk traditions and myths associated with the sacred places. Instead of breaking with it, they reinterpret and incorporate them into Catholic orthodoxy.

The use of caves is tied to the people's beliefs. The folk faith goes beyond the domain of specialists from outside. It links the pilgrims with the sacred according with their customs.

Folk culture today survives mainly in rural areas, often among groups linked by a distinctive cultural background. It tends to resist change and remain attached to long-standing attitudes and behaviors being more traditional and less subject to change (Norton, 2007). Both Feasts briefly described in this paper have resisted change for more than 200 years.

Even though the religious use of caves causes numerous negative environmental impacts, their cultural importance is enormous. This makes cave conservation a very difficult situation. The simple prohibition of cults is not acceptable because religious beliefs usually have positive impacts on regional economies and the pilgrims' quality of life. It's believed that what is should be done is to work towards maintaining such heritage sites that exist while discouraging the use of other caves for this purpose.

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REFERENCES

Amorim, J., 2006. *Nossa Senhora da Lapa: Síntese histórica de uma devoção multissecular*. -Santuário da Lapa, 19p.,Viseu, Portugal.

Dallen, J.T. & Olsin, D.H., 2006: *Tourism, Religion and Spiritual Journeys*.- Routledge, *285 p.,* New York/London.

Evia Cervantes, C.A., 2007: El Mito de la Serpiente Tsukán.- Universidad Autônoma de Yukatán, Mérida/México.

Forte, J.; Madeiros, S.; Medeiros, G.; Ferreira, C.; Lemos, R.; Mendes, H.; Neves, C.; Alves,P.; Guedes, E. Barcelos., 2008: Caves, worship and religion: some portuguese case studies. (Unpublished).

Kohler, H.C., 1989: *Geomorfologia cárstica na Região de Lagoa Santa-MG.* Doctorate Dissertation.113p., University of São Paulo, Brazil.

Mello, O., 2003: *Vazante, meu bem quere*. Prefeitura Municipal/Votorantim Metais, 287p., Vazante, Brazil.

Norton, W., 2007: *Human Geography*.- Oxford University Press, 552p., New York.

Steil, C.A., 2003: Romeiros e turistas no santuário de Bom Jesus da Lapa.- Horizontes Antropológicos, 9/20, 249-261, Porto Alegre, Brazil.

Steil, C.A.,1996: *O Sertão das Romarias: um estudo antropológico sobre o Santuário de Bom Jesus da Lapa-Bahia.*- Vozes, 309p., Petrópolis.

Vukonić, B., 1996: *Tourism and religion*.- Pergamon, 200p., Oxford.