26th INTERNATIONAL KARSTOLOGICAL SCHOOL
"Classical Karst"

26. MEDNARODNA KRASOSLOVNA ŠOLA "KLASIČNI KRAS"

SHOW CAVES AND SCIENCE

TURISTIČNE JAME IN ZNANOST

ABSTRACTS & GUIDE BOOK

POVZETKI & VODNIK

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1) first plan of Postojnska jama made by Nagel in 1748; 2) entrance to Postojna Cave in the early 1900s; 3) first railway built in 1872; 4) survey of the Škocjan Caves in 1921 (R. and F. Oedl, P. Fuhrich, and A. Meeraus); 5) *Leptodirus hiochenwartii*, the first scientifically described cave animal discovered in 1931; 6) measurement of New Križna Cave with theodolite; 7) meteorological station in Postojna Cave System / 1 – prvi načrt Postojnske jame (Nagel, 1748); 2 – vhod v Postojnsko jamo na začetku 20. stoletja; 3 – prva jamska železnica zgrajena 1872; 4 – izmera Škocjanskih jam leta 1921 (R. and F. Oedl, P. Fuhrich, and A. Meeraus); 5 - *Leptodirus hiochenwartii*, prva znanstveno opisana jamska žival odkrita 1931; 6 – teodolitska izmera Nove Križne jame; 7 – meteorološka postaja v sistemu Postojnske jame

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PROGRAM

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9:00 **Opening ceremony & 200 years of Postojnska jama** / Otvoritvena slovesnost in 200 let Postojnske jame

9:20 **Introductory talk & Keynote lecture** / Uvodno in plenarno predavanje

M. Batagelj: *200 years of Postojnska jama tourism and present-day challenges*

A. Mihevc: *Tourism and cave and karst science in Postojna*

9:50 **Session 1 (Show caves & science)** / Sklop predavanj 1 (Turistične jame in znanost)

A. Kranjc: *"Scientific" research in show caves of Slovenia – from the Antiquity to the end of the 19th century*

A. A. Cigna: *Science and show caves*

S.-E. Lauritzen: *Karst resources, tourism and conservation in Norway*

11:20 *Coffee break* / Odmor za kavo

12:00 **Session 2 (Visiting-underground interaction)** / Sklop predavanj 2 (Interakcija podzemlja in obiskovanja)

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S. Šebela: *Nearly 10-years of air temperature monitoring in Postojnska Jama and Predjama (2009 – 2018)*

F. Gabrovšek et al.: *Micro-meteorology of Postojnska jama, Slovenia: Instrumentation, Driving forces and Characteristics*

M. Prelovšek: *Impact of anthropogenic CO_2 increase on speleothem deposition*

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15:20 **Session 3 (Show caves of the world)** / Sklop predavanj 3 (Turistične jame sveta)

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D. Cailhol et al.: *Grotte de Saint-Marcel: a major French cave system for Speleology, Sciences, Tourism and Education*

M. Kalantari et al.: *The Challenges of Sustainable Development of Karst Caves Tourism – A Case Study of Zarrin (Dodza or Smoking) Cave*

D. Trnavac Bogdanović et al.: *Evaluation of the speleological geoheritage of Serbia – Case study of the show cave Petnička Pećina (Petnica Cave)*

S. Gucel: *Caves of Kyrenia Mountains: research, education and conservation*

17:30 **Poster presentation** / Predstavitev posterjev

19:30 **Unresolved mysteries of karst & "ice-breaker"** / Nerazrešene skrivnosti krasa in uvodno druženje

Cultural Centre Postojna / Kulturni dom Postojna

IZRK

Tuesday, 19th June 2018 / Torek, 19. junij 2018

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M. Brenčič: *Analysis of annual visits to Postojnska jama – historical and statistical sciences approach*

F. Drole & S. Glažar: *Simple 3D model of Postojna cave based on Gallino survey 1924-1928 combined with newly measured cave surveying data*

E. K Ando: *Integration of Human Impact Studies and Sociological Surveys for Effective Show Cave Management: Report of On-going Project in Japan*

Ł. Lewkowicz: *The history of cave tourism in the Polish-Slovak transfrontier area until 1939*

10:30 *Coffee break* / Odmor za kavo

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C. Vigne: *The Chauvet Pont d'Arc Cave Replica: a technical, scientific and territorial challenge for a new way to enhance underground heritages*

N. Zupan Hajna: *Interpretation of karst science – Postojnska jama EXPO*

S. Tutiš et al.: *Start of project implementation "Center of excellence - Cerovačke caves; sustainable management of natural heritage and karst underground"*

D. Paar et al.: *Importance of Caves in Croatia as the Locations for Outdoor Science Education*

A. Martín-Pérez et al.: *The role of Castañar cave's research studies in the dissemination of Earth science*

C. L. Ramsey & P. A. Griffiths: *Misinformation, magical mystery tours, and extreme adventures: caves and tourist information in British Columbia, Canada*

Cultural Centre Postojna / Kulturni dom Postojna

13:00 *Lunch & departure to Postojnska jama* / Kosilo in odhod proti Postojnski jami

15:00 **Afternoon field trip (A) - Postojnska jama** / Popoldansko terensko delo (A) - Postojnska jama

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8:15-10:30	**Registration** / Prijava	Cultural Centre Post. / Kulturni dom Post.
8:30	**Session 6 (Bio & microbio monitoring)** / Sklop predavanj 6 (Bio in mikrobio monitoring) S. Polak: *Terrestrial cave fauna monitoring in touristic part of Škocjan caves, Slovenia* P. Kozel & T. Pipan: *Monitoring of obligate subterranean dwelling fauna in Postojna Cave System* K. Vugrek Petljak et al.: *Results of Veternica cave monitoring as a basis for sustainable visitor management, Zagreb, Croatia* J. Mulec: *A monitoring plan using microbiological indicators to balance protection and exploitation of major tourist caves in Slovenia*	
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10:30	**Session 7 (Bio-mix)** / Sklop predavanj 7 (Bio miks) N. Baković & J. Fressl: *Disruption of the subterranean ecosystem continuum caused by lampenflora* S. Pfendler et al.: *UV-C treatment of Lampenflora proliferating in show caves* I. Lučić: *How the Postojna cave tourism shaped the image of today known olm?* S. Skok et al.: *Antibiotic resistant* Escherichia coli *strains in karst waters and on tourist footpaths in show caves in Slovenia* B. Chirol: *Victor Caumartin – pioneer of microbiology in caves*	
12:20	*Lunch* / *Kosilo*	
14:00	**Afternoon field trip (B) - M & μ show caves** / Popoldansko terensko delo (B) - M in μ turistične jame	
20:00	**Evening presentation** / Večerno predavanje (A. Mihevc: *Presentation of past International Karstological Schools "Classical Karst"*)	IZRK

Thursday, 21st June 2018 / Četrtek, 21. junij 2018

8:00	**Whole-day field trip (C) - Show caves and karst of Krka River basin** / Celodnevno terensko delo (C) - Tur. jame in kras Dolenjske
20:30	**Reception at the Institute** / Pogostitev na IZRK

Friday, 22nd June 2018 / Petek, 22. junij 2018

8:30	**Whole-day field trip (D) - Show caves and karst of Ljubljanica River basin** / Celodnevno terensko delo (D) - Tur. jame in kras Notranjske
18:00	

Oral presentations

- PowerPoint presentations should be given to the organizers **during the break before the Session starts**. Duration of the presentations is evident from the programme.

Posters

- Poster size: suggested max. format is 70 cm x 100 cm (**portrait layout**).
- Each author(s) should prepare a **1–2 minute presentation (1–3 slides)** where the essence of their poster is presented. These short presentations will be presented at the beginning of the poster session. Afterwards, the posters will be displayed and the authors will be able to answer the questions and discuss their research in detail.
- **Leave the posters and short poster presentations (.ppt, .pdf) at the registration desk on Monday, June 18th, before the lunch break**.
- Stand by your poster during the poster display.

Lunch

- Lunches are not organized on field trips and during the session days with the exception of the *Whole-day field trip (C)* and *Whole-day field trip (D)*, when simple lunches will be provided.
- Lunch breaks are timetabled into the schedule during the session days (Monday, Tuesday and Wednesday).

Field trips

- **Register for each the field trips** at the registration desk.
- Bus departure for the field trips is from the parking place at the Postojna bus station (marked as No. 3 on the Map of Postojna, p. 10)
- Take care for additional information and changes regarding the bus departures.
- **Walking shoes and field clothes** are obligatory. **Headlamps** are recommended since the IKS is dedicated to (show) caves but not all are equipped with electric lighting.
- Drinking water will be available on all busses.
- **Insect repellents** are recommended as we will be walking in the areas populated with **ticks** (*Ixodes ricinus*) that transfer mainly lyme desease and tick-borne meningitis. Check yourself in the evening after each field trip!
- **Participation on the excursions is voluntary and at your own risk.** The organisers do not accept any liability for any loss, damage, injury or death arising from or connected with the excursions. Participants are advised to arrange an appropriate insurance policy. The participants are obliged to to comply with the instructions of the organisers.

Predavanja

- Prosimo, da PowerPoint predstavitve oddajte najkasneje organizatorjem **v odmoru pred začetkom vaše sekcije**.

Posterji

- Velikost posterjev: priporočamo največji format je 70 cm x 100 cm (**pokončna lega**),
- Vsak avtor (oz. avtorji) naj pripravi 1–2 minuti dolgo predstavitev (1–3 diapozitivi), v kateri naj bodo predstavljeni bistveni vsebinski poudarki prispevka. Kratke predstavitve bodo predstavljene na začetku sekcije. Sledil bo ogled posterjev, kjer bodo avtorji lahko odgovarjali na morebitna vprašanja udeležencev.
- **Posterje in kratke prestavitve (.ppt, .pdf) pustite pri mizi za prijavo udeležencev, in sicer v ponedeljek, 18. junija, do odmora za kosilo**.
- Med ogledom posterjev stojte poleg svojega posterja.

Kosilo

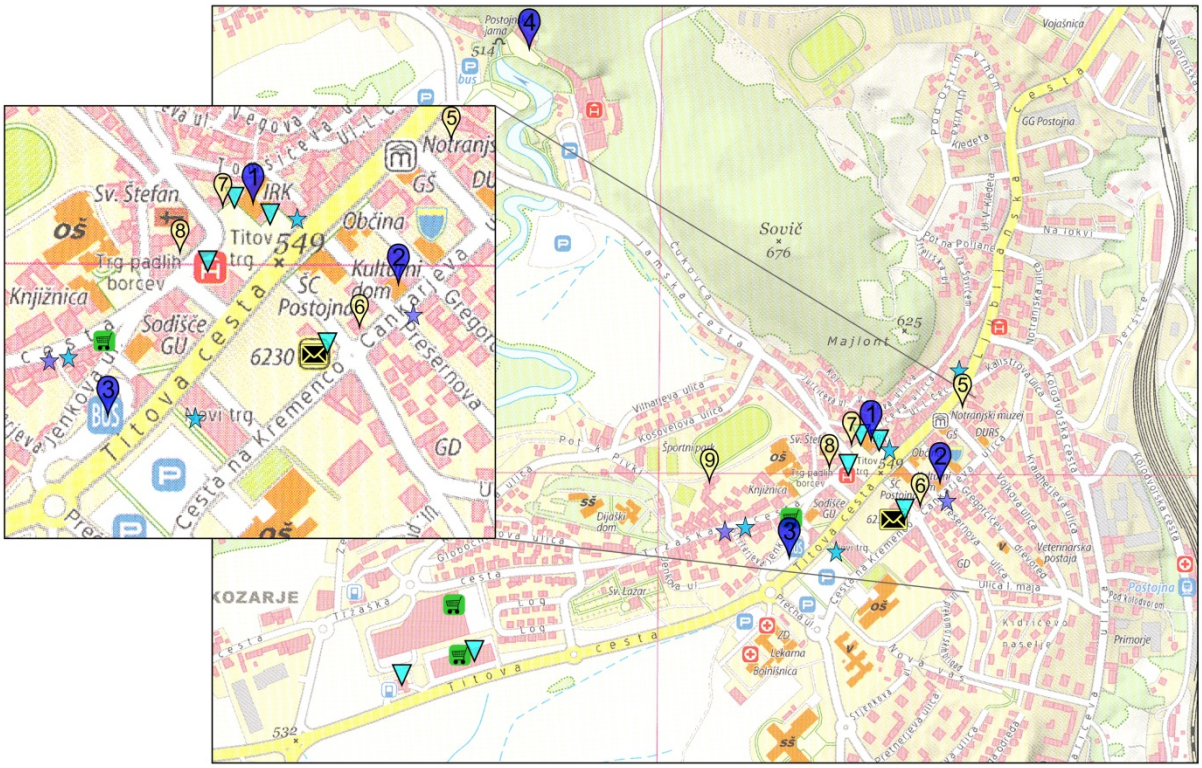
- Kosilo med predavanji in ekskurzijami ni organizirano, razen na *Celodnevnem terenskem delu (C)* in *Celodnevnem terenskem delu (D)*, za kateri bomo pripravili enostavne pakirane obroke.
- Odmori za kosilo so v času predavanj vključeni v program.

Terensko delo

- **Prijava na terensko delo** poteka pri mizi za prijavo udeležencev.
- Odhod avtobusov je z glavne avtobusne postaje Postojna (označeno s št. 3 na karti Postojne, str. 10).
- Bodite pozorni na dodatne informacije glede morebitnih sprememb o odhodih avtobusov.
- Obvezna je **terenska obleka in obutev**. **Naglavne luči** so močno priporočljive, saj bomo obiskali turistične jame – niso vse elektrificirane.
- Za vse udeležence bo na avtobusih na voljo pitna voda.
- Priporočamo uporabo **repelentov proti insektom**. Hodili bomo po območjih, kjer se nahajajo **klopi** (*Ixodes ricinus*), ki so lahko prenašalci povzročiteljev nevarne lymske borelioze ali meningitisa. Svetujemo, da se po vsaki eksurziji zvečer pozorno pregledate!
- **Udeležba na terenskem delu je prostovoljna in na lastno odgovornost.** Organizator ne prevzema odgovornosti za morebitne izgube, škodo, poškodbe ali smrtne primere, ki bi nastali v povezavi s terensksim delom. Udeležencem svetujemo, da si pred odhodom na terensko delo uredijo ustrezno zavarovanje. Udeleženci so tekom terenskega dela dolžni upoštevati navodila organizatorja.

MAP OF POSTOJNA

KARTA POSTOJNE



1. Karst Research Institute ZRC SAZU / Inštitut za raziskovanje krasa ZRC SAZU
2. Cultural Center of Postojna / Kulturni dom Postojna
3. Postojna bus station / Avtobusna postaja Postojna
4. Entrance to cave Postojnska jama / Vhod v Postojnsko jamo

Places to eat: / Možnost prehrane:

5. Pizzeria and restaurant „Minutka“ / Picerija in restavracija „Minutka“
6. Bistro „Štorja pod stopnicami“ / Bistro „Štorja pod stopnicami“
7. Restaurant „Proteus“ / Restavracija „Proteus“
8. Bistro „Bar Bor“ / Bistro „Bar Bor“
9. Pizzeria and restaurant „Čuk“ / Picerija in restavracija „Čuk“

- Fast Food / hitra prehrana
- Bakery / pekarna
- Market / trgovina
- ATM / bankomat
- Post Office / pošta

INVITATION TO A SPECIAL SESSION: UNRESOLVED MYSTERIES OF KARST

(Monday, 18th June, 2018)

This year's IKS will be as always a great opportunity as a meeting point between experienced and new researchers from different parts of the globe. Last year's Special Session on the "Mysteries in Karst Science" was very successful, in that a number of answers to some important questions in karst science were provided, and others questions were shown to be actively investigated at the moment. Usually talks in schools and congresses deal with progress of ongoing research and with their results. This session, however, has the aim to present the still-unresolved problems and to promote and stimulate research. In contrast to many other scientific fields, karstologists most often try to collaborate in order to resolve problems. This session intends, therefore, to promote further important world-wide collaborations. During the session, the talks do not necessarily show any results, hence, talks are usually short but because questions are formulated, the discussions should be longer. Therefore, talks are limited to max. 5 minutes, while discussions may last 10–15 minutes.

You are all invited to contribute to the session. Please send a brief problem outline and description to praezis@speleo.ch.

With best regards,
Philipp Häuselmann (moderator)

POVABILO NA POSEBNO SEKCIJO: NERAZREŠENE SKRIVNOSTI KRASA

(ponedeljek, 18. junij 2018)

Kot je že v navadi, tudi letošnja MKŠ predstavlja odlično priložnost za srečanje tako uveljavljenih kot tistih manj uveljavljenih raziskovalcev krasa iz različnih predelov sveta.
V zadnjih letih, ko prirejamo posebno sekcijo, t.i. "Nerazrešene skrivnosti krasa", se je izkazalo, da je tovrsten način sodelovanja med raziskovalci zelo učinkovit, saj je bila tekom let razrešena marsikatera raziskovalna dilema, z mnogimi izmed njih pa se raziskovalci trenutno še aktivno ukvarjajo.
Običajno predstavitve na izobraževanjih, delavnicah in kongresih podajajo informacije o poteku raziskovanja ter končne rezultate raziskav. Pristop te sekcije pa je drugačen, saj je njen namen predstavitev še nerešenih raziskovalnih problemov ter spodbujanje raziskovalnega dela. V nasprotju z mnogimi drugimi panogami je pri reševanju krasoslovnih raziskovalnih vprašanj pogosto vzpostavljeno sodelovanje strokovnjakov z različnih področij, kar v širšem mednarodnem okviru spodbuja tudi ta sekcija.
Predstavitve naj bodo kratke, največ 5 minut; predstavljeni naj ne bodo rezultati raziskav, temveč raziskovalna vprašanja. Diskusija pa je lahko daljša, od 10 do 15 minut.

Vabim vas, da se aktivno udeležite sekcije. Prosim vas, da krajši povzetek raziskovalnega problema in njegov opis pošljete na e-naslov *praezis@speleo.ch*.

S spoštovanjem,
Philipp Häuselmann (moderator)

FIELD TRIPS

TERENSKO DELO

Afternoon field trip **(A):**
POSTOJNA CAVE SYSTEM
Tuesday, 19th June 2018, 15:00–20:00

Popoldansko terensko delo **(A)**
POSTOJNSKI JAMSKI SISTEM
Torek, 19. junij 2018, 15.00–20.00

Peter Kozel, Janez Mulec, Tanja Pipan, Mitja Prelovšek

Postojnski jamski sistem je preko 24 km dolg splet podzemeljskih rovov z več vhodi. Povezuje dve reliefni depresiji, flišno Postojnsko kotlino in Planinsko polje. Tvori jo hidrološko aktiven Rov podzemeljske Pivke, v večjem delu pa vzporedno tudi vodoravni rovi nad višino recentnih poplav. Slednji so od odkritja (1818) izkoriščeni v turistične namene. S turistično rabo so tesno povezane tudi znanstvene raziskave v jami; leta 1831 je v njej Luka Čeč odkril prvo znanstveno opisano jamsko žival, drobnovratnika, jama je bila natančno izmerjena, do danes pa so v njej odvijale tudi številne geo(morfo)loške, hidro(geo)loške, (mikro)biološke, meteorološke, arheološke in paleontološke raziskave. Turistični razvoj Postojnske jame je bistveno pripomogel tudi k ustanoviti sprva italijanskega speleološkega inštituta, leta 1947 pa k ustanovitvi Inštituta za raziskovanje krasa, ki se je kasneje vključil v mrežo inštitutov Znanstvenoraziskovalnega centra SAZU.

GENERAL OVERVIEW

Postojna Cave System is a braided network of hydrologicaly active and relict passages formed below a karst plateau between two strike-slip faults/fault zones (Predjama and Idrija) influencing the development of basins at both sides of the karst plateau (Fig. 1). Cave passages were formed in folded and faulted bedded limestones and dolomites of Cretaceous age. It is a typical stream cave system draining the surface water, as well as gaining input of sediments from the Pivka Basin (510 m a.s.l.) to the Planinsko polje (Planina Polje; 460 m a.s.l.). The total length of passages is 24,120 m while the vertical range (115 m) is dominated by collapse entrances and sumps. The roof thickness is usually several decades of meters. The cave system connects five historical entrances (Postojnska jama, Otoška jama, Magdalena jama, Črna jama, Pivka jama) connected by open-water stream passages or sumps; the latter were by-passed by artificial tunnels between World Wars I and II. Connection with Planinska jama (Planina Cave) was confirmed by several tracing tests. Although the Postojna Cave System was partly accessible through the mentioned historical entrances, the longest and the most attractive passage was discovered in 1818 by Luka Čeč, a cave guide. Substantial effort has been made from 2015 onwards to connect the Postojna Cave System with Planina Cave. Postojna Cave System is designated as a "cradle of biospeleology" since the first cave animal was recognized and scientifically described from here in 1831 (*Leptodirus Hochenwartii*), although the olm (*Proteus anguinus*) has been mentioned already in 1689. Due to the extensiveness of the cave system, its location close to the Southern Railway (Vienna–Trieste/Trst), and the effective interaction between the show cave and science, the Postojna Cave System is an important environment for multidisciplinary speleological research (including geo(morpho)logy, hydro(geo)logy, (micro)biology, meteorology, archaeology and palaeontology) and it also highly influenced the establishment of the Italian Speleological Institute between World Wars I and II, in addition to the Karst Research Institute in 1947.

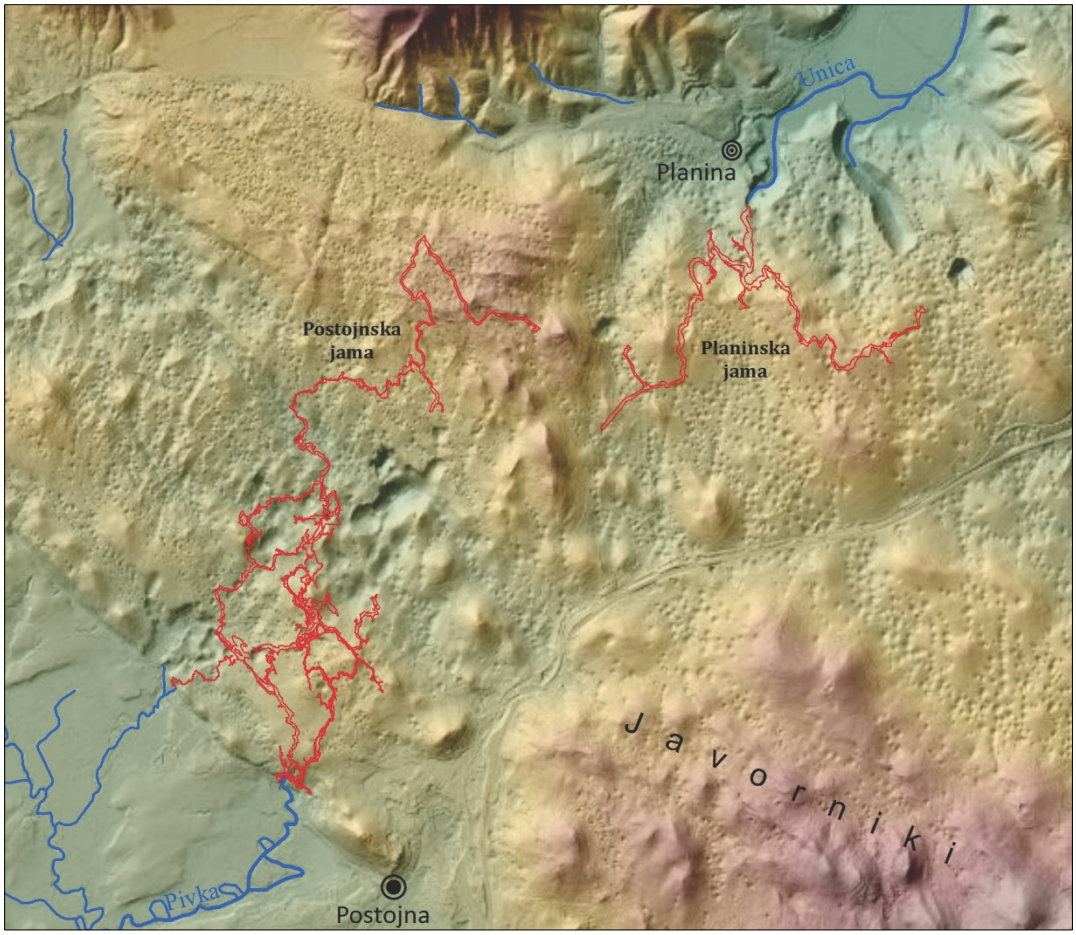


Figure 1: A geomorphological map of karst between the Pivka Basin and the Planina polje with the location of Postojna Cave System and Planinska jama (Nadja Zupan Hajna, 2017).

CAVE TOURISM

Despite the fact that several entrances of the Postojna Cave System have been known for centuries, real touristic development only started after 1818 when extensive and sinter-decorated cave passages were discovered by cave guide Luka Čeč on the right bank of the entrance chamber, Veliki Dom (Great Hall). After discovery, new entrances were excavated (in 1819, 1866, 1930s, 2002) by removal of sediments or blasting and artificial tunnels were excavated to connect Postojna Cave with Črna Cave and Pivka Cave and to reduce flooding of the Pivka River between Word Wars I and II. The touristic pathways were established from 1818 onwards, a manually operated railway was introduced in 1872 and was later extended to motor-driven carriages (1924) on a double-track circular railway (1968), the cave was electrified and activities, additional to the cave visits, with infrastructure were added outside the cave (including the Cave Palace, souvenir shops, the restaurant and the museum) and inside the cave (the post office, souvenir shop, toilets and the aquarium). Without a doubt, all stated interventions highly impacted the cave morphology and the cave climate (e.g., ventilation-air exchange, temperature, relative humidity, CO_2 concentration), as well as the visual appearance of the cave and the additional nutrient supply (causing, for example, lampenflora). From 108 visitors in 1819, the number of visitors grew to 4,000 one year after the opening of the Southern Railway (1858) and increased exponentially up to 1990 when the Yugoslav Wars resulted in a steep decrease from almost 900,000 visitors per year (1990) to 153,000 in 1991; mostly in the first months of the year (Paternost, 2004). Subsequently, the number of visitors increased again to almost 780,000 visitors in 2017. Up to 2018, the Postojna Cave System was visited by a total of more than 38 million visitors. To monitor the impact of tourism on the cave environment and to respond with appropriate (sustainable) measures, the cave is the subject of intensive climatic and spelobiologic monitoring, more intensively since 2009.

(MONITORING OF) CAVE CLIMATE

The original purpose of climate research in Postojna Cave was to measure the natural background values (e.g., range, seasonal dynamics) and elucidation of basic natural processes influencing cave temperature. Such studies were already being performed in the middle of the 19th Century (Schmidl 1954), later (1933–1936) by Crestani and Agnelli (1939), as well as Gams (1974) and still continue today with data loggers (e.g., Šebela and Turk 2011). Later, research was upgraded to the evaluate the impact of visitors (e.g., Šebela et al., 2013, Šebela and Turk 2014), to understand the relationship of cave air carbon dioxide with the geochemistry of percolation and sinking waters (Prelovšek et al., 2018) and carbon isotopic composition (Mandić et al., 2013) and to evaluate impact on various speleogenetic processes (e.g., speleothem deposition and dissolution of cave walls). Due to the important implications to health, research on radon is also abundant (e.g., Šebela et al., 2010, Gregorič et al., 2013, Gregorič et al., 2014). The impact of the railway on dust particles transported by air was measured and evaluated by Muri et al., (2013). Meteorological parameters of concern include cave air temperature, CO_2 concentration, relative humidity, and wind speed and direction. Measurements are carried out with either automatic monitoring at fixed locations (Grašič et al. 2017) or by occasional research with portable hand-held instruments (Prelovšek et al. 2018).

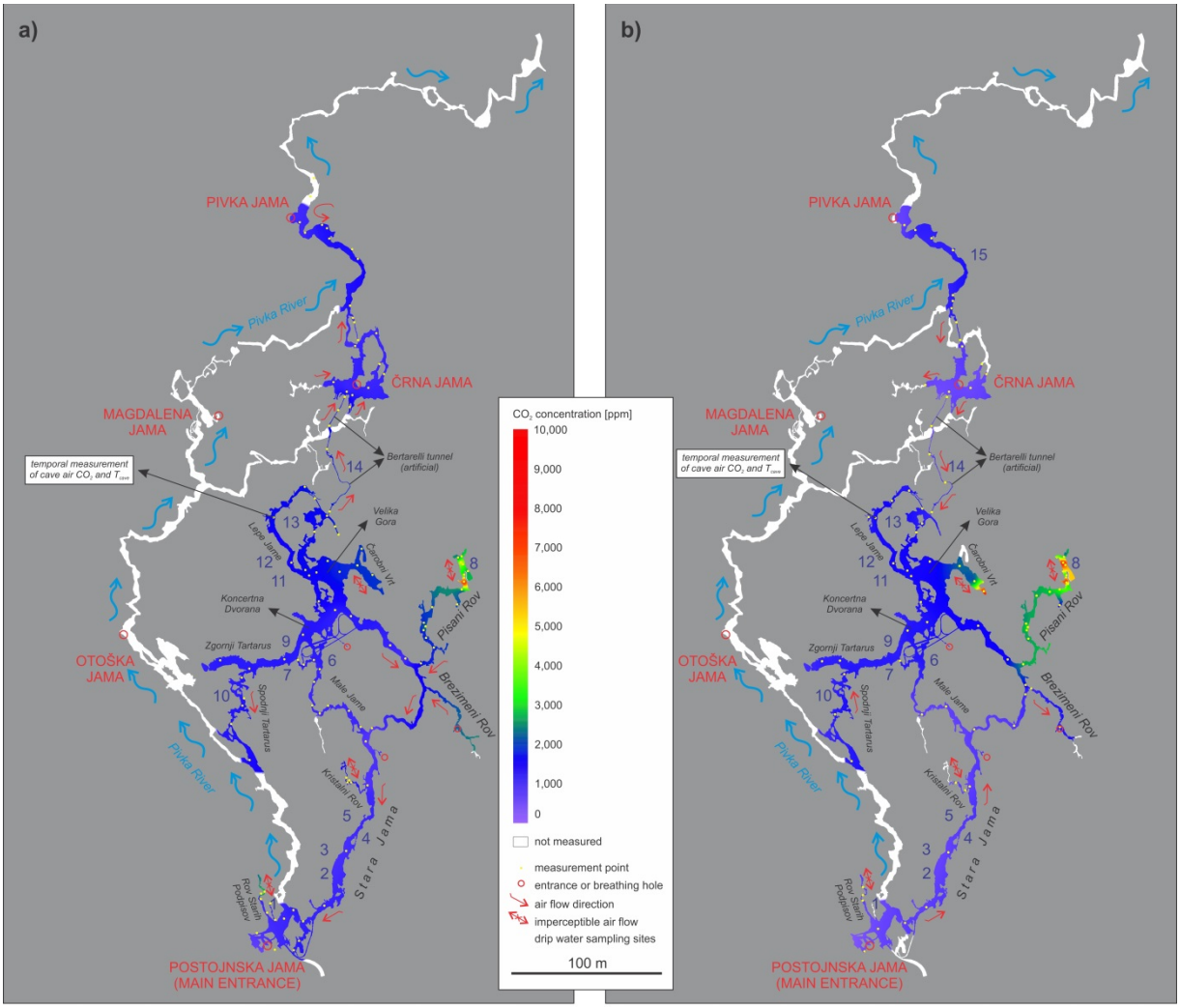


Figure 2: Cave air CO_2 concentration and ventilation regimes in the Postojna Cave System (modified after Prelovšek et al., 2018).

The climate of the Postojna Cave System is mostly controlled by natural conditions (e.g., the outside climate, the location of several entrances and the Pivka River), artificial adaptations (e.g., the opening and enlargement of entrances and building of tunnels connecting different entrances) and visiting

(via energy and CO_2 release). Ventilation is primary driven by buoyancy of cave air (chimney effect) and to a lesser extent by outside wind. Locally, ventilation is also induced by heat transferred by the Pivka River. As a result, there is relatively high spatial and temporal variation of cave air temperatures (Šebela and Turk, 2017) as well as CO_2 concentrations (Prelovšek et al., 2018; Fig. 2) over the Postojna Cave System.

The CO_2 concentration of the air in Postojna Cave (400–7,900 ppm) is controlled by CO_2 sources (human respiration contributing ~20,000–58,000 ppm per breath, outgassing of dripwater and water seeping from the vadose zone with pCO_2 concentrations of 5,000–29,000 ppm, and the underground Pivka River having pCO_2 concentrations of 2,344–4,266 ppm) and CO_2 dilution or "sinks" (inflow of outside air with a CO_2 concentration of ~400 ppm; Prelovšek et al., 2018). During the winter months, intensive ventilation reduces the cave air CO_2 concentration to outside levels (~400 ppm), even deep into the cave system. CO_2 dilution is less pronounced in summer ($CO_{2(min)} \approx 800$ ppm), since the ventilation rate is not as strong as in winter and the outside air that enters the cave through breathing holes and fractures is already enriched with soil/vadose CO_2. During spring and autumn, the daily alternation of the ventilation regime with a smaller rate of air exchange results in yearly cave air CO_2 peaks of up to ~2,400 ppm. Some dead-end passages are less affected by ventilation, resulting in cave air CO_2 concentrations $< 7,900$ ppm. In Lepe Jame, during high visitor numbers there is some indication of decreased calcite precipitation (~10-20 %) but since pCO_2 in percolation water is substantially higher than CO_2 concentration in the ventilated cave atmosphere, there is no concern of a conversion from precipitation to dissolution.

SPELEOBIOLOGICAL MONITORING

A critical factor in the biology of the subterranean fauna and one that increases the risk of extinction is geographical rarity. Some stygobionts and troglobionts are numerically rare and are at increased risk of extinction because of low reproductive rates, increased sensitivity to environmental stress and, in the case of bats, because of their propensity to cluster in large numbers in a few caves. Threats to the subterranean fauna are of four general kinds; alteration of the physical habitat, changes in water quality and quantity, direct changes to the subterranean fauna and global warming. The selection of sites for preservation requires detailed inventory data, but available evidence suggests that a majority of species can be protected at least at one site and that a relatively small percentage of total land area is required. A variety of mechanisms are available for site protection, including listing tham as a Ramsar wetland or as a UNESCO World Heritage Site. Design of a reserve is highly dependent on the nature of the fauna being protected (Culver and Pipan, 2009).

The main goal of biological monitoring in caves is to assess the current state of particular subterranean habitats through observation of the fauna. The monitoring consists of repeated long-term observations of subterranean fauna and environmental parameters in selected sampling places. In monitoring, we focus usually on endangered or/and indicator species, in particular habitat. Above all, we are interested in changes of the fauna following changes of environmental conditions. Especially in show caves, the monitoring provides many important data in supporting their proper management. In show caves, the initial state of the habitat, prior to the tourist exploitation, cannot be determined and relies only on published data, if any. In such cases, one can only compare tourist and non-tourist parts of the cave, if such natural places still exist.

The proposed monitoring methodology should include:

- Search and selection of relevant literature;
- Speleological survey of the cave;
- Identification of (micro)habitats in the cave;
- Sampling of subterranean fauna (Figs. 3 and 4);
- Measurement of physical and chemical parameters;
- Taxonomic analysis;
- Statistical analysis;
- Dissemination of results.

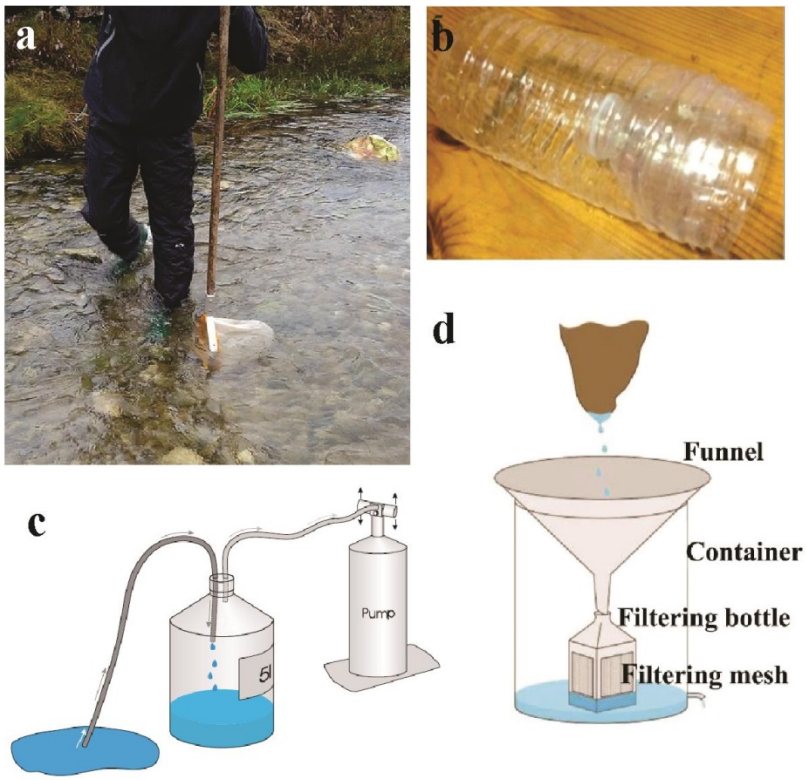


Figure 3: Selected methods for aquatic fauna sampling. 3a) "kick-sampling" method; 3b) baited trap (photo: M. Pečnik); 3c) suction pump (Pipan, 2005); 3d) device for percolation water sampling (Pipan, 2005).

Figure 4: Baited pitfall trap for sampling terrestrial fauna, placed on the ground and below cave ceiling (Kozel et al., 2017).

LAMPENFLORA

The influence of the long history of tourism in Postojna Cave is clearly visible on cave formations. Even today, smoked and sooted surfaces from torches and oil lamps are evident in some places in the cave. Postojna Cave was one of the first caves in the world with permanently installed electric lighting, which was placed already in 1884. In 1941, Morton reported on the presence of mosses around lamps (Morton, 1941). At that time, the presence of green plants growing independently of sunlight deep in the underground was considered a real scientific phenomenon. The term "lampenflora" is nowadays established to designate the phenomenon of proliferation of principally phototrophic organisms near artificial light sources at sites where under natural conditions they would not appear (Mulec, 2015). Altogether 34 different species of mosses and ferns were identified in lampenflora in Postojna Cave during seven independent sampling campaigns (Mulec, 2014a). Sampling for microscopic phototrophs revealed that the majority of taxa belonged to Cyanobacteria (59 %), followed by Chrysophyta (25 %) and Chlorophyta (16 %) (Martinčič et al., 1981; Mulec et al., 2008). Vascular plants were not reported as a part of lampenflora in Postojna Cave.

Due to the high number of tourists who visit Postojna Cave, exceeding 700,000 per year, and a relatively long lighting period of more than 1,000 hours per sector per year in the tourist part, lampenflora represents a serious problem for speleothems and objects of cultural heritage, including historical signatures and inscriptions in the cave section named Rov novih podpisov (Mulec, 2014a). Lampenflora is sometimes strongly adhered to the rocky substrata with a significant biodeterioration effect. Light has been shown to change cave atmosphere conditions (e.g., temperature, humidity, aerosols) and lampenflora indirectly influence cave fauna, as these are usually adapted to (nearly) oligotrophic conditions (Mulec, 2015).

Lampenflora colonises some part of the cave to a large extent; that is why the removal of lampenflora became a regular activity of the cave management. Until 2010, the removal of lampenflora was based on a solution containing active chlorine (sodium dichloroisocyanurate dihydrate, $C_3H_4Cl_2N_3NaO_5 \times 2H_2O$), which is commonly used as disinfectant, biocide, industrial deodorant and detergent (Huthmacher and Most, 2000). Application was carried out in the winter each second year after the end of regular tourist visits. Because chlorine compounds react with many natural substances and create different toxic products, an alternative procedure was developed to remove lampenflora. Nowadays, a 15 % and 20 % v/v solution of hydrogen peroxide is used in Postojna Cave to eliminate lampenflora on insensitive calcite surfaces without the presence of cave animals. Hydrogen peroxide is not the ultimate solution in the fight against lampenflora; further activities are continuing to find a specific biologic targets instead of using the unspecific oxidizer. An alternative approach to attenuate growth of phototrophs could be the use of lamps with tunable emission spectra, for example, green instead of white light, but many phototrophs are able to synthesize accessory photosynthetic pigments, and their growth under unfavorable light spectrum is only slowed down (Mulec, 2014b; Roldán et al., 2006). In the latest period, in Postojna Cave more attention is given to lighting regime, positioning of lamps and frequent removal of the re-emerging lampenflora around lamps.

BIOLOGICAL AIRBORNE PARTICLES

Biological airborne particles are natural tracers and, together with other environmental parameters, give a detailed view of conditions in the cave atmosphere and responses to climatic changes (Mulec et al., 2012). Microorganisms in the cave air have different histories and origins. They can originate from external environments and enter in caves associated with the movement of air masses. Some become airborne due to water splashing and mist formation from underground rivers or percolation waters. While other microbes become airborne from sedimented minute material during aerosolisation caused by wind, and particularly in tourist caves, some microbes originate from visitors who shed microscopic material associated with clothes and skin microbiome.

Mass tourism significantly impacts the quality of cave air. For example, a single person sheds about seven million particles and cells per minute, each of them carrying along on average four microbial cells (Binnie, 1991). Furthermore, coughing and loud talking release around 10^4 droplets, and

sneezing up to 10^6 droplets (Stetzenbach, 1997). In a 2-year study of the characterisation of airborne biological particles in the Postojna Cave System, ten sampling sites were selected in the tourist and wild parts of the cave. Environmental parameters (temperature, humidity, air pressure, air flow, carbon dioxide, radon, distance from the cave entrance and distance from the river flow) explained the highest variance in structure of airborne microbial communities in the winter (0.62) and in the summer (0.49) while, in the transitory periods, they explained much less (0.08–0.25). In the transitory seasonal period, temperature seems to have a significant impact ($p < 0.05$) on bioaerosol abundance. Cultivation of impacted samples showed that the average counts of fungi usually exceed bacterial counts, except at the site along the tourist pathway. A gravimetric depositional sampling method was used to isolate airborne free-living amoebae. The commonly identified taxa were mycetozoans and acanthamoebae, both producing highly resistant spores and cysts. Airborne amoebae were detected at all sampling sites, but they were constantly present only in the touristic walking zone. Some isolates were of potential medical relevance (Mulec et al., 2012).

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Afternoon field trip **(B):**
M AND μ SHOW CAVES
Wednesday, 20th June 2018, 14:00–19:15

Popoldansko terensko delo **(B)**
M IN μ TURISTIČNE JAME
Sreda, 20. junij 2018, 14.00–19.15

Mitja Prelovšek, Janez Mulec

Škocjanske jame so sklop več jam na območju porora Reke s skupno dolžino 5.800 m, ki jih ločujeta dve udornici – Velika in Mala udorna dolina. Okoli 450 km^2 veliko vodozbirno območje leži večinoma na flišu (54 %) ter apnencu (41 %), preostanek pa predstavljajo naplavine Reke s pritoki. So izreden in zelo pester primer kontaktnega krasa in kot take, hkrati tudi z estetskih razlogov, od 1986 vključene na globalni seznam UNESCO dediščine.

Prva turistična pot je bila do Tominčeve jame urejena že 1823. Sledilo je raziskovanje in turistično urejanje notranjosti glavne jame. Leta 1904 je bila odkrita Tiha jama, umetni predor do nje s strani Globočaka pa je bil izkopan leta 1933, s čemer je bila začrtana glavna pot turističnega obiska. V letu 2017 je Škocjanske jame obiskalo skoraj 178.000 ljudi.

Zaradi pomembnosti Škocjanskih jam so bile tam izvedene številne strokovne raziskave; sprva arheološke, nato pa speleogenetske in geomorfološke, geološke, hidrološke, klimatske in (mikro)biološke. Poseben poudarek v okviru hidroloških raziskav se dotika podzemnega toka Reke skozi Škocjanske jame in dalje preko več kot 5 jam proti izviru Timave. Jama je bila zadnjič celovito izmerjena v 90. letih, z LiDAR pa nedavno, februarja 2018. V zadnjih letih v njej potekata dva raziskovalna projekta, ki sta vezana na kraške raziskave v funkciji sonaravnega turističnega upravljanja z jamo.

1 – ŠKOCJANSKE JAME (ŠKOCJAN CAVES)

GENERAL OVERVIEW

Škocjanske jame refers to a group of caves formed at the sinking point of the Reka River under the Kras plateau (Fig. 5). Caves are separated by two collapses; the Velika dolina (Big doline) and the Mala dolina (Small doline). Altogether the caves are 5,800 m long and 250 m deep. The catchment area (~ 450 km^2) is located mainly on impervious Flysch rocks (54 %), while the rest is composed of Cretaceous limestones (41 %) and alluvium (5 %). The sinking point is at 314 m a.s.l. while the terminal sump is located at 190 m a.s.l. At Škocjanske jame, the following Reka discharges are characteristic: Q_{avg} = 8.26 m^3/s, Q_{max} > 350 m^3/s, and Q_{min} = 0.18 m^3/s. The underground part of the Reka River was traced in several downstream caves (Kačna jama, Jama 1 v Kanjaducah, Jama v Stršinkni dolini-Jama Sežanske Reke and in Labodnica) before it finally emerges at the surface as the Timavo Spring about 35 km NW of Škocjanske jame. The biggest chamber in Škocjan Caves has a volume of 2.1 Mm^3 (Mihevc, 2001).

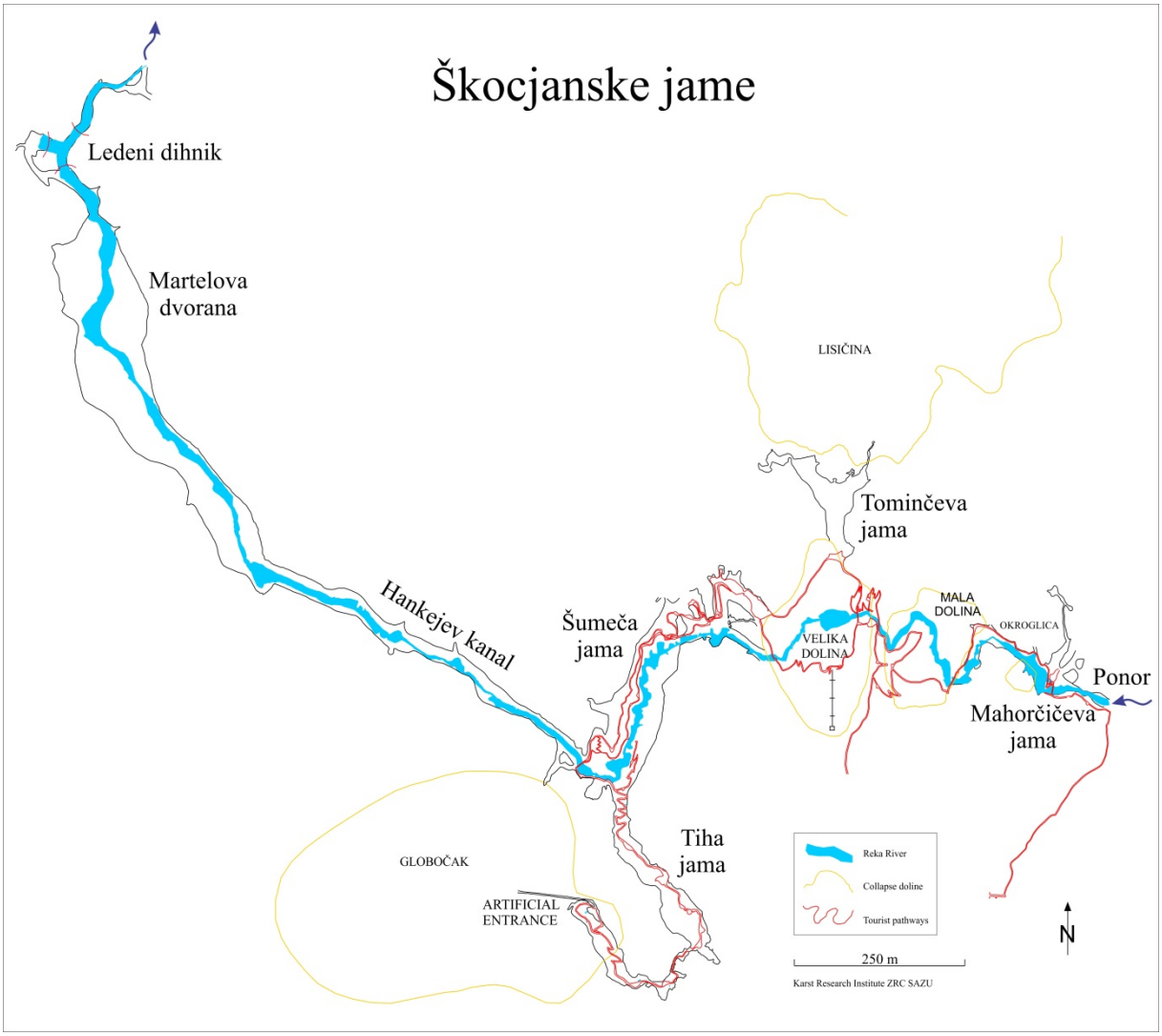

Figure 5: Plan of Škocjanske jame (Škocjan Caves) with main tourist infrastructure.

The caves, especially Tominčeva jama (Tominc Cave), have been visited from Paleolithic times onwards, and due to the impressive sink of the Reka River they were well-known in Antiquity. In 1823, under the encouragement of the fast touristic development of Postojnska jama, Tominčeva jama was already adapted for visiting (Puc, 2015). In 1851, cave explorers reached the 6th waterfall (ca. 500 m from the sink) but the most extensive exploration of underground Reka River passages

started in 1884 by cavers of DÖAV (Littoral section of Austrian Alpine Club) and locals, and successfully ended in 1890 when the terminal sump (The lake of death) was reached. After discovery of Tiha jama in 1904, construction of an artificial tunnel from the collapse doline Globočak followed in 1933 and the nearly present-day tourist route was established. In 2017, Škocjanske jame were visited by almost 178,000 visitors.

Due to it's importance, a lot of research has been conducted in Škocjanske jame focusing on archaeology, speleogenesis and geomorphology (Mihevc, 2001; Slabe, 1995; Prelovšek, 2012), geology (Gospodarič, 1983, 1984; Knez, 1996; Šebela, 2009, 2016), cave sediments (Kranjc, 1989; Zupan Hajna, 1995), hydrology of drip water (Kogovšek, 1984), as well as (micro)biology (Mulec, 2014; Mulec et al., 2008, 2017; Pipan, 2013; Polak, 2012). Special emphasis was paid to the hydrology of the Reka River in Škocjanske jame and downstream towards the Timavo River (Gabrovšek and Peric, 2006; Gabrovšek et al., 2018). The cave was surveyed several times; the last time completely by theodolite in the 1990s (Drole, 1997) and in February 2018 by LiDAR scanning. A few years ago there were several successful diving expeditions to connect Škocjanske jame with Kačna jama but some hundreds of metres of passages have remained unexplored.

Due to the aesthetic value and the unique development of various karst phenomena related to the Reka River sink, Škocjanske jame were inscribed on the UNESCO world heritage list in 1986. The cave, included into the regional park, is managed by Škocjan Caves Public Service Agency.

Two applicative research projects financed by the Slovene Research Agency have been running in Škocjan Caves recently, carried out by the Karst Research Institute ZRC SAZU with project partners (University of Ljubljana, Faculty of Medicine; Slovenian National Building and Civil Engineering Institute; MEIS Environmental Consulting d.o.o.):

- Natural resources of karst show caves: a balance among protection, exploitation, and promotion (code J7-7100);
- Karst research for sustainable use of Škocjan Caves as world heritage site (code L7-8268).

CAVE CLIMATE

General characteristics of cave climate were studied by Kranjs and Opara (2002), continued in the 2000s and 2010s and have been recently upgraded within the research project *Karst research for sustainable use of Škocjan Caves as world heritage site* performed by the Karst Research Institute ZRC SAZU, MEIS Environmental Consulting d.o.o. and Škocjan Caves Public Service Agency. Special attention was paid to the background values of relevant climatic parameters (including temperature, relative humidity, wind velocity and direction, and CO_2 concentration), anthropogenic contribution, as well as consequences of touristic use of the caves.

From a climatic point of view, Škocjan Caves are divided into two sections: (i) the main stream passage along the Reka River as the dynamic part and (ii) Tiha jama as the static part of the cave. The stream passage is highly influenced by two wide entrances with intensive ventilation driven by a chimney effect and the Reka River temperature that maintains surface characteristics; in winter time, air enters the cave through the lower entrance and exits through the upper one (Scmidlova dvorana; Schmidl chamber), while the Reka River can have temperature around 0 °C. As a result, the Reka River freezes in Hankejev kanal (Hanke's channel) and the cave walls dry extensively. In summer time, a reverse circulation is observed with condensation of water vapour on cave walls and mist at the interface between relatively colder air exiting the cave and relatively warm air entering the cave. At Ponvice (Rimstones), temperature varies seasonally between 17 °C during summer and 5 °C during winter time (Kranjc and Opara, 2012). Ventilation also influences the shape of speleothems. Temperature of Tiha jama is quite constant at about 12 °C with relative humidity close to 100 %.

In the last months, special attention was paid to CO_2 sources and sinks in the cave. The Reka River is recognised as a constant CO_2 source with a theoretical pCO_2 of 1,000 ppm during high discharge (178 m^3/s) and < 15,500 ppm during low discharge (< 1 m^3/s). Drip water also constantly supplies cave air with CO_2 since the pCO_2 of drip water is between 14,000 and 35,000 ppm. The only "sink" determined up until now is dilution of cave air with outside air that has a CO_2 concentration of about 400 ppm. Occasional measurements of CO_2 fluxes from drip water at Šotor (Tent) in Tiha jama

indicate rates between 0.1 and 0.5 ppm/s/m^3; at the Ponvice site, CO_2 fluxes are much higher (2.2 ppm/s/m^3) but this happens only several days per year when the spring that supplies water to Ponvice is hydrologically active (Prelovšek, unpublished).

TOURIST PATHWAYS

Cave pathways are inevitably connected with show caves; despite the fact that pathways, especially concrete ones, completely destroy the cave floor, pathways limit direct anthropogenic impact to a relatively small area and, thus, preserve nearby natural cave floors. In Škocjan Caves, pathways are relatively unique compared to other caves since they were originally related to cave exploration (access pathways) and to avoid flooding (safety pathways), while some of them were dedicated only for tourism (tourist pathways). Due to mostly (semi)vertical walls, many of them are carved into the rock, connected by bridges and, therefore, form veritable masterpieces of stonecutting and underground engineering.

The first tourist pathways, which simplified access to the collapse dolines and Tominčeva jama (Tominc's Cave) but gated to control visitor numbers, were constructed in 1823 (Puc, 2015). Discovery of new passages that were later included into the touristic tour (Tiha jama/Sillent passage in 1904), as well as digging of a tunnel with an artificial entrance (1933) with an inclined elevator (1986), resulted in several changes to the pathways, including building new ones, omission of old ones, changing direction of the tourist visit, shortening of tourist visits, and fragmentation of original visit into several pieces. As a result, in 1986, only 1,640 m of the total 7,650 m of constructed cave pathways formed part of the tourist route (Mihevc, 2004). With renovation of the old pathways over the last decade, especially between the first Reka River sink and the Velika dolina, about 3,000 m of pathways is in use nowadays.

MICROBIOLOGICAL MONITORING OF TOURIST IMPACT IN ŠKOCJAN CAVES

Microorganisms play different roles in the underground, from an active speleogenetic factor up to the energy support for higher trophic levels (Culver et al., 2012). The microbial world in Škocjan Caves is dynamic and strongly susceptible to external influences. Microorganisms utilise movements of water and air masses as well as migratory organisms to colonise new habitats. The Škocjan Caves host a population of bats that regularly bring particles from the outside into the underground (Mulec et al., 2016). With their excrements, they make a significant introduction of organic molecules and microorganisms. Visitors, more than 150,000 per year, are another important vector of introduction and transport of biological particles. Tourists bring into caves a considerable quantity of organic material on their footwear. Because tourists bring and spread, especially by footprints, many live microorganisms ($>$ 10,000 Colony-Forming Units per 100 cm^2) (Mulec, 2014), measures to reduce such input should be implemented in the future management plan.

Air is an important habitat for microorganisms, as well as a vector of their transmission. Biological particles in the air (aerobiology), the influence of atmospheric parameters on their distribution, seasonal oscillation and concentrations can be studied in karst caves. In tourist caves, the presence of tourists is an additional factor that significantly affects the quality of cave air (Mulec et al., 2012). Along the tourist route in Škocjan Caves, the concentration of microorganisms typical for human microbiome was considerably elevated. For example, when 310 tourists passed the monitoring site in the section Tiha jama (Šotor), the concentration of airborne bacteria increased 40 times from their base concentration before the tourists' arrival. The increased concentration of airborne microbes due to tourists, persisted several hours after tourists vacated the cave passages (Mulec, 2014). A mix of bacteria associated with human skin microbiome and natural habitats were found in the cave air. A few of the isolates were attributed to Risk Group 2 (e.g., *Acinetobacter johnsonii*, A. junii, *Aerococcus viridans*, *Bacillus cereus*, *Brevundimonas diminuta*, *Staphylococcus epidermidis*, *S. haemolyticus* and *S. pasteuri*). Furthermore, a strong positive correlation between tourist numbers and the rise in the concentration of airborne bacteria was clearly indicated for this cave section (Mulec et al., 2017).

Artificial lighting represents the biggest change for cave environments. Electric lighting was introduced in Škocjan Caves in 1959. Surfaces that were artificially lighted gradually adopted a greenish colour that is attributed to eukaryotic algae, cyanobacteria, mosses and ferns. This community, known as lampenflora, is usually strongly adhered to the substrate and is responsible for its deterioration (Mulec, 2015). Lampenflora is clearly observed in Škocjan Caves along the tourist route and, in some locations, it is already encrusted within the flowstone. Especially the encrusted lampenflora is a legacy of inappropriate management of this issue before the Škocjan Caves Regional Park was established in 1996.

Despite the sectoral lighting, the lights are switched on for a relatively long time because tourist tours inside the cave are organised throughout the year. In a study carried out in 2003, 21 taxa of microscopic phototrophs were identified in lampenflora, of which 57 % were cyanobacteria, 29 % belonged to Chrysophyta and 14 % to Chlorophyta. The most common microscopic phototroph was the green alga *Trentepohlia aurea* (Mulec et al., 2008). The moss *Eucladium verticillatum* was common in the lampenflora (Mulec and Kubešová, 2010).

The restriction of lampenflora growth is one of the major challenges for cave managers. In the years 2013–2014, halogen lamps were replaced with LED lamps and additional lighting sectors were introduced. The advantage of these kind of lamps is the possibility of fine tuning of an emission spectrum, which to a lesser extent enables the growth of lampenflora. Similar as in Postojna Cave, the remediation of insensitive calcite surfaces colonized by lampenflora includes the application of a 15 % (v/v) solution of hydrogen peroxide (Mulec, 2014).

Due to electric installation and various electric devices, the underground in the tourist part of Škocjan Caves is challenged by ultrasonic noise derived in a broad range (10–123 kHz) that can be effectively minimised with the installation of protective housings (Mulec, 2014).

2 –SVETA JAMA (ST. SERVULUS CAVE)

Every show cave, even the smallest ones, has some special peculiarities that draw the attention of visitors. Sveta jama is located at the western edge of Classical Karst. It is 231 m long and 44 m deep, among which the deepest part is accessible for cavers only. It is one of the shortest Slovenian show caves but it draws attention due to cultural heritage related to religion. The cave is named after St. Servulus (San Servolo; born in Trieste/Trst, Italy) who possibly lived in the cave for more than one year in the 3rd century. The cave was mentioned already in 1463. Valvasor, that visited the cave in the 1678, reported occasional mass held in the cave in memory of St. Servulus. At that time, the altar was already established, while the lower part of the cave was used as a wine cellar by the earl, graf Benvenut Petač, that lived in the nearby partly renovated ruins of the castle (the same that, in 1633, established concession (gave rights) for touristic use of the first show cave in the world; Vilenica Cave). Up to World War II, the cave was an important pilgrimage place for people from Trieste and Istria. In 1946, the altar was destroyed and the pilgrimage was abandoned. To follow tradition, from 2006 onwards, each year a mass is organised on the anniversary of St. Servulus' death; 24th May. The basin of holy water (font) that is chiselled into flowstone was hydrologically "studied" by Valvasor in the 17th century. The cave is nowadays advertised as an underground church and managed by a local caving club. Tourist visits lasts 30 min and the cave is not electrified. It is used for educational purposes (e.g., biology, cave meteorology) for primary school students and occasionally for weddings. Shaw and Čuk (2012) made a comprehensive review of pictures from the cave until the 19th century. Due to marginality, the cave never draw special attention from modern researchers; however, Mulec et al. (2015) did some research on the characterisation and fluorescence of yellow biofilms in the cave. Additionally, occasional measurements of temperature, carried out for basic pedagogical purposes, indicate the cave acts as a closed depression with below-freezing temperatures in the Entrance Hall.

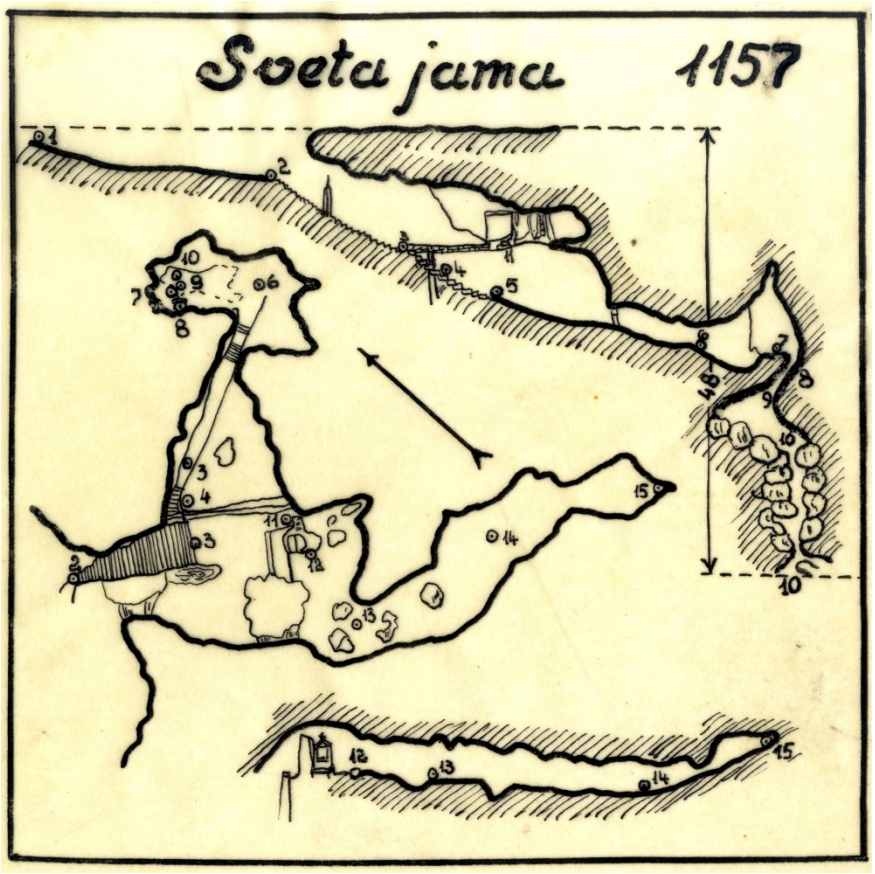

Figure 6: Plan and cross-section of the Sveta jama (St. Servulus Cave).

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Whole-day field trip **(C):**
SHOW CAVES AND KARST OF THE KRKA RIVER BASIN
Thursday, 21st June 2018, 8.00–20.00

Celodnevno terensko delo **(C)**
TURISTIČNE JAME DOLENJSKEGA KRASA
Četrtek, 21. junij 2018, 8.00–20.00

Mitja Prelovšek, Nataša Ravbar

Dolenjski kras ločijo od klasičnega generalno nižja nadmorska višina površja, višji delež triasnega dolomita ter nižja količina padavin. Fliši niso prisotni, je pa na karbonatnih kamninah priotne več ilovice. Jame, tudi turistične, so krajše. Med turističnimi izstopata Županova jama (3.000-4.000 obiskovalcev letno) in Kostanjeviška jama. Željnske jame pri Kočevju uradno niso priznane kot turistična jama, se pa v zadnjih letih krepijo prizadevanja za ureditev tovrstnega statusa. Največ raziskav med omenjenimi jamami se je izvajalo v Županovi jami, zlasti meritev temperature (Ravbar in Košutnik, 2014), znatno prej pa je Gospodarič (1987) v njej raziskoval jamske sedimente. Mulec s sodelavci (2008) je v jami raziskoval zeleno razrast (lampenfloro) ter delce v jamskem zraku (neobjavljeno). Prelovšek (neobjavljeno) je v jami vzorčil in analiziral preniklo vodo za ugotavljanje trdote ter vsebnosti CO_2. Precej manj raziskav je vezanih na bližnjo, a manj znano Krško jamo, ki predstavlja visokovodni preliv izvira Krke. Pot bomo nadaljevali po dolini zgornje Krke, ki je prepoznavna po številnih deloma antropogeno pogojenih lehnjakovih pragovih, preko obširne gozdnate kraške planote Kočevskega roga z jamami, ki so bile po 2. svetovni vojni uporabljene tudi za množične poboje; s slednjega vidika so območja jam zlasti okoli Krena širše prepoznavne, simbol povojnih pobojev, jame pa v javnosti velikokrat konotirajo negativno. V sklepnem delu se bomo ustavili v zgodovinsko pestrih Željnskih jamah, ki ne navdušujejo s kapniki, ampak z množico oken ter naravnih mostov, v zimskem času pa z ledenimi kapniki. V zadnjih letih (2015-2018) smo v okviru projekta Life Kočevsko v njih spremljali kvaliteto podzemne vode, ki se je glede na ostala merilna mesta okoli Kočevja kljub negativnemu slovesu povezanem z industrijsko-komunalnimi oblikami onesnaževanja (premogov prah, neočiščena komunalna odpadna voda) izkazala kot ena izmed najboljših na Kočevskem polju.

1 – ŽUPANOVA JAMA (MAYOR'S CAVE)

GENERAL OVERVIEW

The Cave of Županova jama is located in Central Slovenia at the northern rim of the Dinaric karst. The cave was discovered in 1926 by a local mayor, Josip Perme, and is, thus, called The Mayor's Cave. Before its discovery, the locals were only familiar with one of the cave's chambers, which they used as an ice pit, also mentioned by Valvasor (1689). After the discovery, the mayor invited a group of cave explorers from Ljubljana to survey the cave. It has been the first bigger cave of the Dolenjska region, which was described and researched by a professionally composed interdisciplinary programme of the Slovenian Cave Registry (Bohinec, 1927). The publication of the results of this work is considered the first Slovenian scientific speleological publication. The mayor forced the touristic development of the cave, financed by himself, and opened the cave to the public the following year. In recent times, annual visitor numbers average between 3,000 and 4,000.

The cave is formed in thick to massively bedded limestone layers of Liassic (Lower Jurassic) age. It has two entrances at the elevations of 434 m and 465 m a.s.l. that are roughly 120 m apart. The current known length of the cave is 812 m, with a known depth of 70 m. This is a relict cave that consists of eight collapse chambers connected by narrow passages (Fig. 7). The bottom of the cave is covered by $<$ 30 m-thick clastic sediments and flowstones of Late Pleistocene age that were deposited in a stratigraphical sequence: allochthonous red loam with sand is followed by flowstone, brown loam with gravel and finally flowstone (Gospodarič, 1987).

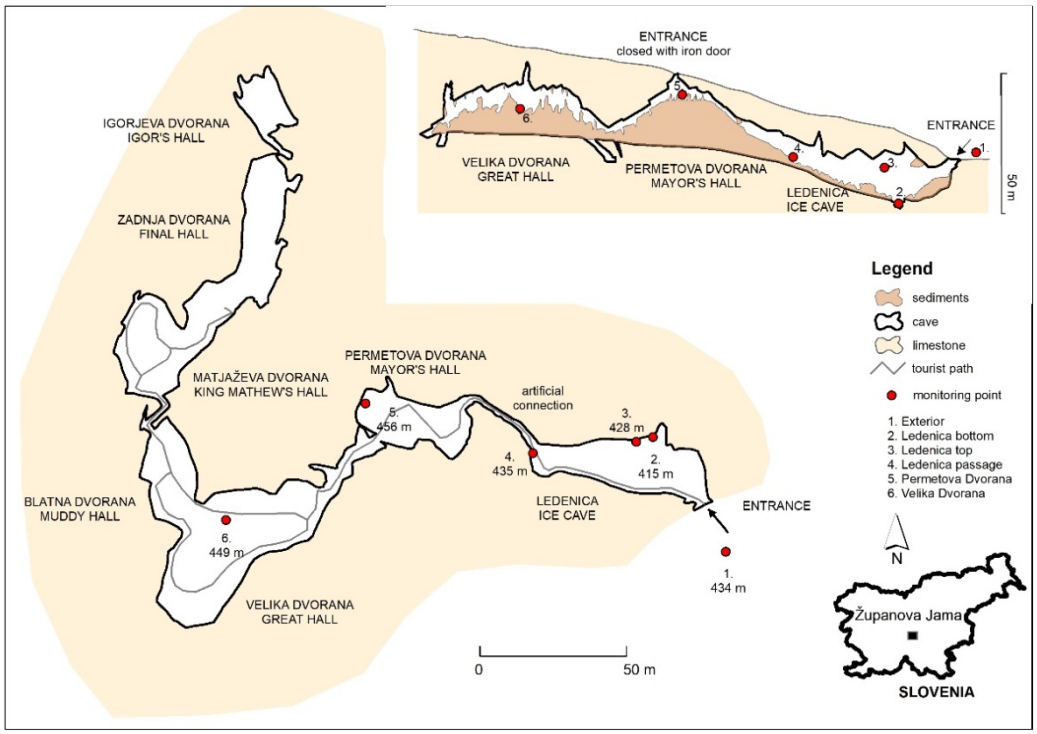

Figure 7: Ground plan and profile of the Županova jama (Mayor's Cave) with locations of air temperature monitoring points (Ravbar and Košutnik, 2014).

CAVE CLIMATE

Parts of Županova jama are characteristic for their spatial and temporal air temperature (T) variations. To better characterise the T regime and variability, and to carefully plan the maintenance work and possible interventions, detailed T monitoring and data analysis has been carried out since 2009. For monitoring, a BaroDiver and T-button DS1922L data loggers have been used. T data was recorded hourly and, in some periods, every half hour. The monitoring took place in the Ledenica (Ice Cave), Permetova Dvorana (Mayor Perme's Hall) and Velika Dvorana (Great Hall). The first two

chambers are open to the surface while the rest of the cave is separated by constrictions and is climatically isolated. Ledenica is a lower lying chamber that has a pocket-shaped morphology with steep walls. On one side it is open to the surface and on the other it is connected to the chamber of Permetova Dvorana. The cross-sectional area of the entrance is about 24 m^2 and the constrictions further into the cave are each about one m^2. Permetova Dvorana is a bell shaped, 11 m high chamber with an entrance at the top that is permanently closed with a partially airtight iron door. The monitoring results show the air T in Velika Dvorana is generally very stable throughout the year and is normally unaffected by the external atmosphere. The monitored values range between 9.4 °C and 9.9°C, being a few tenths of a degree lower than the mean annual air T observed outside the cave and at the Grosuplje meteorological station (ARSO, 2016). In contrast, the Ledenica and Permetova Dvorana chambers display distinct seasonal climatic cycles (Fig. 8) and seasonally also daily fluctuations (for more information see Ravbar and Košutnik, 2014).

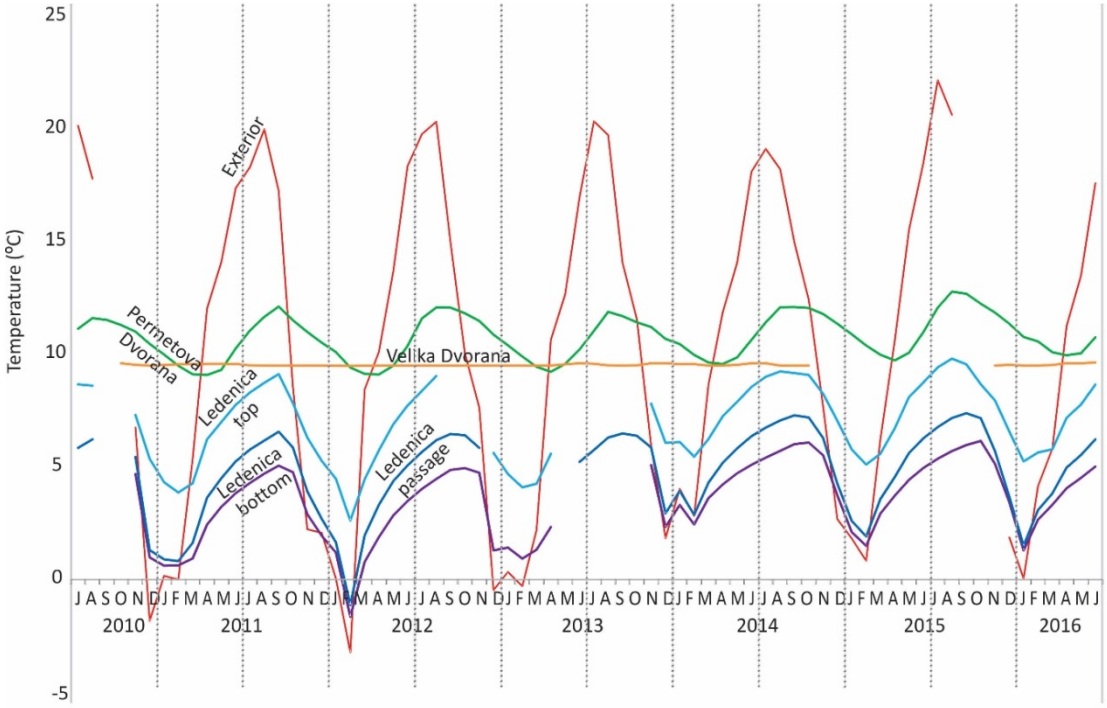

Figure 8: Mean monthly air temperature of external and interior of the Županova jama.

The lowest absolute temperatures were recorded in Ledenica. At the bottom of the chamber, T values may drop to several degrees below zero (T_{min} = −4.6 °C). Also annual air T amplitude is the highest at the bottom (T_{max} = 5.5 °C) and top (between −3.9 °C and 6.8 °C) monitoring points and reaches up to about 11 °C. The highest monitoring point in Ledenica (passage), which is also the most distant from the entrance, never freezes and has the highest T values in this part of the cave (between 1.8 °C and 9.6 °C) reaching the amplitude of 7.8 °C.

All three monitoring points exhibit a well-pronounced seasonal trend that coincides well with the trend of the external air T. In general, there is a sharp drop in the cave's air T at the beginning of the cold part of the year. A subsequent exponential rise of the cave's air T in the warm part of the year persists as long as the external air T remains elevated, and it continues rising for additional 1–2 months. Compared to Ledenica, the seasonality of air T in Permetova Dvorana is less pronounced. Air T yearly varies by ~3.7 °C (8.8 °C to 12.5 °C).

Although the cave does not rank among Slovenia's top tourist attractions, in the observed period nearly 3,500 people visited the cave annually. Daily visitor numbers ranged from 2 to 182 people, 22 being the average daily number. In the cold half of the year, separate groups of a few individuals during weekends prevail, while larger, mainly school groups are characteristic during the warm half of the year. Each group spends about an hour in the cave.

Occasionally, temperature rise due to the tourist visits can be observed in Permetova Dvorana ($V \approx 50\ m^3$) and Velika Dvorana ($V \approx 15{,}750\ m^3$), although the range of anomalies does not surpass a few tenths of a degree. A maximum increase of 0.77 °C was observed in Permetova Dvorana (16 June, 2011, daily sum of 182 tourists), and a maximum increase of 0.4 °C was observed in Velika Dvorana (22 January, 2011, daily sum of 180 tourists). Despite the detected T elevations, the values usually stayed below the normal annual variation values in Permetova Dvorana, but may occasionally exceed the normal maximum air T in Velika Dvorana. At both monitoring points, the temperatures decreased to their initial values and recover their natural trends within a few hours after the visit, taking an average of 4.5 hours and a maximum of 12 hours in Permetova Dvorana and an average of 3.9 hours and maximum of 11 hours in Velika Dvorana.
On a few occasions, the iron door of the higher-lying entrance has been left open for special events for ~10 hours per event. Consequently, the warm air bursts towards the Ledenica have been observed. The T in Ledenica passage rose even for ~1 °C, surpassing T_{max}. The solution to the problem has been in preparation.

CARBONATE WATER GEOCHEMISTRY

In 2014 and 2015, several samples of drip water in Velika Dvorana (Great Hall) were taken directly at the outflow from the cave roof to get a general insight into the carbonate water geochemistry before interaction with the cave atmosphere. Sampling reflects the end of summer (November) and end of winter periods (May). Temperatures of the drip waters indicate equilibration of different (seasonal) heat sources and sinks (transfer by drip water, ventilation and geothermal flux) from above and nearby cave passages. The water temperature at the same sites were 9.8 °C–10.4 °C and 9.9 °C–10.3 °C, with the highest temperatures in May and the lowest in November, which is probably a result of time-lapse (duration of outside temperature signal) spanning half a year. Water temperature is within the frame of the cave atmosphere temperature variation (Ravbar & Košutnik, 2014). In all cases, water was close to saturation with respect to calcite (SI_{Cal} from −0.02 to 0.19 with an average of 0.07) with relatively high hardness (from 2.41 to 2.86 mmol/L of $Ca^{2+} + Mg^{2+}$) independent of discharge. From 97 % to 99 % of hardness is represented by Ca^{2+} indicating high prevailance of limestone over dolomite (2–6 %) above the cave passage. In November, water was harder indicating higher pCO_2 in the epikarst at the end of autumn as a result of the summer ventilation regime (and CO_2 production rate). pCO_2 before CO_2 outgassing was between 1.48 % to 2.24 % with the pH, as a result, relatively low (7.085–7.409).

LAMPENFLORA

Županova jama is equipped with tourist infrastructure, including concrete footpaths, protective fences and electrically powered lighting. Although it is visited by much fewer visitors than the two most visited caves in Slovenia (Postojna Cave and Škocjan Caves), their impact on the cave ecosystem should not be ignored.
Visitation of Županova Cave was particularly increased after the installation of permanent electric lighting in 1937. Some sections in the cave are strongly lighted, at some points even more than 1,000 lux, and particularly these sections are prone for lampenflora development.
As in many other tourist caves, such high illuminance of surfaces should be avoided. Namely, the luminosity in the range of 50 to 100 lux is usually sufficient for easy orientation and short visits of dark spaces. Similar to other tourist caves, phototrophs identified in the lampenflora were common taxa, adaptive to various environmental conditions, usually being able of fast reproduction, such as *Trentepohlia aurea*, *Chlorella* sp. and *Synechocystis* sp. (Mulec et al., 2008). Ten Bryophytes were identified as a part of the lampenflora community. In a comparative study of lampenflora in Slovenian tourist caves, the surfaces in Županova Cave were on average exposed to the highest measured PPFD values (Photosynthetic Photon Flux Density), and the taxonomical analysis revealed the lowest dissimilarity species index (Mulec and Kubešová, 2010).

ROCK SWABS AND BIOLOGICAL AIRBORNE PARTICLES

In a preliminary study in 2016, several swabs from a tourist footpath and a touched stalagmite were collected. The highest concentration of culturable microbiota per surface unit (Colony-Forming-Unit/ 20 cm^2) was observed in the narrow artificial passage (Umetni rov). The morphology of cave voids and air circulation play an important role in distribution of airborne particles. Interestingly, in the same narrow passage of the cave (Umetni rov) a relatively higher concentration of biological particles compared with other parts of the cave was observed (unpublished data).

2 – KRŠKA JAMA (KRKA CAVE)

Krška jama (Fig. 9) was a well-known cave for locals since Copper and Iron Age pottery was found inside and because it was used as hiding place during Ottoman invasions. It was already mentioned and visited by Valvasor in the 17th century; at that time it was accessible through a small upper entrance. It is an overflow cave of the 94-km-long Krka River (right tributary of the Sava River) at 268 m a.s.l. draining about 200 km^2 of extensive bifurcational areas traced by many tracing tests (Kogovšek and Petrič, 2006). In order to reduce floods in the upstream poljes, the main entrance that was originally blocked by colluvium was excavated 1935; further hydroengineering work (drilling of tunnels above water-filled passages) was far from being completed resulting in unalteration of flooding. The main attraction of Krška jama is the spring of the Krka River, the stream passage with a permanent water body and, to some extent, *Proteus anguinus* that lives in the cave as a part of much more extensive habitat. However, since Proteus is considered as a qualifying species (Natura 2000 network) as well as a vulnerable one (IUCN and national Red List), the Proteus exhibition in a glass aquarium, established in 1997, is now prohibited. Due to the hydrological role of the cave, speleothemes are small and rare. Together with dived passages, the cave is 820 m long. In the last decades, the cave is managed by the local Krka Tourism Society. The cave attracts annually around 5,000 visitors. Due to biological reasons (bats, Proteus hunting) the cave was closed in 1996. In the same year, permanent electric lighting was installed, path and fences were renovated.

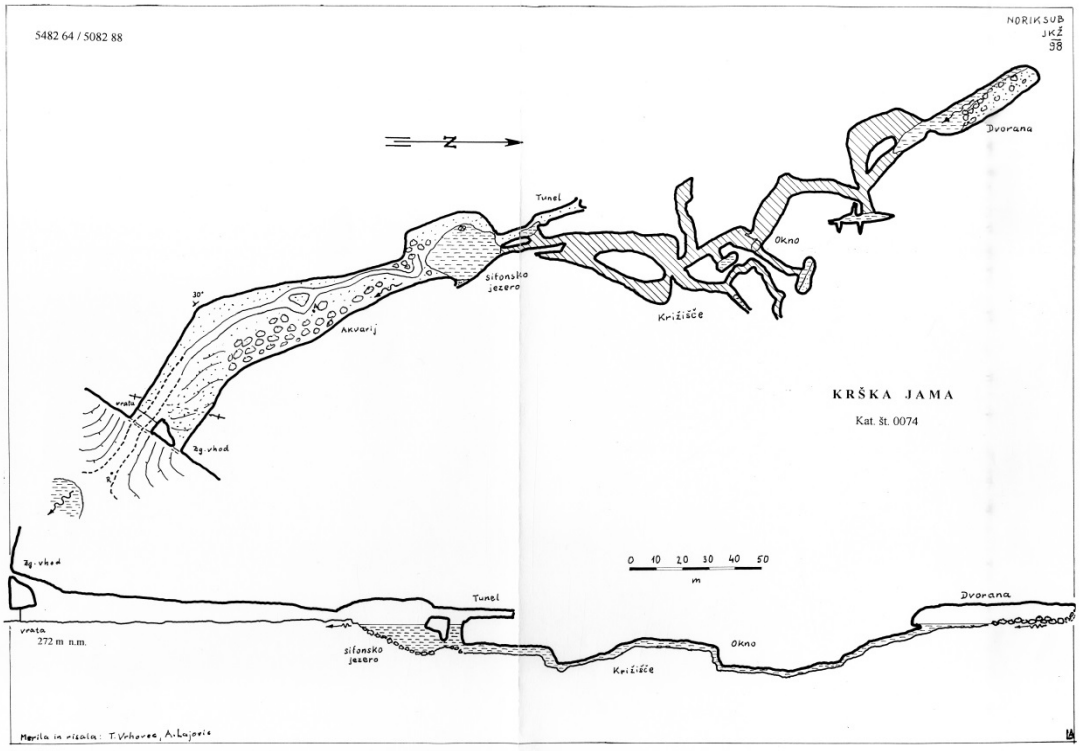

Figure 9: Plan of Krška jama (Krka Cave; T. Vrhovec (Norik-sub) and A. Lajovic (JKŽ)).

Above a nearby spring, 500 m SW of Krška jama, a 740 m long stream cave Polterica was discovered in 2003; despite the fact that the cave is not legally accepted as a show cave and is without touristic infrastructure, 180 m of the cave can be visited with local cavers and is a part of the tourist offerrings of the Krka Tourism Society. About 10 km north from Krška jama, *locus typicus* (type locality) of *Proteus anguinus* (olm, cave salamander) is located.

LAMPENFLORA

The tourist part has one single lighting sector. However, the introduced amount of light gives enough energy for lampenflora to develop. Quite a few rocky surfaces in the proximity of lamps – many of them are partly or totally covered by sediments – are visibly colonised by lampenflora.

Ten cyanobacterial and algal species were identified in the community of lampenflora, the most commonly were: *Gloeocapsa minuta*, *Navicula contenta*, *N. harderi* and *Trentepohlia aurea* (Krivograd-Klemenčič and Vrhovšek, 2005). In addition to microscopic phototrophs, in the community of lampenflora, four species of Bryophytes and two belonging to Pteridophytes were identified as well. The diversity of lampenflora phototrophs in Krška jama is not high; the identified phototrophs are present also in other Slovenian caves as part of lampenflora (Mulec and Kubešová, 2010). Interestingly, its fast development, three years after installation of electric lighting (Krivograd-Klemenčič and Vrhovšek, 2005) indicates favorable conditions, likely connected with the active water flow, available on-site nutrients and rich inoculum.

PROTEUS ANGUINUS

The Krka River floods the tourist pathways during high water period that makes the cave inaccessible for visits. Diverse stygobitic fauna inhabit the Krka River, including *Proteus anguinus*. Being a top predator and an indicator for the health of karst waters, it is of high importance to know its population and environmental conditions. In the frame of the project "Emerging microbial threats to endemic troglobiotic amphibian *Proteus anguinus*" funded by the Slovenian Research Agency, a monitoring program (2017–2018) started to ascertain the physico-chemical and microbiological conditions in the aquifer and the health status of the animal.

3 – TUFA DAMS ON KRKA RIVER

The uppermost part of the Krka River is characterised by relatively low-altitude karst developed in Triassic dolomites, as a result, CO_2 concentrations in the underground are relatively high (1.5 %–2.5 %) as well as water hardness (3.0–3.6 mmol (Ca^{2+} + Mg^{2+})/L or 300–360 mg as $CaCO_3$/L; Prelovšek, unpublished). When underground water appears at the surface, CO_2 outgassing is followed by oversaturation with respect to calcite and calcite begins to precipitate out of the water as tufa (travertine). Formation of tufa-related features (e.g., dams, bed crusts, coatings) is enhanced also by Krka River tributaries with high hardness and very weak transport of coarse material, aquatic (micro)organisms, and hydroengineering works. The latter, which was described by Mihevc (1996; Fig. 10), was used to gain water power for mills, where people built/raised dams using rocks and wood pillars that were later overgrown by tufa. Since the majority of calcite precipitation occurs at the downstream part of the dams forming an overhanging feature, the millers had to regularly cut the tufa to avoid breaking of the overhang. If dam breaking would occur, the water is strong enough to erode the dam within several decades; therefore, despite the fact that dams seems to be completely natural tufa dams, at least higher tufa dams at Krka River should be considered as cultural heritage enhanced by natural processes.

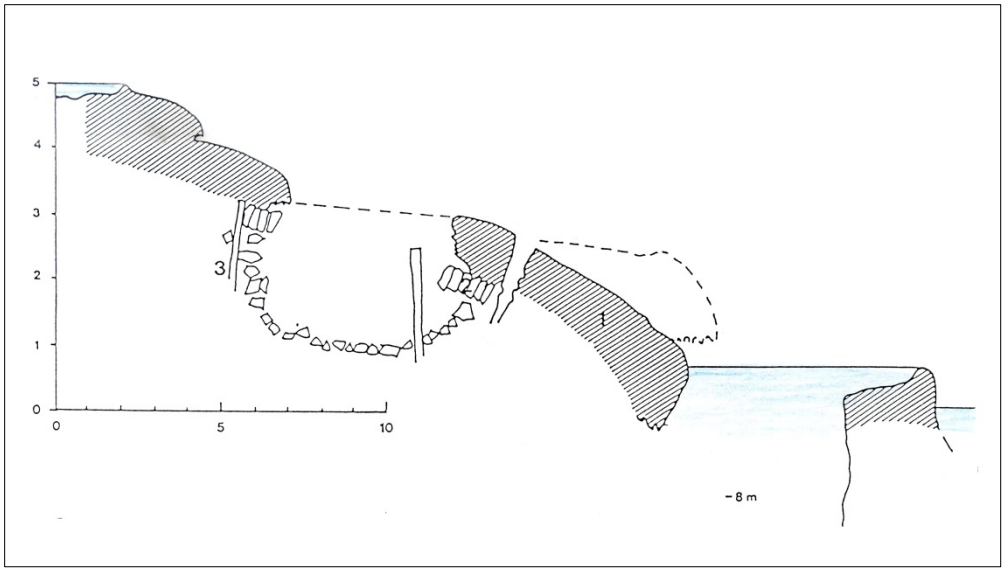

Figure 10: Cross-section of dam close to Dvor settlement as evident by remains of a bomb crater formed during World War II ((1) broken tufa overhang; 2) dam crest made of stacked rocks; 3) wooden pillars with gravel filling; Mihevc, 1996).

4 – KREN

There are several decades of caves that are not officially designated as show caves but they are attractive and occasionally opened to public due to some other reasons (historical, cultural, wine cellars, recreational activities). From a historical perspective, caves were important hiding places, especially during Ottoman invasions and World War II. After World War II, several caves were places of mass executions of "class C" war prisoners and civilians; to hide extra-legal executions, caves in extensive forests were used, among which the karst area of Kočevski Rog (Kočevje forest) was one of them. After executions, a lot of caves were subject to (partial) demolition. Kren is one of the most known, also symbolic, due to the vicinity of Kočevje (regional centre and railway station), the high density of caves and relatively high number of people (some thousands) executed. After 1990, rumours were louder and louder, field investigations slowly started and followed by raising of a chapel in 2004 with some other monuments. Due to decency, caves with mortal remains are excluded from visiting. Due to the executions, caves are to some extent negatively connoted with crimes.

5 – ŽELJNSKE JAME (ŽELJNE CAVES)

GENERAL OVERVIEW

Kočevje municipality that extends over 555 km^2 of prevailing forest area is almost completely karstic with 862 registered caves (March 2017; 1.55 caves/km^2). The vast majority of the caves cannot be used for touristic purposes due to poor accessability, vertical entrances, or cave dimensions. Nevertheless, there is one cave system that has been used partly for touristic purposes but, presumably due to absence of attractive speleothem formations, to a very limited extent.

Željnske jame is a 1,600 m-long and only 12 m-deep cave system located only a few metres under the surface and, due to ceiling breakdown and three small brooks sinking into the cave system, it is accessible through many entrances (Fig. 11). Beside numerous ice formations during winter time, windows, arches and natural bridges are the main tourist attractions of the cave system that can substantially complement the present-day direction of regional tourism (wilderness, bear watching, walking and cycling forest trails). The cave system is located at 475 m a.s.l. in the vicinity of the regional

centre (Kočevje; 8,300 inhabitants) and formed at the edge of a coal basin; therefore, speleogenesis might be related to limestone dissolution by sulfuric acid formed with oxidation of sulfides in coal layers. While the lower cave passages are still hydrologically active, the upper passages are dry. The caves have an interesting history; they were important hunting shelter during the end of the last glacial, a popular site for walking during Valvasor's era in the 17th century (Valvasor, 1689), surveyed by Nagel in 1748, the entrance parts were occasionally inhabiteted by gypsies, and the caves were severely polluted during brown coal mining (19th century–1978) and nearby suburban settlement. It is highly questionable if proteus was able to live in the cave stream but populations can be found further downstream. The cave system is formally not registered as a show cave but tendency of Kočevje municipality in the last years is to solve problematic access over private land, to raise cave infrastructure (fences, paths, information panels), and to designate the cave system officially as a show cave. Activities started in 2018 with preparation of the Cave Adaptation Plan.

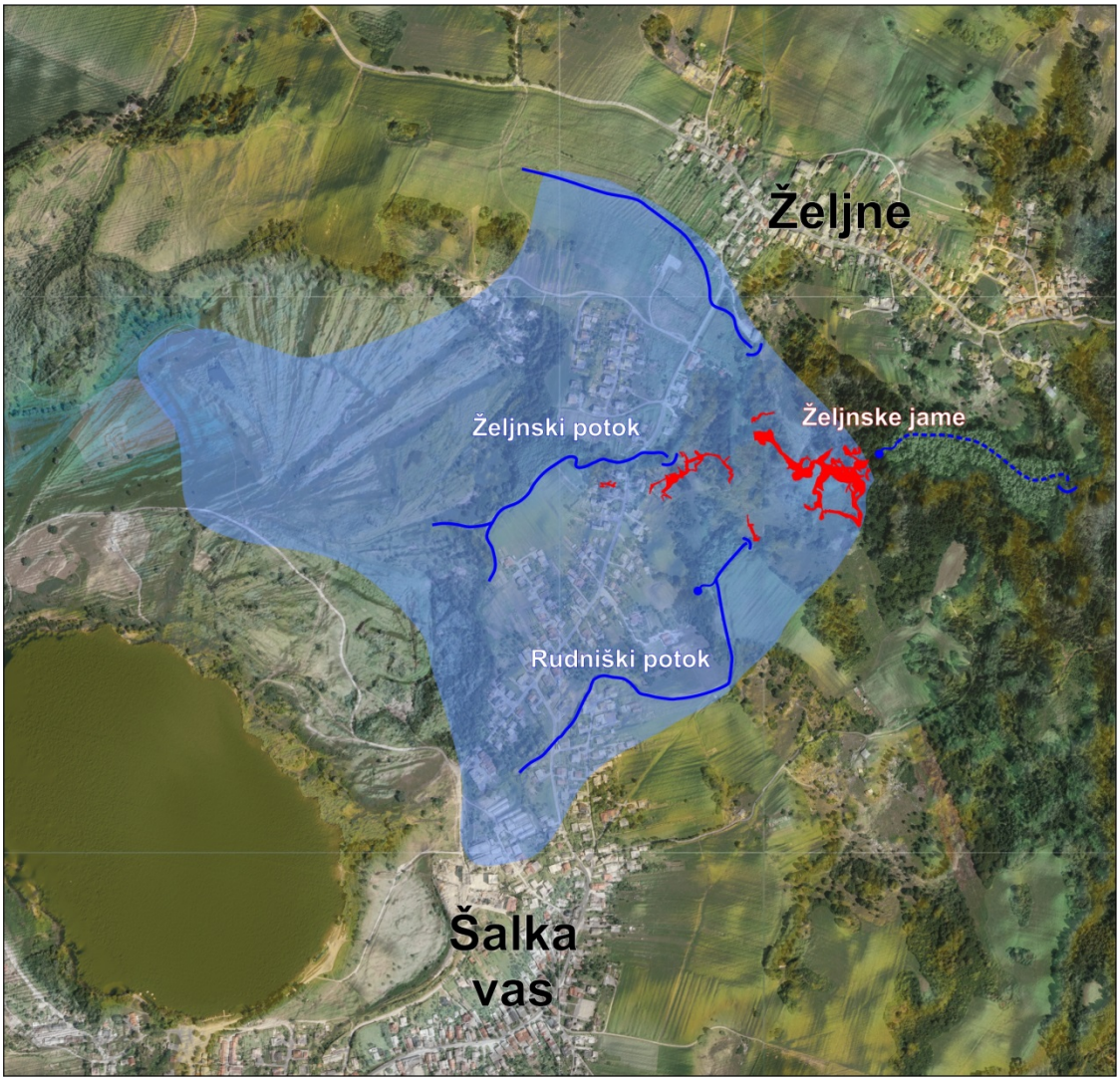

Figure 11: Location of Željnske jame regarding to two nearby settlemets (Šalka vas and Željne), three sinking streams (Željnski potok, Rudniški potok, and unnamed) and coal mining basin filled by water (bottom left). Željne Caves catchment area (blue) is estimated using LIDAR scanning; due to mining activity, the coal basin is now excluded from Željnske jame catchment area and discharge of Rudniški potok (Mining Stream) decreased significantly.

UNDERGROUND WATER QUALITY

In 2014, the Life project, entitled Kočevsko, started with several activities related to the proteus habitat (formation of register of polluted caves, cave clean-ups, inventory of underground animals and determination of underground water quality in selected stream caves). Determination of underground water quality was done on local stream caves draining settled and agricultural areas as well as two main regional springs draining local stream caves diluted by authigenic recharge of unpopulated forest areas. Eight sampling campaigns were done in the period 2015–2018 covering different seasons to indicate water quality, suitability of underground water for proteus, drainage areas, possible polluters as well as measures to reduce pollution. Among seven local stream caves, Željnske jame site was recognized as problematic in the past due to coal mining and untreated waste water from the nearby settlement. However, results show that water quality is not problematic regarding nitrate (avg. 6.81 mg NO_3^-/L), phosphates (avg. 0.08 mg PO_4^{3-}/L), and chlorides (avg. 16.5 mg Cl^-/L), indicating present-day treatment of waste water as an acceptable measure to strongly reduce pollution. However, traces of mining can be still observed as high concentrations of sulphates (avg. 180.04 SO_4^{2-}/L) and several-metres-thick coal dust deposition that was not washed away due to the low water gradient and reduction of the catchment area. Downstream populations of proteus indicate acceptable water quality and repopulation of areas where proteus must disappear during period of the highest pressures on water (after World War II until the 1990s; Prelovšek, 2016). Oxygen saturation in water was strongly reduced (most probably due to oxidation of sulphides into sulphates) but never falls below 60 %; it is also evident that biochemical oxygen demand (BOD_5) that water without sediments has low BOD_5 (< 2 mg O_2/L), while addition of sediment into water can increase BOD_5 to over 9 mg O_2/L. Water quality in the majority of other local stream caves indicates strong pressure from agriculture, as well as poorly treated or even untreated water from settlements, resulting in proteus extinction from at least two localities where water is occasionally anoxic due to decomposition of slurry or drained underground untreated from pools with animal slurry.

Table 1: Physical and chemical parameters or water from Željne Caves.

	Date	2015/4/1	2015/8/17	2015/12/1	2016/1/26	2017/8/24	2017/12/13	2018/2/13	2018/5/23	Natural backgr.
FIELD	T [°C]	8.7	15.4	8.7	6.7	10.9	7.5	6.3	10.0	
	SEP [µS/cm]	882	526	785	937	971	614	841	845	
	pH	7.417	7.248	7.375	7.538	7.551	7.356	7.214	7.483	
	O_2 [%]	65.9	59.9	71.5	77.6	80.2	77.2	83.3	74.2	
	O_2 [mg/L]	7.25	5.62	7.98	9.11	8.44	8.77	9.79	7.95	
LAB	Alkalinily [mmol/L]	5.47	3.20	5.53	5.80	5.94	3.87	4.71	5.22	
	Ca^{2+} [mmol/L]	4.16	2.12	3.94	4.54	4.43	2.75	3.63	4.19	
	Mg^{2+} [mmol/L]	0.53	0.33	0.45	0.66	0.80	0.32	0.53	0.85	
	NO_3^- [mg/L]	7.57	6.39	8.24	7.09	5.40	9.79	5.98	4.03	<4
	SO_4^{2-} [mg/L]	216.61	12.66	172.79	282.72	285.60	124.53	180.57	164.83	
	PO_4^{3-} [mg/L]	0.09	0.31	0.07	0.04	0.00	0.07	0.03	0.04	<0.1
	Cl^- [mg/L]	8.80	7.1	9.4	10.8	16.5	16.5	38.0	3.4	<2
	BPK_5 [mg/L]	/	/	/	/	/	1-2	0.5-1	0.5-1	<0.5
	$BPK_{5;\ with\ sediments}$ [mg/L]	/	/	/	/	/	/	>20	4	
PHREEQC	Ca/Mg	7.8	6.4	8.8	6.9	5.5	8.6	6.8	4.9	
	SI_{Cal}	0.42	-0.11	0.36	0.56	0.64	0.05	0.07	0.48	
	$pCO_{2\ (eq)}$	9,550	9,333	10,715	7,586	7,762	7,943	13,183	7,943	
	$pCO_{2\ (eq;\ if\ SICal=0)}$	25,704	9,333	25,119	27,542*	34,674*	9,120	15,488	24,547	

**minimum concentration since $SI_{Cal} > 0.5$)*

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Whole-day field trip **(D):**
SHOW CAVES AND KARST OF THE LJUBLJANICA RIVER BASIN
Friday, 22nd June 2018, 8:30–18:00

Celodnevno terensko delo **(D)**
TUR. JAME IN KRAS NOTRANJSKE
Petek, 22. junij 2018, 8.30–18.00

Mitja Prelovšek

Porečje Ljubljanice predstavlja jedro klasičnega krasa. Med številnimi tipičnimi kraškimi pojavi bomo pobliže spoznali Križno jamo, Cerkniško polje s požiralniki in ponornimi jamami, skupino izjemnih kraških pojavov v Rakovem Škocjanu in Planinsko jamo.

Križna jama je splet 8.273 m rovov med Cerkniškim (~550 m n.v.) in Loškim poljem (~570 m n.v.) ter Bloško planoto (~720 m n.v.). Glavne posebnosti so desetine podzemnih jezer, ki so nastala za sigovimi pregradami, kosti jamskega medveda ter visoka biotska raznovrstnost, čeprav brez proteusa. Leta 2017 je jamo obiskalo okoli 12.500 obiskovalcev, od tega 93,5 % suhi del, medtem ko ostaja vodni del zaradi izmerjene občutljivosti načrtno manj obremenjen.

Cerkniško polje ostaja na podlagi historičnih raziskav za svetovno najbolj znano kraško polje s presihajočim jezerom. Naraščanje vode je posledica dviga podtalnice v kraškem zaledju in, ker je kapaciteta podzemlja znatno nižja od polja, preliva nanj; ob tem je verjetno zmanjšan tudi odtok s polja. Presihanje so že od 2. polovice 19. stoletja regulirati, a se načrti zaradi različnih interesov niso nikoli v celoti udejanili. Požiralno sta najbolj pomembni pojavi požiralniki v dnu ter sistem jam Karlovic.

Rakov škocjan je najverjetneje nekdanji jamski prostor, ki je bil po udiranju znatno modificiran s površinskimi procesi. Na do- in odtočni strani je ohranjen del jamskih rovov v obliki naravnih mostov. Največ vode priteka s Cerkniškega polja in Javornikov skozi Kotliče in Zelške jame, odteka pa skozi Tkalco jamo.

Planinsko jamo tvorijo veliki večinoma vodni jamski rovi dolžine 6.735 m, ki povezujejo Planinsko polje s Pivško kotlino in Rakovim Škocjanom. Predmet turistične rabe so vhodni del ter Pivški rokav s Paradižem. Z jamo upravlja bližnje Jamarsko društvo Planina.

1 – KRIŽNA JAMA (KRIŽNA CAVE)

GENERAL OVERVIEW

Križna jama is located between Cerknica polje (~550 m a.s.l.), Lož polje (~570 m a.s.l.) and Bloke plateau (~720 m a.s.l.). The cave attracts attention especially due to it's high biodiversity (45 defined troglobionts – 4th place in the world), more than 2,000 bones of *Ursus spelaeus* excavated in 1878, and the stream that pours over more than 40 underground lakes. The latter, as well as the regionally-outstanding size of passages, makes it attractive for tourism receiving about 12,500 visitors in 2017, with exponential increase over the last years. Scientific research started with paleontological excavations in the late 19th century. Between world wars, passages upstream of the 1st lake were intensively researched and mapped along a length of 5 km and later extended to present-day length of 8,273 m. In the 1960s, as well as in 2007 (Kogovšek et al., 2008), tracing tests were performed to get an impression about the catchment area toward Bloke plateau and the downstream connection with springs located at the SE edge of Cerknica polje. Research on cave sediments (origin of allochtonous sediments, U/Th and palaeomagnetic dating) was conducted in the 1970s (Gospodarič, 1974), 1990s and after 2003 (Bosak et al., 2010). Processes of calcite precipitation along the underground stream, formation of lakes behind rimstone dams and damage to them due to touristic use were intensively studied after 2004 (Prelovšek, 2012). Paleontological and archaeological findings are documented by Bavdek et al. (2009). Special attention was drawn to the cave bear findings (Pacher et al., 2014). The downstream continuation of the stream passage, known as Križna jama 2 (1,415 m), was discovered in 1991 and later strictly closed due to high sensitivity. The Križna jama 2 was exactly surveyed with theodolite (Drole, 1997). Calcite precipitation was studied and compared with Križna jama (Prelovšek, 2012). The sump between two caves was recently dived to −124 m.

TOURIST USE

Owing to the cave's somewhat remote location, intensive development as a show cave did not begin until relatively late, in the mid-1950s. Actually from mid-1990s and officially from 2005, the cave is managed by a local cave and tourism society (The Society of Friends of Križna Jama; Prelovšek, 2011). From the perspective of touristic use, the cave is divided into four guiding sections (Fig. 12):

- dry tour (entrance–1st lake);
- stream passage 1 (Jezerski rov (Lake passage): entrance–Kalvarija);
- stream passage 1 (Pisani rov (Coloured passage): entrance–Kristalna gora);
- side passages in dry part (Medvedji rov (Cave Bear's Passage).

None part of the cave is electrified; instead of fixed lights, hand and head lamps are used. The dry part is the easiest accessible part of the cave, spacious, well-ventilated and with a big entrance that was enlarged just before Work War II due to military operations. The cave floor is composed of rock-fall material, clay and flowstone. The path is made by removal of bigger blocks and moderate levelling of the ground. Yearly-maintained wooden fences are located on steeper slopes. Concrete is strictly avoided to preserve the cave and minimise adaptation; however, this is a presenting one of the present-day drawbacks for further increase of visiting. The majority of tourists are taking the 1 h tour in dry part and only 6.5 % (818 tourists in 2017) were able to visit stream passages due to cave conservation guidelines (vulnerability of rimstone dams) as well as prohibition of guiding during floods and droughts. In 2017, 55 % of tourists were Slovenians and 45 % were foreigns.

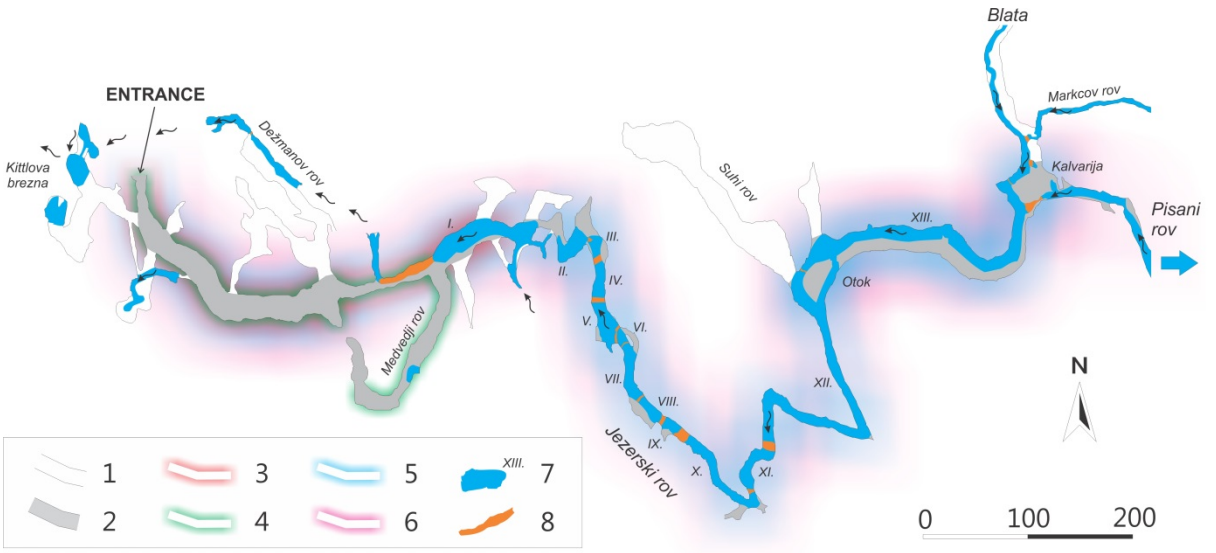

Figure 12: Plan of Križna jama (Križna Cave) with guiding sections (1 – non-touristic part of the cave, 2 – touristic part of the cave, 3 – dry tour, 4 – Cave bear's passage, 5 – stream passage "Jezerski rov", 6 – stream passage "Pisani rov", 7 – lakes, 8 – rimstone dams; modified after Prelovšek, 2011).

CALCITE PRECIPITATION & TOURISM

Tourist use of the stream passage is connected with a transition from the lower to the upper lake over rimstone dams. The latter are the result of calcite precipitation from water; two decades of calcite precipitation measurement with micro-erosion-metres (MEMs) downstream of the 1st lake indicate a precipitation rate of 0.08 mm/a. Upstream towards Kalvarija (Calvary), calcite precipitation rate diminishes, which is connected to the downstream increase of calcite oversaturation (Prelovšek, 2012). The same phenomena can be observed in Pisani rov. The upper crust of the rimestone dams (~1–2 cm) is quite hard but below a much softer flowstone is located. Walking over rimstone dames results in abrasion; if the latter exceeds natural restoration, the upper crust would be completely abraded and the softer part of the rimstone dams could be eroded, even by natural processes (stream carrying silty-sandy particles). Since, in principle, we cannot influence the deposition of calcite and, in this way, reduce the vulnerability of the flooded section of the cave, the amount of abrasion in the flooded section is reduced by limiting the numbers of tourists to five people per day including a guide, and, since 1991, the compulsory use of rubber boats (Archives of the Cave Exploration Society of Ljubljana), by instructing visitors on how to walk over the rimstone dams before the visit starts, by close supervision of tourists during guided visits by the guide and by supervision of cavers' expeditions in the cave. To get an insight into the suitability of conservation measures, MEM measurements of calcite precipitation and anthropogenic erosion started in 2006 along the tourist route and away from it. Results of MEM measurements clearly show that despite the use of practically all measures to ensure the protection of the rimstone dams and the surface of the lakes behind them, which also impede the freedom of movement of visitors to the cave, levels of wear, particularly of the higher-lying rimstone dams closer to Kalvarija, are at the limit of natural regeneration. We are, nevertheless, of the opinion that without additional infrastructure measures, which would mean a significant intervention in Križna Jama, it is practically impossible to achieve better results.

2 – CERKNICA POLJE / KARLOVICA CAVE SYSTEM

Cerknica polje is a rimmed karst depression developed along the regionally important Idrija fault zone that, in the area of Cerknica polje, divides Upper Triassic dolomites from Cretaceous limestones. Due to its hydrological intermittency and studies related to this, it is an outstanding phenomenon of Classical Karst and the most famous polje in the world. Most of the year, at least some parts of

Cerknica polje is flooded; therefore, this karst polje is often considered as the Cerknica lake. The polje's base that covers 38 km^2 and is located at an elevation of about 550 m a.s.l. It is fed by several springs and drained through numerous sinks; some springs acts also as sinks and are considered as estavelas. The polje's flooding is related to increased inflow during precipitation or snow melt as well as a general rise of the groundwater level resulting in a flow of water from surrounding low-capacity karst massifs to the high-capacity polje and probably also a reduced capacity of sinking at these times. Sinks are located either at the polje's bottom or at the rim of the polje as stream caves; the most extensive and well-known is the 9,535-meters-long Karlovica Cave System. While sinks at the polje's bottom drain water directly to the springs of Ljubljanica, caves at the rim of the polje divert water to Rakov Škocjan and Planina Polje.

Figure 13: Sinks at the bottom of Cerknica Polje during dry season (photo: M. Blatnik).

In the vicinity of Cerknica polje, Karlovica is maze type cave system, while further continuation toward Zelške jame (Zelše Caves) is developed as a trunk passage. Due to collapse, less than a hundred metres of passage is unexplored to connect Velika Karlovica and Zelške jame. Karlovica Cave System is officially not recognized as a show cave but, due to vicinity of Cerknica polje and exensive horizontal passages, entrance parts often attract visitors during dry seasons.
After the World War I, several ideas, plans and, to a lesser extent, activates were raised to completely dry up the polje for agricultural purposes or to pond the polje as a source for hydroelectricity. Despite the fact that some construction already started already in the 19th century (removal of floating debris at cave entrances, deepening of the cave floor, raising of rakes for catching floating debris) and intensified at the end of the 1960s (sealing of cave entrances, drilling of the 35-metre-long tunnel), plans were far from realised due to technical problems, a lack of funding and contradicting interests (e.g., agriculture, energy production, fishing, tourism, nature conservation). In order to support construction plans with field data, research was focused to the fields of hydrology, geology and speleology. Nowadays, Cerknica polje is recognized as a wetland of international importance (Ramsar site), an important Natura 2000 site based on the EU Birds Directive and a centre of the Notranjska Regional Park.

3 – RAKOV ŠKOCJAN

Rakov Škocjan is a 2-km-long karst valley located between Cerknica and Planina polje and well-know due to various impressive and preserved karst phenomena: natural bridges, stream caves at the spring and sink, collapse dolines, several karst springs and Rak surface stream as a fraction of the sinking Ljubljanica River. This location was well-known at least from the Palaeolithic and Iron Age and

visited and studied by several prominent naturalists, e.g. J. W. Valvasor, F. A. Steinberg, and V. Putick. As such, the karst valley was protected already before World War I as Windischgrätz's private park, it was state-protected as a natural monument in 1949 and today is a landscape park. It is believed to be an old cave passage exposed to the surface due to karst surface denudation in a topographical depression in the karst plateau between poljes, which was later modified by surface karst processes. This karst valley has been formed in Lower Cretaceous limestones. Several tracing tests proved that the surface stream in Rakov škocjan is getting allogenic water from Cerknica polje (Gams, 1966; Gospodarič and Habič, 1979; Gabrovšek et al., 2010) as well as autogenic water from the Javorniki Mountains (Kogovšek, 1999; unpublished); mostly through Zelške jame (Zelše Caves; 7,338 km long; 517 m a.s.l.) and Kotliči (Kettle) spring, left tributary of Rak stream. The surface stream leaves Rakov Škocjan through Tkalca jama (Weaver's Cave; 2,885 km long; 496 m a.s.l.). During low water levels the main surface stream (Rak) dries up, while long-term precipitation can result in flooding of the valley by < 19 m (515 m a.s.l.). Springs in the karst valley, as well as the geological structure, were studied in detail by Gospodarič et al. (1983). Important sites are now connected by an educational trail. Geodiversity was evaluated by Stepišnik and Repe (2015).
Little Natura Bridge is a 20-metre-long arch or remnant of the cave ceiling, 42 m above ground level, located in the upstream part of Rakov Škocjan. Big Natural Bridge is 9.5–17 m high, 15–23 m wide and 56 m long remnant of a cave passage separated from the downstream Tkalca jama by 170 m.
The entrance part of Zelške jame is a fragmented underground passage partly exposed to the surface due to ceiling collapses. Already in 1880s, protective gates were erected at the cave entrance. Nowadays Zelške jame are officially recognised but no longer managed as a show cave due to too high accounting demands for the cave manager as a NGO and local Rakek Caving Club.

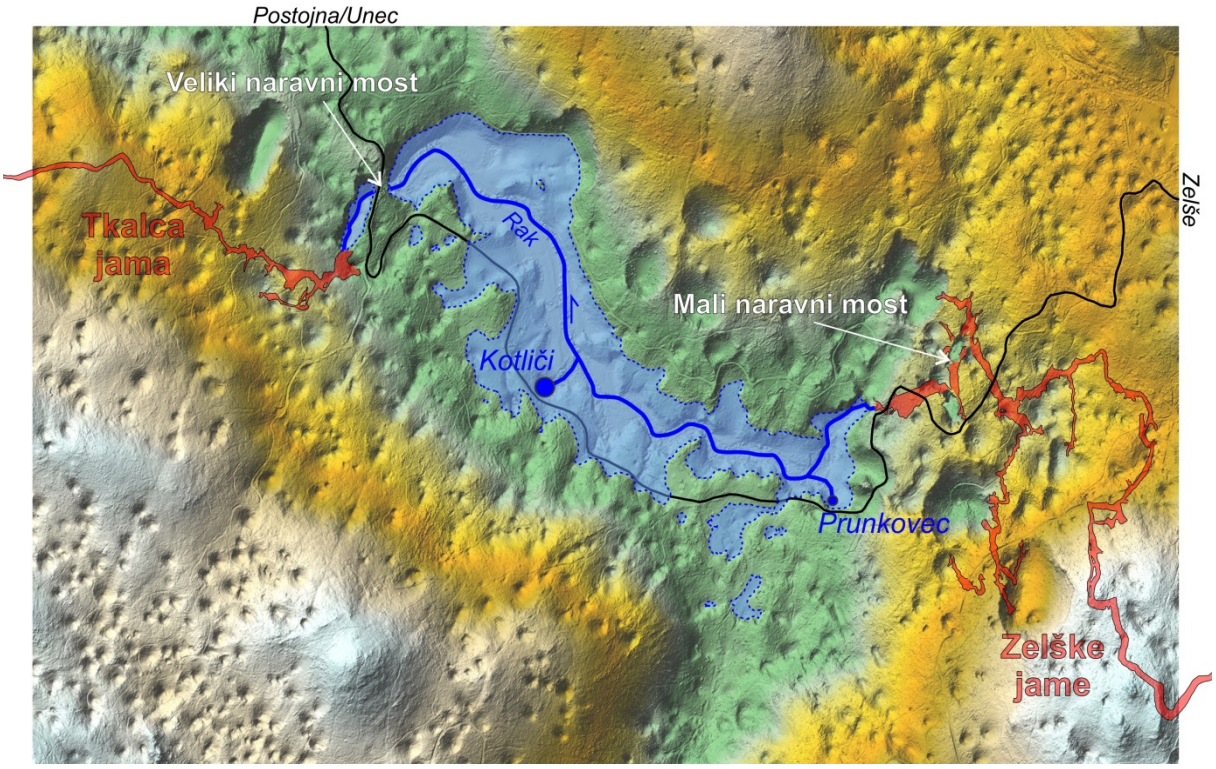

Figure 14: Rakov Škocjan with spring (Zelške jame) and sinking (Tkalca jama) stream caves.

4 – PLANINSKA JAMA (PLANINA CAVE)

Planinska jama, located at the SW edge of Planina polje at about 445 m a.s.l., is a 6,735-metre-long stream cave conducting by far the highest quantity of groundwater to Planina polje. Despite a split at 500 m from the entrance into the western Pivka branch and eastern Rak branch, on the whole, it is considered as a large trunk-passage cave. Within the cave, two regional streams (the Pivka River from the Postojna Cave System and the Rak River from the Rakov Škocjan and Javorniki Mountains) join into the Unica River with Q_{min} < 0.1 m^3/s and Q_{max} > 100 m^3/s. From May 2015, serious attempts were made to connect the Postojna Cave System with Planinska jama, leaving about 400 m of unexplored underwater passages. Only some higher-elevation passages are not hydrologically active. From a biospeleological perspective, the Postojna–Planina Cave System is recognised globally as the richest underground biological hot spot.

Planinska jama is developed in Lower and Upper Cretaceous limestones (Gospodarič and Habič, 1976). While the first detailed geological investigations and dating attempts were performed by Gospodarič (1976), while palaeomagnetic techniques were used for dating cave sediments (Šebela and Sasowsky, 1999; Zupan Hajna et al. (2008); the results indicate sediment ages < 0.78 Ma. Percolation water was studied by Kogovšek (1982). In the last decade, several tracing tests were conducted in the Planinska jama catchment area (Gabrovšek et al., 2010), as well as hydrogeological research using modern hydrogeological methods (data loggers, numerical modelling, discharge measurements), in order to improve the drinking water supply for Postojna and Pivka municipalities (Slovene Research Agency Project L1-7555). Mulec and Prelovšek (2015) measured bio-dissolution rates at the entrance of Planinska jama. Speleobiology is currently focused mainly on DNA investigation of proteus populations (Zakšek and Trontelj, 2017).

Planinska jama is officially recognised as a show cave and managed by the local Planina Caving Club. Two tourist tours are offered; about 500 m long dry one up to the Sotočje (Confluence) and a boat trip into the Pivški rokav (Pivka branch) with Paradiž dry passage rich in speleothems.

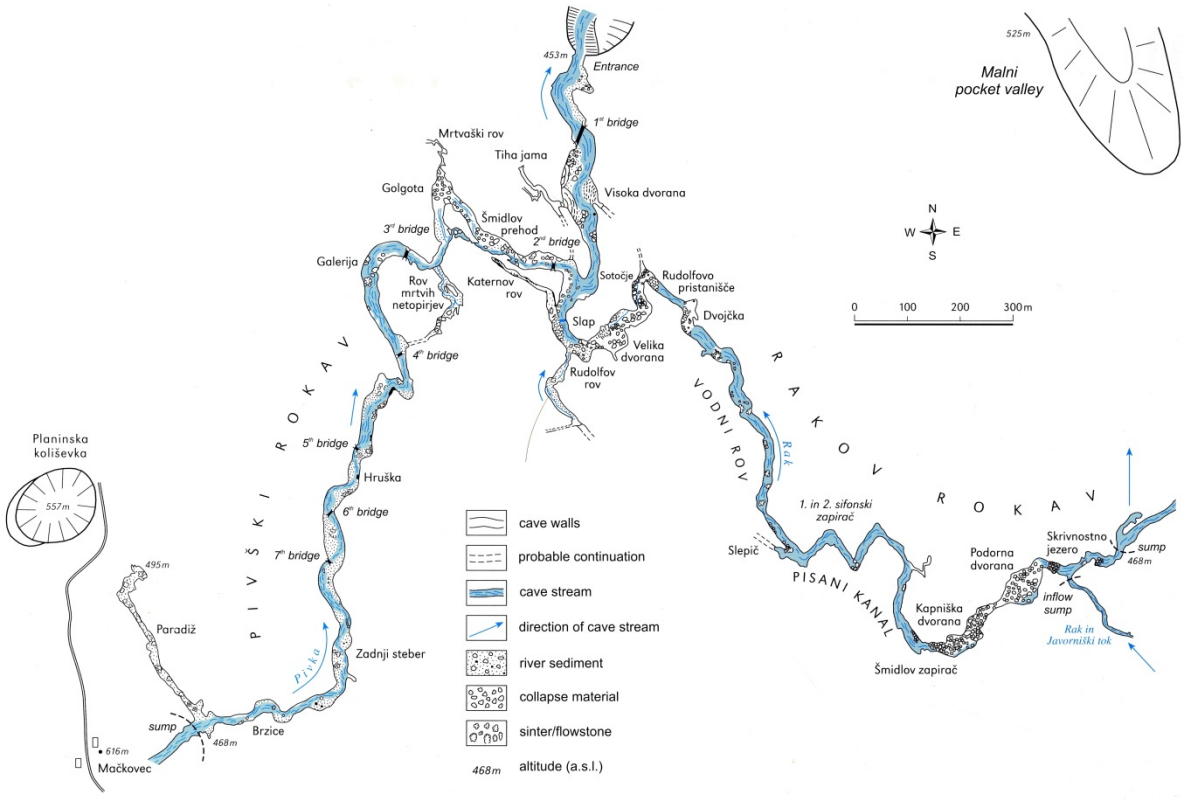

Figure 15: Plan of Planinska jama (modified after Gams, 2003).

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ABSTRACTS

IZVLEČKI

LIST OF ABSTRACTS[1]

[1] - *abstract of oral presentation* / *povzetek predavanja*; - *abstract of poster* / *povzetek posterja*

Trace elements in speleothems from XRF analysis – climate signal and marker horizons

Sledni elementi v sigi na podlagi XRA (rentgenske fluorescenčne) analize – klimatski signal in markirni sloji

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Speleothems (cave dripstones) are invaluable as recorders of past climate changes. They are a part of the meteoric cycle, which acts as a conveyor belt, transporting trace elements, isotopes, organics, etc. through the percolation zone. Sequential microlayers of calcite precipitates will, in turn, contain, adsorb or encrust these components and, thus, make a record of changing surface conditions. Measurement of changing concentrations of these proxies can then be used for deducing past climatic changes. Here, we investigate concentrations of a wide range of trace elements and organics by X-ray fluorescence (XRF) and optical color scanning, respectively. The testing is performed through high-resolution XRF scans along the growth axes of several selected, well-dated speleothems from which also stable isotope records are known. The samples are also scanned photographically in order to make a reference image and a high resolution color and greyscale record. Individual element concentrations are calibrated through independent chemical and bulk XRF analyses of selected zones on the record. So far, we have analysed one Norwegian and one South African stalagmite, where we were particularly interested in the influence of marine-derived precipitation. We have found peak activity of several elements that may work as proxies, like Br, S, U, Fe, Sr, Mg, Cu, etc. The results will then be compared to other speleothems and climate and volcanic events.

Keywords: speleothem, trace elements, color and greyscale record, stable isotopes, South Africa, Norway

Ključne kesede: siga, sledni elementi, barvni in ČB zapis, stabilni izotopi, Južna Afrika, Norveška

Integration of Human Impact Studies and Sociological Surveys for Effective Show Cave Management: Report of On-going Project in Japan

Vključevanje študij človekovega vpliva in sociooloških raziskav za učinkovito upravljanje turističnih jam: poročilo o tekočem projektu na Japonskem

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Caves are partly opened to the public for their unique ecosystems or geomorphologies. Once a wild cave is developed into a show cave, it is inevitable to experience human impacts, and hardly returns to the original condition. Show caves are important tourism resources providing economic benefits to the local society. They should be well-protected from exceeding environmental changes and keep the balance. There are human impacts studies and greatly contributing to improve the show cave management. However, they tend to remain in the range of providing suggestions, they do not mention how acceptable, desirable, and feasible the suggested improvement policies are. Multi-dimensioned approaches that combine natural scientific human impact analyses and sociological evaluation to the results from those human impact analyses are required. In Japan, there are a few human impacts studies and sociological surveys on show caves. Evaluation of the current situation needs to be performed, but the shortage of human impact studies is making it difficult.

The objective of this project is to gain human impact studies and then suggest improvement policies that are highly acceptable to the largest show cave in Japan, Akiyoshi-do Cave. I compared the human impacts between tourism and non-tourism sites, using biological and hydrological applications and performed questionnaire survey to tourists. As the result, significant human impact was confirmed, and modification of show cave management was recommended. Detailed information will be given in the presentation. Microbial structure

analysis, monitoring of the air and a questionnaire survey to cave managers will be performed next. This study is expected to form the first model for the well-balanced show cave management in Japan.

Keywords: show cave management, nature conservation, human impact study, tourism, questionnaire survey, Akiyoshi-do Cave

Ključne besede: upravljanje turističnih jam, naravovarstvo, študija antropogenega vpliva, turizem, anketna raziskava, jama Akiyoshi-do

Bat guano minerals (sulfates / phosphates) in Chameau Cave (Eastern Morocco)

Netopirski gvano (sulfati/fosfati) v jami Chameau (vzhodni Maroko)

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Chameau Cave opens in Bni Snassen massif (atl. 1532 m), in Oriental Region, Morocco, close to the Mediterranean and to the Algerian border. Locally, the Jurassic limestones are covered by typical mediterranean bush. Mediterranean climate has a long dry season, rainfall varies from 360 mm in plains to 600 m on exposed relief. The Chameau Cave is a spring (40–1000 L/s) feeding the oued Zegzel, the only perennial autochtonous river in the region, making a scenery green valley, registered as a site of biological and ecological interest (SIBE), whereas Chameau Cave is a National patrimonial site since 1951. The cave is 1.5 km long, made of large horizontal dry levels, the lower one being temporarily active during floods. Temperature is 18–23 °C, and relative humidity ranges from 60 to 100%. Before its closing, it hosted large bats colonies (*Rhinolophus mehelyi*) using the open spaces along the Zegzel Valley for foraging. Large guano and phosphate deposits are present. We found 11 guano-related minerals, one sulfate (gypsum) and 10 phosphates, including two very rare cave minerals (Al-strengite and spheniscidite). Guano decay produces precursor minerals (gypsum, ardealite), with in place entire replacement of guano by gold-like candy floss gypsum. Intermediate minerals still require ionic activity to allow exchanging cations with clay (crandallite, phosphosiderite) or with organic compounds (sphenicidite). End-member minerals are stable species generated at the contact with limestone (hydroxylapatite, fluorapatite) or with old allochthonous fluvial cave sediments providing Al and Fe (strengite, leucophosphite, variscite). Chameau Cave is an outstanding site for guano-related minerals, thanks to its microclimatic conditions allowing formation of large candy-floss gypsum piles and to the contribution of allochthonous sediments. Beyond this mineralogical diversity, guano mineralization actively boosts condensation-corrosion and wall retreat, which are especially important in this cave.

Keywords: bat guano minerals, sulfate, phosphates, Chameau Cave, Morocco

Ključne besede: minerali netopirskega gvana, sulfati, fosfati, jama Chameau, Maroko

Sinkholes and infrastructures – Risk assesment map

Grezi in infrastruktura – karta tveganja

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Carbonate bedrock overlain by unconsolidated sediments can contain or be prone to catastrophic formation of suffusion dolines (“breakout dolines”, Waltham et al. 2005). This is a threat for construction in most karst areas, where most of the bedrock consists of carbonate rocks. However, this problem is also encountered in the marble stripe karst of Norway, where only about 1% of the total area consists of carbonate rocks. The karst

is mostly restricted to Nordland County, around the Arctic Circle. Despite several instances of breakout doline formation, the matter has not been a priority until now, hence this study.

We have commenced a pilot project of constructing risk assessment maps based on existing geologic and topographic information and field ground-truth data. Dolines are the most characteristic surface karst formations, and they are indicators for what may lie beneath the surface. Several geographic information system (GIS) analyses will be tested to identify already established sinkholes and areas prone to sinkhole formation. In particular, we will develop algorithms for closed depression detection in digital elevation model (DEM) data, and potential risk areas will be identified through overlaying carbonate rock and quaternary sediment polygons on the terrain model. Then, field assessment of selected areas will be performed.

Keywords: karst, dolines, suffusion, catastrophic collapse, Norway, risk assessement map

Ključne besede: kras, vrtače, sufozija, nenaden ugrez, Norveška, karta tveganja

Disruption of the subterranean ecosystem continuum caused by lampenflora

Motnja podzemnega ekosistemskega kontinuuma s strani zelene zarasti

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Existing research of lampenflora in show caves mostly focused on phototrophic organisms and best techniques for their removal. Usually, main negative effects of lampenflora are considered to be impacts on speleothem formations and aesthetic degradation. However, its potential impact on the subterranean ecosystem is rarely discussed. In caves without artificial lighting, phototrophic organisms are regularly present around cave entrances and can be imported by water to other parts of the caves. In show caves, however, large phototroph biomass (i.e., lampenflora) can be found deep inside the caves, in areas with disrupted abiotic conditions (light, surface and air temperature, relative air humidity). Lampenflora creates “islands” of modified habitat that, along with troglobionts, can be colonized by troglophiles and trogloxenes. Changes in the distribution of cave organisms can lead to different patterns, directions and intensity of competition and predation pressures inside caves. Research of lampenflora in Veternica Cave (Mt. Medvednica, Croatia), conducted from 2012 to 2017, indicates that cave organisms interact with lampenflora. Biodiversity of organisms increased on lampenflora and their spatial distribution changed. Existing knowledge is insufficient to conclude if these changes are positive or negative for the subterranean ecosystem, and what is their significance. Since troglobionts evolved under very specific conditions, they are highly sensitive to changes in the environment, so extra precaution is required. It is necessary to carryout further research into the biotic interactions of organisms directly or indirectly connected with lampenflora in order to protect ecosystems of existing show caves and enable the opening of new ones, since they largely contribute to the promotion of subterranean habitat protection and nature protection in general.

Keywords: lampenflora, abiotic conditions, biotic interactions, ecosystem continuum, Veternica Cave

Ključne besede: zelena razrast, abiotske dejavniki, biološka interakcija, kontinuum ekosistema, jama Veternica

Preliminary study of the airflow in Chameau show cave (Morocco, Oriental Region)

Predhodna študija gibanja zraka v turistični jami Chameau (regija Oriental, Maroko)

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Preliminary study of the airflow in Chameau show cave (Morocco, Oriental Region) has been carried out. Chimney effect between both entrances produces strong airflow, with seasonal regime according to the temperature gradient between inside and outside. In addition, several distal large blind passages show significant convective air loops. The main gallery going inward ends in a sump of low thermal water (23–27 °C), which is warmer than the cave temperature (18–20 °C), making an important convective loop. The airflow is supposed to be the main process responsible for strong condensation-corrosion that deeply carved the speleothems and produced significant wall retreat. In order to quantify condensation, we made a first measurement of the convective air flow in the main gallery. Air flow discharge was about 7 m^3/s in March 2018, with a maximum velocity above 0.3 m/s, and a temperature of 19.2 °C for the inward air and 20.2 °C for the outward air. Based on latent heat computation, 4500 L/j of water are evaporated in the lower part of the inward loop and 2700 L/j are condensed along the ceiling in the outward loop.

Keywords: Chameau cave, Morocco, airflow convection, condensation

Ključne besede: jama Chameau, Maroko, konvekcija zračnega toka, kondenzacija

Speleotouristic potentials in the river basin of Mirusha

Potencial jamskega turizma v porečju reke Miruša

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The Mirusha river basin stands in the central part of Kosovo, it is the left branch of the Drini i Bardhë with a surface area of 337 km^2 or 3.1 % of Kosovo surface. This basin in the geological aspect is situated in a very specific territory and is characterized with a rich geodiversity of geological formations. Karstic grounds are created from calcareous of upper Jurassic as well as karbanian formation of the lower and upper Cretaceous.

The main purpose of this paper is to present the spelotouristic values of caves in this region. In the Mirusha basin there are a large number of caves and abyss (over 16 have been identified until now), with corridors and underground gallery over 2000 meters-long. The most important caves in the Mirushsa basin that have potential for the speleotouristic developing include: Dushi Cave, Panorci Cave, Peshterri (Zatriqi) Cave, Residential Cave (Gergavica-Zatriq), Bali Aga Cave, Bottomless abyss, Last Lake Caves (Mirusha's Waters), Azem Galica Cave, The white Queen's abyss, (Mali Akovan).

The speleological potentials that have been located in the Mirusha basin, have not been researched yet from a touristic aspect. They contain a very important potential for sustainable development of speleotouristic in Kosovo and in the surrounding region. Mirusha pond caves are also distinguished by a large number of stalactites and stalagmites, columns and draperies, which beautify them. These caves are specified with a rich biodiversity of endemic fauna and flora (but still not properly researched). Concerning the increase of the beautiful speleotouristic potentials, there is the fact that in the vicinity of the caves there are also natural and cultural monuments with touristic values, such as, Mirusha Water Canyon, Thermal Spring of Banja, and the Bridge of Rabagjive.

In order to improve the conditions and increase the touristic offerings of the caves in the Mirusha pond, it is necessary to undertake such measures as: establishment of directorates for the authentic management of the cave, preparation of a strategy for monitoring and sustainable management of the cave, preparation and implementation of projects for the research of new corridors and galleries, organization of campaigns for self-development for the local community, establishment of information boards throughout main roads and the publication of tour guides. Undertaking these measures will not only increase the number of tourists and cave benefits, but will also add value by turning caves into important tourist spots of Kosovo. The rich geo-heritage of the Mirusha pond represents an important component in the scientific, geological, geomorphologic, biological, hydrological, educational and tourist aspect, which must be managed in the future protected and used for touristical and educational purposes.

Keywords: geological heritage, speleotourism, Mirusha, pond, caves

Ključne besede: geološka dediščina, jamski turizem, Mirusha, jezero, jame

CO_2 concentration monitoring in a tourist Postojna karst cave for protection of natural heritage

Spremljanje CO_2 koncentracij v turistični Postojnski jami za zaščito naravne dediščine

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Karst caves may contain concentrations of CO_2 that are higher than the concentrations in the external atmosphere due to various natural phenomena, and may show characteristic dynamics of changes at a daily and annual level. How much CO_2 increases depends on the ventilation of karst caves, which, in turn, is greatly influenced by the shape – geometry of the cave, the conditions in the external atmosphere, and the seasons.

Moreover, the increase in CO_2 concentration in karst show caves is also influenced by visits from tourists, who increase CO_2 by exhaling air. Determining tourists' contribution to natural CO_2 concentrations represents a great research challenge because of the usually highly complex shapes of karst caves, which is the very reason why they are attracting tourists.

Postojna Cave is one of the most visited show caves in Slovenia owing to its remarkable size and the tourist train, which takes tourists to the central part of the cave and back. In light of its highly complex shape and the incomplete research into the possible air inlets and outlets in the cave, determining the maximum number of tourists that does not affect natural processes within the cave is a great challenge. At present, this challenge cannot be solved using cave system ventilation models.

We went about determining the impact of an increase in CO_2 concentrations as a result of tourist visits by analysing measurements at a measurement site in the karst cave, which is passed by the majority of tourists. In the given case of the Postojna Cave, the site was Lepa Jama. In that location, the following measurements are available: CO_2 concentrations, air temperature at two levels, and rock temperature for a longer span of several years, and statistically processed in 10-minute time intervals.

We first conducted an analysis of measurements for a shorter time period in the summer month of August 2017. August is the peak tourist season. In that period, an artificial passage to Črna Jama was open for a short while to test the possibilities of additional ventilation. For the analysis we used the sunflower diagram tool, which enables a presentation of longer time series data with distinct daily cycles, in the form of a frequency diagram. The analysis results for the given period show an increase in CO_2 concentrations due to tourists, but to an acceptable degree, as the daily concentrations revert to normal after each visit.

Keywords: CO_2 concentration, tourism, karst cave, protection of natural heritage, sunflower diagram

Ključne besede: CO_2 koncentracije, turizem, kraške jame, zaščita naravne dediščine, diagram sončnica

Speleotourism in Slovenia: From the cradle of geotourism towards sustainable management of karst phenomena

Jamski turizem v Sloveniji: od zibelke geoturizma proti trajnostnem upravljanju s kraškimi pojavi

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Slovenia is considered as the cradle of karst geotourism as cave tourism started there as early as the Middle Ages. To date, more than 12,000 caves were discovered from which 22 have the status of tourist caves. From these, five were assessed using the M-GAM model (Modified Geosite Assessment Model) to gain information for better future management strategies for development of cross-border sustainable destination KRASn'KRŠ.

Geotourism destinations included in the study experienced very diverse development processes. The reason for this is the influence of very heterogeneous factors. The aim was to recognize the level of the diversity in geotourism development and to define the weaknesses and opportunities of smaller less developed touristic caves in relation to already developed speleotourism destinations (e.g., Postojna Cave).

By using the M-GAM model we proved the leading geotourism role of the Postojna Cave and Škocjan Caves. The good practice of Škocjan Caves that are managed in the scope of a regional park that includes many karst geosites, should be transmitted to other caves, especially those that are currently managed by local cave societies or local tourist societies and should be included in the management of a broader geo-destination (e.g., protected area, coastal destination, geopark). The results of the study exposed the weaknesses of the individual tourist caves (e.g., interpretative boards, poor promotion) that have to be addressed by the managers of tourist caves in order to properly accommodate the expectations of tourist visitors. According to M-GAM, speleotourists in Slovenia are more "pure" than "general" geotourists as they give much less importance to the human-induced values and they mostly appreciate the natural values of a geosite. They prefer geosites without major tourism infrastructure (only basic) and pay more attention to the protection of geosites.

Keywords: geoheritage, geotourism, sustainable tourism, tourist caves, M-GAM

Ključne besede: geološka dediščina, geoturizem, trajnostni turizem, turistične jame, M-GAM

New methods for temperature reconstructions – Are they applicable in caves from South Africa?

Nove metode rekonstrukcije temperatur – so uporabne v jamah Južne Afrike?

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In order to understand the evolution of symbolic and technological activities in Homo sapiens in South Africa, it is of interest to find out if technological changes took place in pace with climatic change. The archaeological sites (rock shelters) are adjacent to caves, rich in speleothems from which we may extract climatic proxies. During a previous PhD project (Noah 2016) a reconnaissance study was performed, using U-series chronology and stable isotope measurements ($\delta^{18}O_c$, $\delta^{13}C_c$) on speleothem calcite. However, simple oxygen isotope composition of calcite is controlled by a number of factors in the rainwater, percolation and cave processes, which turn any attempts of direct temperature estimates ambiguous. The use of new techniques ("clumped isotopologues" and fluid inclusion thermometry) may yield temperature directly, provided sufficient quality of the material. The aim of this project is to test these approaches on South African speleothems.

A stalagmite (BL3) from Bloukrantz Cave in South Africa is used to test new methods for temperature reconstructions. This sample includes a late Holocene part and, below a hiatus, an older interval dating to

around 40–50 kyr BP. First, the previous $\delta^{18}O_c$ record is replicated in higher resolution and by more closely following the growth axis. This is done in order to test reproducibility and to refine the stratigraphic transects of the sample.

The second part of this project will include clumped isotope analysis on selected calcite samples, and as well as $\delta^{18}O_w$ and liquid-vapor homogenization measurements on fluid inclusions. The 'clumped isotope' technique involves measurements of the distribution of isotopes within the carbonate ions. The main advantage of the method is that it is only dependent on temperature. The main challenge is low concentration of 'clumping' and disequilibrium effects, which are commonly (but not always) observed in speleothems. For the fluid inclusion methods, we will first assess whether the speleothem contains sufficiently abundant and well-preserved fluid inclusions. The applicably temperature proxies will first be tested in the Holocene section of BL3, before applying them on the older part.

Keywords: speleothem, climate change, stable isotopes, clumped isotopes, South Africa

Ključne besede: siga, klimatske spremembe, stabilni izotopi, vezani izotopi, Južna Afrika

Analysis of annual visits to Postojnska jama – historical and statistical sciences approach

Analiza letnega obiska Postojnske jame – zgodovinski in statistično-znanstveni pristop

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Postojnska jama (Postojna Cave) is one of the oldest and most famous show caves in the world. Visits to entrance parts of it are known for a long time but with the discoveries of the inner parts in 1818, by Luka Čeč, tourism in Postojna started to flourish. However, the growth of visits is not constant throughout the years.

Touristic development of Postojnska jama is well documented. Based on various sources, it is possible to reconstruct total annual visits to the cave (from 1819 to 2017). Until now, nearly 38.1 million tourists visited the cave. In spite of the fact that some of the numbers in the time series can be discussed, this data set is unique and no such series are known from the literature. This dataset offers several approaches in interpretation and statistical modeling strategies that enables deeper insights to Postojnska jama tourism development as well as into long-term tourism development in show caves. This dataset is interesting and important from a historical and statistical point of view.

In the first part of the paper, the number of visitors will be compared to various historical events that influenced visits. In the second step, results of the statistical analysis will be presented consisting of two sub steps; the first sub step is represented by data structure analysis and the second sub step is represented by the modeling and forecasting. Until 1960, a general trend can be described with the exponential curve model, periods after this year can be described with a double logistic curve. The latter enables the estimation of the maximum bearing capacity of the cave (890,000 annual visitors). Additional to these monotonic trends in the dataset, five catastrophes were identified, for which mean arrival time, duration and intensity were estimated. Finally, a forecast of future trends will be illustrated.

Keywords: annual visits, historical interpretation, statistical analysis, growth model, forecasting, show caves

Ključne besede: letni obisk, zgodovinska interpretacija, statistična analiza, model rasti, napovedovanje, turistične jame

Prospects of Speleotherapy in Veternica Cave (Zagreb, Croatia)

Možnosti za uvedbo speleoterapije v jami Veternica (Zagreb, Hrvaška)

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Health tourism in Croatia has many opportunities for development, especially within protected areas, such as Nature Park Medvednica. Hidden in the woods of Medvednica Mt., the Brestovac Sanatorium (built in 1909) was, during the first half of the 20th century, one of the best tuberculosis care facilities in all of Europe. In the natural environment of Medvednica Mt., one of the biggest caves of Croatian karst is situated. It is over 7 km long Veternica Cave, known for its complex geological history, paleontological discoveries, signs of presence of Neanderthals and present animals – 18 species of bats were recorded.

Since in the summer period, the first 380 m are open for tourists, the idea of staying in a cave for the purpose of speleotherapy is introduced. To consider this, it is necessary to explore the climate, geochemical and biological properties of the environment. At the same time, it should be determined whether the longer human presence in the cave has influence on the microclimatic properties. Within this work, we give an overview of the present knowledge and guidelines for further research.

Keywords: health tourism, speleotherapy, geochemical properties, microclimate

Ključne besede: zdravstveni turizem, speleoterapija, geokemične značilnosti, mikroklima

Grotte de Saint-Marcel: a major French cave system for Speleology, Sciences, Tourism and Education

Jama Grotte de Saint-Marcel: glavni francoski jamski sistem na področju jamarstva, znanosti, turizma in izobraževanja

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Located in Ardèche (South-east France), grotte de Saint-Marcel is actually a 56 km-long cave system with more than 18 km explored by cave diving. The cave was discovered by the locals in 1835, the cave explorations started a few years later. In 1894, Martel published the first results in "Les Abimes". The Municipality decided, in 1870, to organize a tour of the galleries close to the entrance, the tourists came by boat on the river Ardèche.

From the 1960's, different caving clubs are involved in the systematic exploration of this huge cave system. In 1962, the construction of the touristic road, through the gorges, has increased the tourism activity in the cave. In 1988, a territorial program for cave and karst protection was put in place, and a natural reserve, "Reserve des gorges de l'Ardèche", was created for the sustainable management of nature protection and territorial development, now included in the management of the Gorges de l'Ardèche and Chauvet Cave World heritage.

Saint-Marcel cave system and karst have been the subject of many scientific research programs on speleogenesis, hydrogeology, biospeleology, cave climate, paleo climate, and archaeology, in collaboration with international scientific teams and speleologists. Actually, the research policy focused on paleoclimate records in stalagmites, deep karst aquifers studies, cave ecosystems with a focus on condensation corrosion processes and the evolution of the CO_2 in the different parts of the cave system. Another program concerns archaeology during the Paleolithic period.

For 3 years, the show cave has been developed in partnership with universities and caving associations, with different educational programs for the tourists and pupils. In the frame of field courses, the cave is also used for Master or Bachelor degree training.

This presentation will propose an overview of the cave heritage and the actions ongoing.

Keywords: cave system, karst heritage, speleological exploration, tourism, education

Ključne besede: jamski sistem, kraška dediščina, raziskovanje jam, turizem, izobraževanje

Impacts of Visitors on Cave's Physical Environment

Vpliv obiskovalcev na fizično jamsko okolje

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Studies of impacts on caves usually cover the topics of water pollution, microclimate, lampenflora and cave biota. On the other hand, there is a much more important influence on the morphology of the cave directly from visitors, such as footprints, soiled and broken formations, graffiti. They accumulate in caves and reduce their scientific and aesthetic values.

The caves of the Classical Karst have been in use since Prehistoric times and the use of the caves varied. They were used as shelters, hiding places or in cult manner; as places for deposition (weapons, explosive, as refuse dumps and waste water) and for exploitation of natural sources (karst springs, ice). The most known use since the 17th century has been for tourism and speleology. Due to speleological explorations, development of karstology as a science and the development of tourism, the region and its phenomena have become world known. But long and intense use of caves, particularly in the last two centuries, have caused significant impacts also on caves' physical environment.

The impacts of visitors were studied in 22 caves of the Classical Karst in Slovenia and in two caves of the Classical Karst in Italy (Carso Triestino). The caves were divided into show caves, well-known caves, less-known caves and easily accessible caves.

The most significant impacts are off-trail footprints – trodden fine sediments, destroyed gours and cave pearls; graffiti and broken formations. In show caves, infrastructure causes the most significant and visible impacts, followed by the impacts of cave maintenance (off-trail footprints, broken formations, etc.). Infrastructure for mass visits of caves must comply with regulations on the safety of visitors, but these regulations often require interventions in caves that cause harm on their inventory.

Keywords: Classical Karst, impacts on caves, cave use, cave physical environment

Ključne besede: matični kras, vpliv na jame, raba jam, fizično jamsko okolje

Victor Caumartin – pioneer of microbiology in caves

Victor Caumartin – pionir jamske mikrobiologije

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Victor Auguste Caumartin was born on February 9th, 1913, in Donqueur, a small village fifteen kilometres from Abbeville, in Picardie, the Somme department of France. He passed away in his region Amiens on January 12th, 1997. In 2013, he would have reached the age of one hundred.

There is no doubt, due to his discretion as a researcher, that this academic biologist is little known in our caving literature. However, Caumartin wrote some important articles. Caving became his passion at the age of forty, and as related to me by Michel Siffre, Caumartin was certainly ahead of his time by 40 years in Caving Science.

Keywords: caves, microbiology, Lascaux

Ključne besede: jame, mikrobiologija, jama Lascaux

Science and show caves

Znanost in turistične jame

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Among cavers, the development of a wild cave into a show cave was frequently considered as the loss of the cave itself, from the point of view of its conservation on account of the facilities installed into the cave for the benefit of the visitors and the damage to the cave environment. On the other hand, some facilities, such as the power supply, facilitated a number of studies with successful results. Presently, many show caves became the best place for the development of scientific researches.

A short history of the development of science inside show caves is reported here, as well as the important role played by the Postojna Cave from this point of view. Some examples of underground laboratories connected with show caves are also described.

Keywords: research, cave environment, environment protection, tourism-science symbiosis

Ključne besede: raziskovanje, jamsko okolje, varovanje okolja, simbioza turizma in znanosti

Analysis of air temperature variability as a tool to support a suitable tourism use planning of the Soprador do Carvalho Cave (Portugal)

Analiza spremenljivosti temperature zraka kot orodje za podporo trajnostnemu načrtovanju rabe jame Soprador do Carvalho (Portugalska)

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Detailed measurements of air temperature have been made inside and outside the Soprador do Carvalho Cave (Sicó Massif, Portugal), which is part of a complex karstic cave system with mainly horizontal passages subject to seasonal flooding. A preliminary air circulation model has been defined that will be of great interest for the definition of the criteria to adopt in a possible suitable tourism use of the cave. Contour maps of the spatial distribution of the cave's air temperature, for different seasons of the year, and of the mean temperature gradient, were produced. Temporal trend analysis indicates that the mean air temperature decreases in the first 150 m from the single-entrance and then increases gradually with distance. Generally, the air temperature changes with abrupt morphological/structural variations along the longitudinal section of the cave. The spatial distribution of air temperature responds to convective exchange between the cave and the exterior. During the months when the outside air temperature is at a minimum, or when the daily temperature range is greatest, convective circulation occurs due to an inversion in the thermal gradient of the air. The attainment of spatial stabilization in air temperature is clearly dependent on the distance from the cave entrance, regardless of the season. Thus, new information about the zonation of microclimatic stability within the Soprador do Carvalho Cave has been revealed and two practical considerations can be made. The first 150 m, where the air is least stagnant, are best suited for daily visits. The visits should concentrate on periods with greatest replenishment

of air between the interior and exterior, as a result of convective circulation (November to April). A more robust predictive mathematical model, taking into account the complex role played by rock, water, air and external morphology, particularly their thermal/moisture exchange, will be the next step.

Keywords: cave microclimate, convective air circulation, temperature gradient, cave tourism, Soprador do Carvalho Cave

Ključne besede: jamska mikroklima, konvekcijsko kroženje zraka, temperaturni gradient, jamski turizem, jama Soprador do Carvalho

Microclimatic monitoring of caves open for tourism at the Cavernas do Peruaçu National Park, Minas Gerais, Brazil

Mikroklimatski monitoring turističnih jam v nacionalnem parku Cavernas do Peruaçu, Minas Gerais, Brazilija

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In 2010, the Brazilian National Center for Cave Research and Conservation (CECAV) started a project to gather data to monitor and evaluate possible impacts caused by tourism in seven show caves at the Cavernas do Peruaçu National Park. The research is part of a major Government Plan, known as the National Program for the Conservation of the Speleological Heritage. One of the parameters for monitoring possible changes in the cave environment due to more frequent visitation is the change in its microclimate. Small variations may occur naturally or due to factors associated with anthropogenic activities outside and inside caves, interfering in speleothem formation processes, as well as over cave organisms, for example. This research began at the end of the first semester of 2017 and is planned to last at least 24 months. The main objective is to monitor temperature and humidity along touristic paths, as well as some restricted areas of each cave. Outside atmospheric data are being measured by an automatic weather station. Preliminarily, punctual data was gathered on August 2017 (winter). After this first campaign, automatic data loggers were installed in the caves to record data at 10 minutes intervals. From September to January (spring), outside data showed that the average temperature in the region was 25.8°C and the mean air humidity, 67.57%. The Lapa dos Desenhos showed the highest temperature of 25.1°C and lowest humidity of 58.8%. The Gruta Bonita had its lowest temperature of 21.5°C and highest humidity of 81.9%. Visitation increased 73% from 2016 to 2017, increasing from 3,966 to 6,865 visitors annually. Thus, the main expected result of this project will be the characterization of the microclimate of the caves opened to visitation. Considering that a significant increase of visitors is projected after the official opening of the park, this information will help in the elaboration of parameters to better determine the carrying capacity of these caves.

Keywords: microclimate monitoring, show caves, Cavernas do Peruaçu National Park, Minas Gerais, Brazil

Ključne besede: mikroklimatski monitoring, turistične jame, nacionalni park Cavernas do Peruaçu, Minas Gerais, Brazilija

Simple 3D model of Postojna cave based on Gallino survey 1924-1928 combined with newly measured cave surveying data

Enostaven 3D model Postojnske jame na osnovi Gallinovih (1924-1928) ter kasnejših jamskih meritev

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Theodolite cave survey data of Postojna cave collected by capitano Luigi Gallino (1924–1928), survey data from the Karst Research Institute ZRC SAZU (1983), survey data from Gromap geodetic services (2012) and newly measured exploration cave surveying data by Jamarski klub Železničar, Jamarsko društvo Rakek and DZRJ Luka Čeč (2015) were combined, georeferenced, visualized first in 2D and then transformed into a simple 3D layout model of the cave using various commercial, shareware, and freeware software, including AutoCad, Arcgis, Qgis, LibreOfficeCalc, Speleoliti, Compass, Meshlab, Cloudcompare and Paraview, with a lot of neutral data formats like ASCII text, CSP, DAT, DXF, STL, VRML and PLY.

We are going to describe practical procedures used to produce the final product and a simple way to visualize any cave survey data using a standalone single page web application called "Scene Explorer" exported from Paraview using a python macro "export-scene-macro.py"; the only requirement is the single HTML file without any web server along with the exported scene.

Keywords: archive data, cave survey, AutoCad, Speleoliti, Compass, Paraview

Ključne besede: arhivski podatki, merjenje jam, AutoCad, Speleoliti, Compass, Paraview

The reopening of Chameau Cave (Zegzel, Berkane, Morocco)

Ponovno odprtje jame Chameau (Zegzel, Berkane, Maroko)

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Chameau Cave first opened in 1948 and was the first show cave in Morocco, using a 800 m trail and electricity. For this reason, it is now well-known in the area and beyond. It was first renewed during the last decade under a United Nation program. The cave is exceptional thanks to the size of its passages, its easy access, and its beauty. It has the potential to be a major tourist spot for the Berkane Province. The reopening in 2019 aims for 80,000 visitors. It is conceived that it will have a benefit for the local people, with direct and indirect sustainable activities, and a possibility of development of the hinterland, complementary to the sea resorts.

New technologies for cave management will be implemented, such the “In-Location” platform for guiding and cave lighting. The visitor center will be equipped with desks, food facilities, a 3D show room, and will directly access the cave through a tunnel. The surroundings will be equipped with trails displaying environmental information, a climbing school and a via ferrata.

An international team has been settled to manage the scientific study of the cave, which is expected to be the main underground laboratory in Morocco. The activities are focused on speleogenesis, with a special interest on its hydrothermal origin (spring is 27 °C), conservation of the cave regarding strong condensation-corrosion process boosted by air convections and bat guano, cave sediments (dating, mineralogy of phosphates), and hydrology.

Keywords: Chameau Cave, tourism, cave science, cave management

Ključne besede: jama Chameau, turizem, speleologija, upravljanje jam

Relicts of the earliest processes on an emerging carbonate platform

Ostanki zgodnih procesov pri zakrasevanju karbonatne plošče

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Carbonate platforms are prone to solution weathering (karstification), resulting in a unique karst topography, often associated with circular depressions and a lack of drainage patterns. Nevertheless, some karst areas preserve topography that cannot be explained exclusively by karst processes and are interpreted to be the result of inherited non-karstic features that influenced later karst development and were, thus, preserved over long time-periods; such as the relict alluvial fans on the Matarsko Podolje, Slovenian Dinaric karst.

One such example is also the Nullarbor Plain, Australia. Despite the general flatness across roughly 200,000 km^2, the limestone surface contains parallel, low-relief ridges and swales up to 750 wide and with up to 6 m of relief, which have previously been attributed to joint control. Field work (sampling clay sediments and measuring depths using a hydraulic auger within swales, large fault zones and dongas), remote sensing analysis using TandemX digital elevation data, mineralogical analysis performed at Curtin University, Perth, and grain size analysis performed at La Trobe University, Melbourne, revealed that ridges are stony and swales are filled predominantly with silt- and clay- sized quartz, and minor amounts of carbonate that decreases inland.

Their morphology and sediment depth differ from tectonic features within Eucla Basin, identified by stratigraphic drilling of Geological Survey of Western Australia, implying that they are most likely aeolian relicts of earlier environmental settings after the Miocene sea regression. Based on the direction of the stony ridges, this may indicate the palaeo-wind direction, which is prospective for reconstructing Earth climate during the Miocene and can provide additional insights into the position of the tropical/subtropical/temperate climate belts, given the palaeo latitude of the Nullarbor Plain when these aeolian features were formed.

Keywords: karst geomorphology, relict aeolian features, palaeoenvironmental reconstruction, Nullarbor Plain, Australia

Ključne besede: kraška geomorfologija, reliktne vetrne oblike, rekostrukcija paleookolja, Nullarbor Plain, Avstralija

Age Dating with OSL in the remarkable karst cave system Grotte di Frasassi, Italy

Datiranje sedimentov z metodo OSL v izjemnem jamskem sistemu Grotte di Frasassi

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The Frasassi Caves are among the most famous show caves in Italy. It has been a show cave since 1974 and offers a show cave length of 5000 m to the public. Visible are the Abyss Ancona (a hollow about 180 m long, 120 m wide and 200 m high), the crystallized lake, Niagara, little fairy's castle and among the large quantities of stalagmites and stalactites, the Giants with diameters up to 5 m and heights up to 20 m.

In the cave system, sulphureous water plays a major role. During the Quaternary, the NW–SE striking anticlines of the Frasassi mountains got uplifted. The SW–NE flowing Sentino River, a tributary of the Esino River, cuts through the anticlines and formed the Gorge of Frasassi. Adjacent to the gorge, the Frasassi Cave system developed with the help of sulphureous water and oxidizing bacteria.

In the cave system, a lot of research has been conducted and the cave system itself is continuously explored. Subsurface life of bacteria is studied in great detail. Uplift and incision of the Umbria–Marche region can be studied in the fluvial system of the local rivers and in the connected Frasassi Caves on several subhorizontal levels.

Based on available dating technics (for example, burial age dating of cosmogenic isotopes, U/Th and Radiocarbon dating) it was possible to determine ages for some of these subhorizontal levels. To increase the knowledge about the incision, four additional samples for Optically Stimulated Luminescence (OSL) dating were taken from two different Frasassi Cave levels.

The OSL dating results shed a little bit of new light on the uplift history of the Umbria–Marche region. In the famous Frasassi Cave system, OSL proved to be a suitable method for dating cave sediments. The combination of several different dating technics seems to be the best way to learn more about complicated history of modern landscapes and cave systems.

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Keywords: OSL dating, Grotte di Frasassi, speleogenesis

Ključne besede: OSL datiranje, Grotte di Frasassi, speleogeneza

A workflow for the assessment of karst formation and simulation focused on the oil and gas industry in Brazil

Potek dela za oceno razvoja in simulacije krasa za namene naftne industrije v Braziliji

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From a geological point of view, karstification is a diagenetic dissolution process triggered by fluid percolation in a porous medium and through discontinuities, modifying rock pore structure and permeability and finally generating characteristic geological features, such as dolines and caverns. Karst investigation efforts have started in the context of the Brazilian oil and gas industry when operational issues occurred related to drilling pipes during Pre-salt field exploration phases. Hydrocarbon exploration of Pre-salt fields has cast new challenges considering the deep burial of the reservoirs (by 6 km) and the kind of rocks and fluids involved. Pre-salt reservoirs are formed by carbonate rocks, which are known as materials of high stiffness. Hence, fractures and cracks are prone to emerge in these rocks in the presence of certain strain levels. Although these discontinuities have made oil accumulation possible, they also represent pathways and storage spaces for highly corrosive hydrothermal fluids, such as carbon dioxide. This has originated a number of hypogene processes by partial carbonate dissolution, generating karst structures at different scales. Modelling karst is of utmost importance for predicting and decision-making in critical scenarios. Porous media flow and mass transport governing laws, along with chemical reactions balance, define the base for the computational modelling of karstification processes. This work presents a simulation workflow and the system of equations derived from the governing laws aiming at a computational implementation of the simulation of karst initiation process in carbonate reservoirs. Finally, the workflow is detailed for an implementation in a finite element framework.

Keywords: karst, carbonates, pre-salt, numerical modelling

Ključne besede: kras, karbonati, podevaporitni naftni bazeni, numerično modeliranje

Micro-meteorology of Postojnska Jama, Slovenia: Instrumentation, Driving forces and Characteristics

Mikrometeorologija Postojnske jame, Slovenija: merilni sistem, dejavniki in značilnosti

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Automatic monitoring of micro-meteorology in Postojnska Jama has been developed over the last ten years. A set of cave-meteorological stations have been set-up at several locations, each representing different local micro-climate. A typical set of measured parameters are air temperature, CO_2 concentration and wind direction/velocity. The data collected at the meteo stations are transferred to the web server via Disruption Tolerant Network (DTN). For a DTN transfer, a data-mule carried by the cave train, receives the data from the station and sends it to the node connected to the internet. The whole procedure enables automatic and continuous updates of the data base. Based on the data, key driving mechanisms and weather patterns were identified. The cave shows strong seasonality with inflow of cold outside air in the winter and movement of air from the interior of the massif toward the main entrances during summer. The measurements also enabled identification of the main ventilation pathways. Several other driving forces of cave ventilation have been found and are discussed, such as, strong wind gusts that are common for the region and may induce strong air currents in the cave and floods of Pivka River that may block some of the airways and affect the ventilation patterns. Observations also provided some enigmatic records, such as very high wind velocity in one of the caves related to the system. A variety of microclimates, with amplitudes and patterns of the measured parameters within a cave system, reflect proximity to the surface, local geometry and presence of visitors.

Keywords: cave micro-meteorology, cave ventilation, measurement systems, Postojnska Jama

Ključne besede: jamska mikrometeorologija, jamski zračni tokovi, merilni sistemi, Postojnska jama

Contemporary decantation karren in the Kraków Upland (Poland)

Aktivno razvijajoči se biogeni žlebiči v Krakovskem višavju (Poljska)

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Specific contemporary karren occurring in the southern part of the Kraków Upland were detected in the Racławka and Eliszaówka Valley (30 km of Kraków). As a result of inventory, numerous sites with corrosive karren (more than 200) have been detected.

Karren occurring in the Kraków Upland are developed on the surface of Paleozoic limestone (Upper Devonian and Mississippian). In the area of the studied karren, limestone is characterized by low open porosity, ca. 1% and high $CaCO_3$ content, ca. 100%. Decantation karren are formed on the inclined limestone surface (inclined 50°–90°) situated directly below tree trunks, in particular: *Fagus sylvatica*, *Tilia cordata*, *Pinus sylvestris*.

The karren are formed as a long (up to 40 cm), narrow (0.1–1 cm) channel with sharp edges and smooth interior. They are divided into single, separate channels (straight or meandering). Often in the upper part of the structure, they are linked in a network with thin walls.

Monitoring of karren and hydrochemical analyses of water are conducted in the selected sites in valleys. The morphology of karren indicates that they have been created by runoff water. The present research shows that during formation of karren, dissolution is the most important process. Parameter changes (e.g., pH, Ca^{2+}, and HCO_3^-) are a measure of hydrochemical evolution of water and dissolution. Dissolution of carbonate rock is caused

predominantly by rain water (mean pH is 5.24 and Ca^{2+} concentration is 1.01 mg/L), which becomes more acidic flowing down the tree trunks (pH is 4.88 and Ca^{2+} concentration is 2.03 mg/L) and then drips directly to the rocky surface (pH is 5.83 and Ca^{2+} concentration is 5.04 mg/L). This process can be associated with influence of physiological processes of trees or air pollution accumulated on bark surfaces and then washed out by rain water.

This study was financially supported by the Institute of Geological Sciences of the Jagiellonian University (DS/MND/WGiG/ING/2017/14).

Keywords: decantation karren, karst, limestone, Kraków Upland

Ključne besede: biogeni žlebiči, kras, apnenec, Krakovsko višavje

Paleontensors analysis of a hypogenic karstic system, Lapa Nova Cave, Vazante, Brasil

Analiza paleotenzorjev hipogenega kraškega sistema Vazante v jami Lapa Nova, Brazilija

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The Vazante Karstic System (VKS) is a complex endokarstic and exokarstic system, with epigenic, hypogenic caves and mixed caves, with numerous cavities associated with fault zones and regional fractures, in the tectonic context of the Brasilia Fold Belt. In the VKS deep, well-developed and preserved caves are found that allow the detailed study of the features and structures. The regional caves are formed by fluid percolation in two main plans: the first set corresponds to contact zones between impermeable layers and layers of dolostones; the second set corresponds to fractures with EW and NW directions. The intersections of these planes generate the main zones of dissolution.

The study of these structures was conducted by the structural survey of the veins found in the Lapa Nova I cave and surroundings. The paleotensors were analyzed using the software WinTensor.

In general, the tensor axes are orthogonal, with σ1 showing 80/120 attitude as a compressive component. The axis σ2 shows at times a compressive component and at times an extensive component, and this variation is one point that is being more detailed. The σ3 axis is extensive, showing an alternation in attitudes of 05/230 and 10/340. This alternation is observed in patterns consistent with the patterns of the cave development, in which the extensive component is perpendicular to the slightly obliquous direction of the conduit.

The Brazilian deformation is responsible for generating a set of distentional faults with direction EW and NW, which control the hydrologic flow. The analysis of the paleotensors determined from the cave open joints indicate orthogonal directions of tension being σ1 vertical σ2 and σ3 horizontal with NW and NE direction. The σ3 is always perpendicular from the conduct direction.

Keywords: hypogene speleogenesis, paleotensor, fracture, Vazante Speleologic System

Ključne besede: hipogena speleogeneza, paleotenzor, razpoka, jamski sistem Vazante

Caves of Kyrenia Mountains: research, education and conservation

Jame gorovja Kyrenia: raziskave, izobraževanje in varovanje

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Current knowledge about caves and karst in Cyprus is negligible. The Kyrenia Mountains of northern Cyprus, one of the seven Special Environmental Protection Areas (SEPAs) in the region, are made of limestone and contain over 85 known caves, and possibly as many as 150 or more.

Firstly, only one outdated study from 2007 includes information on bats in the Kyrenia Mountains. Second, Cyprus is the only country in the European Union with fruit bats, which are protected under EU Natura 2000 laws. Third, caves act as ecological "islands" and provide unique habitats due to temperatures and atmospheric conditions that remain stable year-round. Some species are found only in cave environments, resulting in a high potential for undiscovered, rare, and/or endemic faunal species to be found within these systems. Fourth, no legal protections exist for caves in the Kyrenia Mountains. The area is threatened by mining activity and by damage from uninformed visitors. Fifth, no recreational or research caving community exists in Cyprus to study, inform, explore, and advocate for the protection of these systems. More advanced speleological studies need to be conducted, in order to protect and manage the caves. The overall objective of this project is to conduct cave research first-hand. History, plate tectonics, speleothem dating and isotope analysis, bat biology, invertebrate biology, microbiology, archaeology, and palaeontology of caves will be studied.

In Cyprus, we have caves formed in both limestone and gypsum. Some are formed solutionally by water, while others are formed by tectonic movement. The deepest known cave in Cyprus goes down over 200 m into the Kyrenia Mountains.

Currently, no legal cave protections exist for the Kyrenia Mountains. Furthermore, little data exists to support such legal texts. This research will address the priority of natural resources and waste by working to protect caves as a landscape feature of the Kyrenia Mountains. Further, because cave and karst systems are by definition connected with natural underground water filtration systems, protecting caves means protecting water resources. The results will address the priority of nature and biodiversity through its research and outreach projects through our biological research on cave-dwelling bats, invertebrates, and microbes. Species lists will identify important, rare, endemic, and/or endangered species.

Finally, our project will address the environmental and health priority by again preventing the pollution of underground water reservoirs by cleaning and protecting caves and by collecting data to protect these areas from overdevelopment or exploitation.

Keywords: karst, geology, fauna, microbiology, Pentadacylos

Ključne besede: kras, geologija, živalstvo, mikrobiologija, Pentadacylos

Microbial diversity and activity of snottites and biofilms at an underground acid mine drainage site in Båsmo (Nordland), Norway

Mikrobna raznolikost in aktivnost visečih biofilmov ter biofilmov na kislem rudniškem iztoku, Båsmo (Nordland), Norveška

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Snottites, suspended acidic biofilms forming on overhanging surfaces, represent scarcely studied microhabitats. This study aims to describe the microbial diversity and community composition of snottites and other biofilms found in subsurface acid mine drainage, in the abandoned Båsmo pyrite mine (Nordland), Norway, characterised by low temperatures, absence of light and a low-pH water environment (pH ~2.1). Its geochemistry and rock wall mineralogy differ from caves where snottites have also been found and studied previously (e.g. karst caves).

We applied a combination of different microscopy techniques, molecular approaches with Illumina sequencing (16S rRNA genes), fluorescence in situ hybridisation (FISH), geochemical analyses and cultivation.

The biofilm samples were composed of bacteria, filamentous fungi and protists. The estimated number of prokaryotic cells was similar for snottites and acid streamer (biofilm forming in acid water stream) and ranged

between $1.51x10^{11}$ and $1.56x10^{12}$ cells per gram (wet weight). Live/dead staining indicated that 9% to 24% of the prokaryotic cells in the samples were live cells. 16S rRNA gene community profiling revealed one, two or three bacterial taxons dominating in each sample and a low prokaryotic species richness in this extreme environment. Bacterial operational taxonomic units (OTUs) identified in biofilm samples belonged mostly to the classes Betaproteobacteria, Gammaproteobacteria and Nitrospira. 67% to 89% of the sequences in snottite and up to 94% in acid streamer samples belonged to the same OTU, affiliated with the iron-oxidising betaproteobacterium *Ferrovum myxofaciens*, often found in acid mine drainage. In pyrite-rich sediments and stream biofilm mixed with sediments, the majority of the sequences (63% and 53%, respectively) were related to the genus Leptospirillum, another important iron-oxidising bacterium. Rare representatives were related to the families Bacteriovoraceae and Acidobacteriaceae and the genera Acidithiobacillus and Acidiphilium.

Our study shows the diversity of these acidic microhabitats, predominated by iron-oxidising bacteria and closely connected to geochemistry.

Keywords: snottites, biofilms, microbial ecology, fluorescence *in situ* hybridisation, acid mine drainage, low pH

Ključne besede: viseči biofilm, »snottite«, mikrobna ekologija, fluorescenčna *in situ* hibridizacija, kisla rudniška voda, nizek pH

Curious cup-shaped dissolutional features in a dead-end passage of Postojna Cave, Slovenia

Nenavadne korozijske vdolbine v slepem rovu Postojnske jame, Slovenija

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Unusual dissolutional features found in a dead-end passage of Postojna Cave, Slovenia, indicate a delicate interplay between the percolating water geochemistry, cave atmospheric conditions and cave geometry. Found in abundance in a limited area within the terminal chamber of the Pisani Passage, Red Hall, these curious features are shaped like long tubes bored into the cave floor, indiscriminate of carbonate substrate, and henceforth, known as corrosion cups. The corrosion cups do not lie on the tourist route but are found in a passage known for very high CO_2 concentrations, unrelated with the show cave, which can exceed 9000 ppm in summer. Here, we investigate a number of questions to identify the cause and evolution of these mysterious dissolutional forms. Are the cups still forming or are they an ancient feature? What causes the cup-shaped form? Why are they limited to a localised area of the cave? To what extent does the high CO_2 concentration in the cave air promote cup formation? Does dissolution follow seasonal patterns related with cave ventilation?

Using cave surveying techniques, scanning electron microscopy (SEM) of limestone tablets, continuous and spot measurements of the geochemistry of dripwaters and water contained within the cups, we aim to answer these questions and provide a model of the conditions under which dissolution commenced and how this progressed to form the archetypal cup shape. Our research identifies remarkable seasonal fluctuations between calcite precipitation and dissolution regimes, linked with cave air CO_2 concentrations. The unusually high CO_2 concentrations in this chamber provide a natural laboratory for understanding the processes that occur in caves and, importantly, the effects of high CO_2 on cave decorations, such as stalagmites, important for robust palaeoclimate reconstructions. This is particularly interesting for discussions on enhanced CO_2 due to increased cave tourism and related with anthropogenic climate change.

Keywords: Postojna Cave, calcite dissolution, carbon dioxide, geochemistry, SEM

Ključne besede: Postojnska jama, raztapljanje kalcita, ogljikov dioksid, geokemija, SEM, vrstični elektronski mikroskop

The Challenges of Sustainable Development of Karst Caves Tourism – A Case Study of Zarrin (Dodza or Smoking) Cave

Izzivi trajnostnega razvoja jamskega turizma – primer jame Zarrin (Dodza)

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Within the tourism industry, geotourism is a growing type of nature tourism that has gained popularity in Iran. There are several kinds of natural, geological and geomorphological features in different parts of Iran. Caves are one of the most important geological forms that are frequently developed in most karstic limestone complex in wide zones of the country. In recent years, cave tourists have increased rapidly in Iran.

Zarrin (Doudza or Smoking) Cave is located in the Zanjan Province, north-west Iran, which is famous for its limestone caves, such as Katalekhour (20 km) and Alisadr caves, which are two beautiful caves within 11 caves are organized and manage in show caves group. Local people discovered the cave entrance in 1995 after an earthquake. The cave has a depth of ~154 m. Its first part consists of a boulder filled descending steeped collapsed passage. The second part involves two lakes with clear water at the depth of 157 m from the entrance, which are located in the rare of the cave. The recent galleries are the most interesting and marvellous parts. They were supposed to be the main touristic targets of Zarrin Cave. Existing of an unstable, dangerous pathway from entrance to access the main galleries, made it hard to deicide whether the cave is a suitable case as a show cave or not? In addition, prolong modeling result for Zarrin Cave was so low.

This paper aimed at introducing geological and tectonic characteristics of this cave, as main limits and challenges of introducing this cave as a tourist destination (show cave). Finally, the main strategies of protecting and conservation this cave have been identified using SWOT analysis.

Keywords: geotourism, karst, Zarrin cave, Smoking cave, Iran

Ključne besede: geoturizem, kras, jama Zarrin, Iran

Monitoring of obligate subterranean dwelling fauna in Postojna Cave System

Monitoring izključno podzemnega živalstva v Postojnskem jamskem sistemu

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Postojna Cave System is one of the world's biologically best studied caves and best known hotspots of specialized subterranean fauna. The diversity of the obligate cave-dwelling fauna has proved difficult to measure because of the highly localized distributions of most species. We investigated the local diversity patterns of a major component of the obligate cave-dwelling fauna living in the epikarst zone, the karst layer closest to the surface, terrestrial subterranean fauna, and sampling sufficiency at multiple scales. We sampled continuously the abundance of 37 species of copepods dislodged from the epikarst from 20 ceiling drips and terrestrial fauna in monthly intervals for a period of one year. Copepods were collected in a specially designed net that allowed continuous collection. On the other hand, terrestrial fauna was sampled using pitfall traps in both tourist and non-tourist parts of the cave. Such an approach enabled us to identify and assess the risk imposed by tourist use on specialized subterranean fauna due to alteration and destruction of its microhabitats and habitats. Based on species accumulation curves and Chao estimates of total diversity, we determined that

3 to 4 months of continuous sampling were sufficient to find 90% of the species in a drip, and that five drips were sufficient to find 90% of the species in a cave. Because of the scale of variation, and because of the availability of continuous sampling devices, the epikarst component of subterranean diversity seems to be more thoroughly and accurately measured than other components. Altogether, we recorded 21 troglobiotic species; two of them being recorded in the cave for the first time. In the non-tourist parts, slightly higher abundance and species richness of troglobionts were observed. In general, this may suggest only minor impact of tourism activities on specialized subterranean fauna in the cave.

Keywords: cave tourism, monitoring, subterranean fauna protection, troglobionts

Ključne besede: jamski turizem, monitoring, varovanje podzemnega živalstva, troglobionti

"Scientific" research in show caves of Slovenia – from the Antiquity to the end of the 19th century

»Znanstvene« raziskave v slovenskih turističnih jamah – od antike do konca 19. stoletja

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During the long history a scientific research was performed in many of nowadays show caves, obviously scientific in the spirit of its time. The meaning of a scientific research in antiquity is distinctly different from a scientific research in the age of Enlightenment, for example, nevertheless it was important for its time. Posidonius was examining tide and he mentioned Škocjanske jame in connection with the the Timavus Springs. The 16th century humanist F. Imperato went further and tried to prove this underground connection by a tracing test. Valvasor was discussing Postojnska jama and the Reka River, Nagel tried to evaluate the age of a stalagmite column in the Vilenica Cave, B. Hacquet discovered the dolomite, T. Gruber wrote on the underground flow of the Pivka River, just to mention some earlier examples. During the 19th century, the first modern tracing tests have been achieved on the relation Škocjanske jame – the springs of Timavo and A. Schmidl was the first to perform a microclimate research in Postojnska jama. Research of speleofauna started by description of Proteus in 1768 and continued by finding the first cave beetle by L. Čeč; these investigations flourished in show caves too and learned public were attracted to visit and research Classical Karst. At the end of the 19th century, two important and influential scientific books were published, both containing the data on our show caves, these are F. Krauss' Höhlenkunde and E.-A. Martel's Les Abîmes.

Keywords: karstology, history of research, show cave, Slovenia

Ključne besede: krasoslovje, zgodovina raziskovanja, turistična jama, Slovenija

Insights into spatial and seasonal CO_2 variability in a dead-end passage of Postojna Cave, Slovenia

Vpogled v prostorsko in sezonsko spremenljivost CO_2 v slepem rovu Postojnske jame, Slovenija

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Following recent research of Postojna Cave system microclimate, a more specific emphasis is now given to Pisani rov; a relict, dead-end passage of the cave. In Pisani rov, high CO_2 concentrations (> 9000 ppm) and radon levels are regularly observed during summer but until now only assumptions were given for the cause. Continuous measurements of CO_2 concentration at two different heights, air temperature and air circulation during 2017–2018 show high seasonal variability of CO_2 concentration driven mostly by changes in winter–summer regimes of the cave ventilation. In the winter regime, low CO_2 concentrations are the result of inflow of the outside air, low in CO_2, through the cave's main entrance and subsequent dilution of cave air, which in turn, exits the cave through vertical cracks toward the surface. In the summer regime, ventilation is reversed and CO_2-rich air is drawn from the epikarst, which then accumulates at certain sites in Pisani rov.

These high CO_2 sites are very non-uniformly distributed in Pisani rov and may be the result of cave microrelief or surface properties above the cave. Morphological study was aided with 3D cave scan LiDAR data accompanied with surface LiDAR data. Cave chimneys were found to protrude well into the cave-surface interface and may provide a CO_2 point source in summer. In the terminal chamber of Pisani rov (Red Hall), a vertically stratified CO_2 concentration distribution was measured and possible CO_2 traps may explain the higher CO_2 concentrations near the floor. High CO_2 concentrations may also be the cause of unusual dissolution features found in Red Hall. The minimal summer air flow in Red Hall provides a unique possibility to study cave air CO_2 dynamics to elucidate the role of chimneys and cave floor depressions as possible CO_2 point sources and traps.

Keywords: Postojna Cave, CO_2, cave microclimate, spatial distribution, seasonal variability, LiDAR data

Ključne besede: Postojnska jama, CO_2, jamska mikroklima, prostorska razširjenost, sezonska spremenljivost, LiDAR

Preliminary report of ongoing study on tourist impact on variation in cave air CO_2 concentration in Manita peć Cave (Croatia)

Predhodno poročilo tekočih raziskav vpliva turizma na spremenljivost koncentracije CO_2 v atmosferi jame Manita peć (Hrvaška)

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Manita peć Cave (NP Paklenica, Croatia) is relatively small show cave (67,510 m^3, Kuhta, 2010) adapted for visitors in 1937 for its exceptional interior. Due to its morphology (descending channel) the innermost part acts as a 'cold pocket' having the mean annual air temperature (MAAT) of 9 °C (1σ = 0.4 °C) in contrast to external MAAT of 13.7 °C (Surić et al., 2017). Given these settings and increasing numbers of visitors (mostly concentrated in the summer season), a new monitoring campaign has been initiated in February 2018, aimed at the variation in cave air CO_2 concentration. Measurements are conducted along the visitor path on a monthly basis throughout the year, with occasional measurements before and after touristic groups. Winter cave air CO_2 concentration is characterised with minimal spatial and temporal variations (325–464 ppm), while the summer situation is expected to be more unstable. Along with natural increases of cave air CO_2 concentration due to diffusion of summer CO_2-rich epikarst air through the bedrock discontinuities, short-term anthropogenic impact is also expected. Though, due to the cave morphology and relatively low number of visitors, variations are much less expressed than in nearby Modrič Cave (Sršen et al., 2018).

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Keywords: cave atmosphere, CO_2 concentration, show cave, Manita peć Cave, Croatia

Ključne besede: jamska atmosfera, koncentracija CO_2, turistična jama, jama Manita peć, Hrvaška

Geological profile of the Lubuška pit, northern Velebit, Croatia

Geološki profil brezna Lubuška na severnem Velebitu, Hrvaška

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The Lubuška pit is located in the area of the Strict Reserve “Hajdučki and Rožanski kukovi“ within the borders of the Northern Velebit National Park. Its entrance is situated at 1495 m above sea level. During previous speleological expeditions, the pit has been explored to a depth of 508 m. No detailed geological surveys have been carried out so far, except for scattered observations of structural elements at the shallow parts of the pit. The main aim of the recent geological survey during "Lubuška jama 2017" expedition is to construct of a geological profile of the pit. Two lithological units were observed; the Velebit (Jelar) breccia and well stratified Jurassic carbonate complex represented by various limestone types. Sampling was carried out across the whole profile below the depth of 240 m, which is also the depth of the contact zone between the Velebit breccia above and the underlying well-stratified carbonate complex. Rocks and cave sediment samples were collected at 11 locations throughout the profile of the pit at morphologically specific parts, to ascertain the precise depth of sampling. In addition to the sampling, preliminary structural measurements were performed. According to petrographic analysis of rock samples the entire carbonate complex below the Velebit breccia chronostratigraphically belongs to the Callovian-Oxfordian. The specimens include carbonate breccia and limestone variants such as bioclastic wackestone to packstone, micrite limestones and dolomitized limestones. Also, two basic types of clastic sediments were observed: a red silty-clay that fills the cracks in the walls of the channels and stream transported sandy-clay silt deposited next to the siphon lake.

The construction of the schematic geological profile of the Lubuška pit is a contribution to the understanding of the geological structure of Hajdučki kukovi area and the broader area of Northern Velebit.

Keywords: Velebit Mt., Lubuška pit, geological profile

Ključne besede: Velebit, brezno Lubuška, geološki profil

Karst resources, tourism and conservation in Norway

Viri, turizem in varovanje krasa na Norveškem

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The suite of karst surface and subsurface landforms represent a valuable source of resources for science and society. At the same time, these values are threatened through various kind of use by the same society, and the challenge is to work out sustainable protocols for the various aspects of values and use. These criteria will vary between countries and various karst types. Countries with vast areas of well-developed karst and many caves will need different protocols than small countries with small karst areas and few caves. This presentation will review the resources, values, vulnerability and challenges met in Norway, where about 1% of the land surface comprises carbonate rocks, and where most of the karst is of the marble stripe type.

Keywords: karst, cave, conservation, management, Norway, small countries

Ključne besede: kras, jame, varovanje, upravljanje, Norveška, majhne države

The history of cave tourism in the Polish–Slovak transfrontier area until 1939

Zgodovina jamskega turizma na poljsko-slovaškem čezmejnem območju do 1939

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Relationships between man and caves began in the earliest times. The caves of the Polish–Slovak transfrontier area (formerly the Polish–Hungarian transfrontier area) in historical times began to be penetrated in the 13th century. At first, they served people as places of residence or temporary shelter. Then they began to attract treasure hunters, researchers (speleologists) and ordinary tourists. The beginning of speleological research should be sought on the Slovak side of the Tatra Mountains (former Hungarian side). In 1299, the first mention of the caves of the Demänovská Valley appeared in the documents of the Esztergom Chapter. The oldest information about the Tatra cave can be found in the publication of Johannes Patersonius Hain from 1672. The pioneer of cave tourism was the Polish poet Seweryn Goszczyński, who in 1832 visited the caves in the Kościeliska Valley in the Western Tatras. The milestone in the development of cave tourism was speleological activity in the 1870s and 1880s by Jan Gwalbert Pawlikowski. In 1882, the Belianska Cave in the Belianske Tatras was opened for public. In 1886, in the cave - one of the first in Europe - electric light was lit. A significant development in the study of the Tatra caves took place after Poland and Czechoslovakia regained their independence in 1918. A significant contribution to the development of cave tourism in the Polish Tatras in the interwar period were brothers Tadeusz and Stefan Zwoliński. In 1921, the Czech teacher Alois Král discovered the Demänovská Cave of Liberty, which gave a strong impulse for further speleological research on Czechoslovakia. In 1923, the first speleological organization in Poland - the Speleological Club - was established in Zakopane. The aim of the paper is to present the current state of research on the history of cave tourism in the Polish and Slovak side of the transfrontier area until 1939. Studies on the history of cave tourism will be presented chronologically. The most important speleologists and organizations involved in cave tourism will be discussed.

Keywords: cave tourism, show cave, speleohistory, transfrontier area

Ključne besede: jamski turizem, turistična jama, zgodovina speleologije, čezmejno območje

Gypsum deposits in deep caves of the Nullarbor Plain, Australia

Sedimenti gipsa v globokih jamah ravnika Nullabor, Avstralija

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The impressive deep caves of the Nullarbor Plain mainly consist of one long passage with a simple form - flat roofs, smoothly arched walls and dome-like ends prone to collapse. It has been suggested that their formation is due to solution that occurred during pluvial periods in the Oligocene and/or Pliocene, although several other processes have been discussed that may have contributed to their formation such as mixing corrosion, crystal wedging and biospeleogenesis.

Gypsum deposits in the Nullarbor caves are common and have mostly been related to semi-arid Quaternary climate in the region. Gypsum is one of the common minerals in cave deposits and may precipitate due to various factors, such as supersaturated dripwater or during water evaporation. Sulphur may be variously derived from meteogenic sources, decomposition of organic matter in soil or in caves, or biotic and abiotic oxidative recycling of sulphide from the aquifer. However, gypsum may also be a product replacing carbonate minerals as a result of sulphuric acid speleogenesis. Motivated by limited knowledge of deep cave formation on the Nullarbor Plain, little or no relation to surface karst geomorphology, and a presence of chemoautotrophic

aquatic microbial communities, the sulphur isotopic composition of gypsum was analysed to verify the link between gypsum and sulphuric acid speleogenesis. Nevertheless, its high $\delta^{34}S$ values do not indicate sulphuric acid speleogenesis of deep caves on the Nullarbor Plain nor the correlation to the chemoautotrophic bacteria.

Keywords: Nullarbor, sulphuric acid speleogenesis, gypsum, Australia, cave, speleogenesis

Ključne besede: Nullarbor, speleogeneza žveplene kisline, gips, Avstralija, jama, speleogeneza

Advantages in cooperation between public research institutions and privately run natural heritage sights

Prednosti sodelovanja med javnim raziskovalnim zavodom in zasebnim upravljavcem naravne dediščine

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The Anton Melik Geographical Institute ZRC SAZU, founded in 1946 by the Slovenian Academy of Sciences and Arts, deals with geographical research on Slovenia. This includes the understanding of landscape evolution and its past and future environment (e.g., climate, hydrology, vegetation). Caves are natural archives of environmental data, and thus, an important natural laboratory for scientific research.

The company Postojnska Jama, d. d. has a well-established tradition of managing cave tours and events, which started in the 1820s when the Postojnska Jama was set up as a show cave. Since then Postojnska Jama has become renowned not only as one of the world's great sights but has unleashed a wave of scientific research and set the world beginnings of the new branch of science-speleobiology. The company is bound to respect the fragile environment of the cave and pays a great deal of attention to preserve the environment.

In order to remain attractive, scientific institutions need to open up to economic and business collaboration, where sharing mutual knowledge gives an important boost to the quantity and quality of research output. Collaboration between Postojnska Jama and Anton Melik Geographical Institute ZRC SAZU proves that researchers and private companies can work closely together based on recognition of mutual advantages, benefits and respect towards nature. This cooperation started in 2010 with the focus on cave sediments and their applications for reconstructing palaeohydrological conditions. It now continues with additional focus on flowstone science, which aims for reaching important scientific knowledge that will maximise the social and economic benefits of new ideas by transforming the scientific research results into a commercial and educational product. The cooperation between science and business is meaningful and productive for participating partners and for society.

Keywords: Postojnska Jama Cave, Anton Melik Geographical Institute, ZRC SAZU, public research institution, natural heritage sight, collaboration

Ključne besede: Postojnska jama, Geografski inštitut Antona Melika, ZRC SAZU, javni raziskovalni zavod, naravna dediščina, sodelovanje

How the Postojna Cave tourism shaped the image of today known olm?

Kako je Postojnska jama oblikovala podobo sedanjo podobo proteusa?

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In mid-2016, media interest for the Postojna Cave olm became one of the most frequent cave-related topics in the public media from around the world. It was about hatching of the olm in the Postojna Cave vivarium. Exactly 250 years have passed since the first scientific description of *Proteus anguinus*. During that long period of time, great enthusiasm for *Proteus anguinus* – similar to one in 2016 – has been expressed on several

occasions. Till now, the karst science made considerable breakthroughs of knowledge of subterranean fauna: its morphology, biology, systemic and other aspects of the field. However, representation of an olm in the newest media coverage has intentionally some important features that are not scientific. In almost every article, an olm is a young dragon and a "star" among the subterranean fauna. Mix of these features / roles with which the modern notion of this animal is faced, is mostly generated by experience of tourist guides in the Postojna Cave in Slovenia. For a long time, this was the only place the wider public recognized as a home for Proteus. Tourism has to operate with images that attract the audience and secure higher rates of tourist revenue. In this paper, we will discuss the cultural background that enabled the Postojna Cave tourism to significantly shape the worldwide public perception of olm.

Keywords: science, tourism, Postojna Cave, proteus

Ključne besede: znanost, turizem, Postojnska jama, proteus

Climatically controlled sedimentation in a deep cavern, south Velebit Mt., Croatia

Klimatska pogojenost sedimentacije v globokih jamah južnega Velebita, Hrvaška

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Little is known about the controls of clastic deposition in deep limestone caverns, particularly those with no known connection with the surface. Such caverns are occasionally discovered by tunneling, but seldom studied in detail. One of several caverns discovered during construction of St. Rok road tunnel in S. Velebit Mt. was largely filled with clastic sediment, and sampled shortly after its discovery in 1999, in approximately the mid-part of the tunnel. The cavern sediment is of mixed carbonate-siliciclastic composition with alternating mm- to cm-thick layers of medium- to fine- and very fine-grained arenite. Individual arenite layers differ in grain-size, color, matrix and iron content. Some very fine-grained arenite layers are draped by thin red-brown clay laminae. The sediment organization indicates that the deposition was strongly controlled by seasonal (annual?) changes in water discharge. Medium-grained arenite was deposited from stream flow, apparently during periods of relatively high discharge, whereas, fine-grained and very fine-grained arenites were deposited during slow percolation and stagnant water. This sediment pattern is very similar to clastic varves, and reflects paleoclimatic pattern on Velebit Mt. high parts, but ca. 300 m below the topographic surface.

Keywords: clastic sedimentation, paleoclimate, cavern deposit, External Dinarides

Ključne besede: klastična sedimentacijapaleoklima, jamski sedimenti, zunanji dinaridi

The role of Castañar Cave's research studies in the dissemination of Earth science

Vloga raziskav v jami Castañar pri diseminaciji vsebin ved o Zemlji

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Castañar Cave is a touristic cave located in Extremadura, Spain, well-known for the abundance of aragonite speleothems. It is one of the main geological sites of the Global UNESCO Geopark "Ibores Villuercas Jaras".

Since its opening to the public in 2003, several research studies have been taking place concerning the cave microclimate, microbiology and the geology of the host rock and speleothems.

Castañar Cave is one of the very few karstic features in the area, due to the predominant siliciclastic lithology. It formed by dissolution of Mg-carbonates (dolostones and magnesites) interbedded with shales and sandstones. The high amount of Mg^{2+} in the cave waters causes the predominance of aragonite compared to calcite in speleothems, and enables the formation of huntite, dolomite and sepiolite. Weathering of the host rock results in the formation of the characteristic red clays that cover the cave's walls. Variations in the water chemistry have caused transformations of the speleothems, such as dissolution, micritization, dolomitization and aragonite to calcite inversion, making Castañar Cave an excellent site for the study of meteoric diagenesis.

The results of the studies carried out in the cave have been used to create the contents of the visitor centre, to prepare explanatory panels of the geology of the surrounding area, and have been published in a book for the general public. Castañar visitor's centre plays an important role for environmental education, hosting regular visits of school and organising workshops. The geological studies of Castañar area are also presented in "Geolodía", a series of geological excursions for the general public.

In this way, communication of the research performed in the cave raise awareness among visitors of the need to protect it for its singularity, not only in aesthetics terms, and also becomes an important tool in the transmission of scientific values to society.

Keywords: Castañar Cave, aragonite, diagenesis, dissemination of geosciences

Ključne besede: jama Castañar, aragonit, diageneza, diseminacija geoznanosti

Tourism and cave and karst science in Postojna

Turizem in znanost o jamah in krasu v Postojni

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The natural phenomena as caves, sinks, large springs or intermittent springs and lakes stimulate human curiosity, making them famous and inducing tourism, and some of the tourists are scientists. In Postojna Cave, tourism and cave science evolved through several centuries and even this very School is the result of that relationship.

Entrances to caves were known and visited long before they were connected to a single cave system Postojnska Jama. For science, of importance are the descriptions of Valvasor (1689), Nagel (1748), Hacquet (1778) and Gruber (1779). In 1818, the large inner parts of the cave were discovered, which lead the municipality of Postojna to form the Cave Commission. As the Commision was educated and was following the tradition of Enlightment, it forced the sustainable use of the cave, high level of visits and support to cave exploration and study.

Bones of extinct animals that were discovered in cave were collected and studied already in 1819 by the curator of the Ljubljana Museum. In 1797, Jeršinovič found in the cave Proteus anguinus, a cave animal that was previously known from springs only. But when 1821 cave guide Čeč found in a cave an eyeless beetle, which was recognised by biologist Schmidt as a cave adopted animal, this was the beginning of speleobiology. A tourist guide with good illustrations and extensive text describing cave and karst was published in 1830 by Hohenwart.

The fame of the cave brought to Postojna many important scientists. Schmidl (1854) explored and described the caves in the area from all points of the view. His book is considered as the first scientific book on speleology. The cave was explored by Putick and, in 1889, the caving society Antron was founded. In 1891,

Cvijič briefly visited the cave. The cave was visited by Martel and Kraus and they included the data from local researchers to their books.

By the end of 19th century, the cave and cave tourism had become so important that Postojna started to think about the foundation of a museum and an institute devoted to caves and karst. The preparations were stopped by the outbreak of the war, but the idea survived and in 1927 the Instituto Italiano di Speleologia was established. The second war, again with border changes, halted karstology until in 1947 when the present Institute for Karst Research continued.

Growing contacts between karstologists lead to the organisation of the Speleological congress in Ljubljana and Postojna and the foundation of the International Speleological Union in 1965. And in 2001, the Permanent seat of UIS was established at the Institute for Karst Research ZRC SAZU. This and numerous scientific meetings that followed were always supported by the management of Postojnska Jama and were possible because of the touristic infrastructure of Postojna.

Keywords: tourism, Postojnska jama, speleology, science, history, Postojna

Ključne besede: turizem, Postojnska jama, speleologija, znanost, zgodovina, Postojna

Scientific research at the Bijambare caves

Znanstvene raziskave v jamah Bijambare

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The first scientific research in Bijambare caves (year 1900) was performed by speleobiologist V. Apfelbeck, who found an endemic beetle *Antroherpon stenocephalum*. In the second half of the 20th century, paleontologist Mirko Malez performed excavations in the Middle and Upper Bijambare caves, where he found the remains of the cave bear *Ursus spelaeus*, but also the flint tools from the time of aurignacien.

Recent scientific studies in the Bijambare caves started in 2006 during the project "Construction Of Bijambare vacation complex-Phase 1" financed by European Union and Canton Sarajevo. Within the scope of this project, the cave was equipped with an environmental monitoring system collecting data on air temperature, air humidity and carbon dioxide concentration. This system was further expanded a few months later when the site joined the project C6 (Climatic Changes and Carbon Cycle in Canyons and Caves) supervised by the Palermo Branch of the Italian National Institute for Geophysics and Volcanology.

Data provided by these two projects formed the backbone of a PhD research (University of Nova Gorica - Karst Research Institute, Postojna) started in 2006, concluded in 2014 and aimed to investigate and quantify inorganic carbon fluxes within the unsaturated zone of karst. As part of the PhD research, monitoring was expanded to drip water quality/quantity, isotopic composition, stalagmites growth rate, Radon concentration and included a specifically designed experiment with an artificial release of a known amount of carbon dioxide in the cave environment. Recently (2008–2010), stalagmites from Bijambare cave were collected and analyzed for paleoclimate reconstruction but results have not yet published.

More recently, the study of bats is being performed.

Keywords: Bijambare caves, paleontology, climatology, archaeology, bat research, Bosnia and Herzegovina

Ključne besede: jame Bijambare, paleontologija, klimatologija, arheologija, raziskave netopirjev, Bosna in Hercegovina

Automatic measurements in Škocjan caves for sustainable use and protection of natural heritage

Avtomatske meritve v Škocjanskih jamah za trajnostno rabo in zaščito naravne dediščine

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For sustainable use and protection of natural heritage of Škocjan caves, which are in UNESCO list of world heritage, automatic micrometeorological measurements are used. Long-term continuous monitoring of this outstanding karst cave is based on high quality automatic measurements of the most important physical quantities.

Automatic monitoring system design, construction and operation is based on seven years of experiences and recommendations obtained from Postojna Cave automatic cave information system, on a good practice from many years of experience in the field of automatic measurements in the outer atmosphere and the principle of continuous improvement based on the recommendations of the ISO 9001 standard for quality assurance. Cave information system is based on several automatic measuring stations and central unit. Each station is according to its location equipped with several sensors for measuring air and rock temperature, air flow speed and direction and CO_2 concentrations. Measured data are collected, controlled, processed, archived and presented at central unit.

For data transfer from automatic measuring stations to central unit DTN (Delay and disruption network) protocol is used. It was originally developed for deep-space communications and terrestrial areas with poor or non-existent communication infrastructure and well tested and improved for cave environment in Postojna Cave automatic cave information system.

This work presents conditions that are provided for establishing high quality automatic measuring network sustainable use and protection of Škocjan caves. High accuracy of measurements and long term data real time availability is achieved using relatively small number of high quality automatic cave stations.

Keywords: automatic cave station, karst cave, cave information system, automatic measurements, DTN network

Ključne besede: avtomatska jamska postaja, kraške jame, jamski informacijski sistem, avtomatske meritve, odložljiva omrežja DTN

A monitoring plan using microbiological indicators to balance protection and exploitation of major tourist caves in Slovenia

Monitoring plan na osnovi mikrobioloških indikatorjev za uravnoteženje zaščite in rabe glavnih slovenskih turističnih jam

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Each cave is a subject to significant changes in terms of morphology, climate and impact on underground organisms once it is opened to the public. In show caves, a normal two-way ecosystem interaction of the biotope and biocenosis is intercepted by tourism that affects the natural state of caves. Two caves in Slovenia, Postojna Cave and Škocjan Caves, are typical examples for tourist mass visitation, which leaves its imprint on the cave ecosystem. Tourists affect directly the cave atmosphere and contact surfaces. They bring and disperse a high concentration of airborne bacteria. Elevated concentrations of airborne bacteria usually persists for a few hours after tourists leave the monitored area. In Postojna Cave, a tourist train impacts the movements of air masses, and particularly the distribution of airborne fungal spores. Based on previous studies on airborne microbiota in both cave systems, a monitoring plan has been proposed to monitor the distribution of various sized fractions of airborne particles. Tourists are responsible for dispersing organic material and microbes on

their shoe soles. A disinfection barrier at the cave entrance proved to be a proper solution to reduce the introduction of organic material. Tourist use of caves with lighting brings in the underground light eutrophication, and as a result, communities of lampenflora develop in the vicinity of lamps. Manual removal of lampenflora and an application of buffered hydrogen peroxide solution have been used in both caves to eliminate and restrict lampenflora. Spectrophotometric measurements are used to monitor the status of the exposed surfaces and to alert the management before the visible lampenflora biofilm develops. A regular monitoring of tourist impact in caves, which reflects in infrastructure, lighting, climate and alien biomass, is crucial, as it might irreversibly affect the integrity of the cave ecosystem and its natural biota.

Keywords: conservation, cave management, aerobiology, lampenflora

Ključne besede: varovanje, upravljanje jam, aerobiologija, zelena razrast

GIS model to estimate seasonal microclimatic changes in the Speleobiološka Postaja (Postojnska Jama, Slovenia)

GIS model za ocenjevanje sezonskih mikroklimatskih sprememb v Speleobiološki postaji (Postojnska jama, Slovenija)

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Speleobiološka Postaja or Vivarij arranged in Rov Novih Podpisov [Gallery of New Signatures], is a small portion of Postojnska Jama maintaining and exhibiting cave animals within the educational and biologically-oriented touristic offer. This part of the cave system covers about 0.11 ha and receives at least 100,000 visitors per year.

Air temperature and CO_2 monitoring is organized since March 13, 2015 providing scientifically supported cave microclimatic data. This helps to understand dependence between the natural underground environment and anthropogenic impact and to further suggest expert mitigation recommendations.

The 2017 mean annual air temperature in the middle part of Vivarij was 12.4 °C with an annual range of 1.43 °C. This indicates a temperature value with 2.41 °C higher than outside mean annual air temperature. In the same year, in the highly visited Velika Gora collapse chamber from Postojnska Jama (hosting approximately 775,000 visitors in 2017) the measured mean annual air temperature was 11.15 °C, which is 1.42 °C higher than the mean outside annual air temperature. To outline, in mid-August 2015, the small volume of Vivarij, coupled with the growing annual number of tourists and the closed metal door at the northern part of the chamber are the main reasons for recording a maximum CO_2 concentration value of 4,110 ppm. Similarly, in the beginning of August 2016 we measured here up to 3,130 ppm of CO_2 while the door was closed. In the middle of August 2017, when the metal doors were opened, the CO_2 concentration was 2,470 ppm, though the number of visitors increased and the outside and inside temperatures were higher than in the previous two years.

To detect if there are critical seasonal changes in the Vivarij and its extended northern area, while touristic peaks, we performed a GIS analysis using IDW (Inverse Distance Weight) interpolation tool for the air temperature data. The GIS analysis included five weeks matching all climatic seasons and covering the most important Slovenian national holidays, prone to high touristic visits during 2017.

We use the temperature values recorded in four points of the Vivarij and extended neighbouring northern area, for each day at 12 AM and 12 PM, with a mean range set to 9 to 10.7 °C representing the intervals below as minimum, and above this range as maximum. The data interpolation shows a positive trend for maximum values with overheating large areas from Vivarium, especially in the days matching national holydays. Also decreasing/increasing values of temperature are related with the periods of open/closed door in the Vivarij. To compare, we overlap to the map with the interpolated values of air temperature the graph with CO_2 values measured in two of the points of Vivarij (before and behind the door) for the month of August from three consecutive years (2015 to 2017). Results strongly support recommendations that during summer ventilation

($T_{out} > T_{cave}$) metal doors connecting Vivarij with the rest of the cave (Stara Jama) must be opened. Such simple mitigation action helps to actively decrease anthropogenic induced air temperature and CO_2 concentrations, and to maintain proper microclimate for the exhibition of cave animals.

Keywords: air temperature, CO_2, cave management, Speleobiološka Postaja, Postojnska Jama, microclimate monitoring

Ključne besede: temperatura zraka, ogljikov dioksid, upravljanje jame, Speleobiološka postaja, Postojnska jama, mikroklimatski monitoring

The potential of subterranean systems as touristic attractions in the Riviera Maya

Potencial podzemnega sistema kot turistične zanimivosti riviere Maya

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During the 1970's, Mexico was going through a good and stable economic stage due to the commerce of its oil, this situation gave the Mexican government the opportunity to develop the touristic activity in the south of the country, which was the starting point of the creation of the city now known as Cancun. National and international investors started to promote the sun and beach tourism, not just in Cancun but it also started to grow all over the coast of the state of Quintana Roo, today named the Cancun-Tulum corridor or the Riviera Maya. As the years passed by, and with the influence of foreign tourists, the touristic offer started to diversify and one of the most relevant activities, due to its environmental and cultural value, is caving. This activity is common around the Yucatan Peninsula because of the karstic origin of its soil that helped created different forms such as underground rivers, caverns and cenotes (water holes). The great majority of these formations are partially or fully filled with water, which gives them the property of being the only repository of freshwater in the Peninsula. Besides their natural function to supply water, these underground systems have a biological, scientific, cultural and historic relevance because of the different creatures that live there, the anthropologic discoveries of the Maya culture, the geomorphology and the social significance. The touristic usage has become socially meaningful as the revenue of many families on the region, that have cenotes or other kind of caverns on their lands, come from this activity. Unfortunately, these spaces have become vulnerable to water pollution, ground erosion, loss of species and social conflicts because of the lack of a proper management and legislation. For these reasons, the objective of this work is to show the potential of the subterranean systems as touristic attractions in the development of sustainable tourism in the Riviera Maya.

Keywords: tourism, Riviera Maya, caves

Ključne besede: turizem, riviera Maya, jame

Microbial activity in alluvial sediment in the Reka River (Škocjan Caves, Slovenia)

Mikrobiološka aktivnost v rečnem sedimentu Reke (Škocjanske jame, Slovenija)

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Rivers in karst caves deposit sediments, which are a mixture of inorganic and organic materials, and biota. Alluvial sediments were sampled in Škocjan Caves at the syphon after 6.3 km of the underground water flow of the Reka River and compared with externally deposited river sediment, old cave sediment and karst soil sampled above the cave system. The concentration of the majority of heavy metals (As, Cr, Cu, Zn, Ni, V, Co, Hg) was lower in the Reka River sample before sinking into underground: the concentration of nutrients (C, N,

P, S) slightly varied among sites, and the concentration of cultivable microorganisms in all samples was of similar values (e.g., ~107 CFU/g of dry weight). Microbial utilization of 31 different substrates (Ecoplates, Biolog) at 20 °C was used to ascertain the community-level physiological profiles. All the substrates were metabolized by microbes from the old sediment that was sampled approximately 20 meters above the current Reka River flow and close to the tourist footpath. The majority of tested substrates, specifically 77%, were metabolized by microbes from the samples from externally deposited river sediment and karst soil, while microbes from the sediments near the syphon exhibited less metabolic capacity for biodegradation, ranging from 35% to 65%. Microbial activity was monitored using isothermal calorimetry. Sediment samples were mixed with the water from the Reka River, incubated at different temperatures (10 °C, 20 °C and 30 °C), and the heat flow was measured. The highest amount of heat energy released was in the sample of karst soil. Although microbiota in sediments was part of the same cave system, its metabolic capacity and response to external stimuluses varied among sites.

Keywords: cave, sediment, microorganisms, metabolic activity

Ključne besede: jama, sediment, mikroorganizmi, metabolna aktivnost

Importance of Caves in Croatia as the Locations for Outdoor Science Education

Pomembnost jam na Hrvaškem kot lokacij učilnic na prostem

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Modern education in Croatia tends to put central emphasis on competences within the scientific education (STEAM = Science, Technology, Engineering, Arts and Mathematics), as these knowledge and skills are the foundations of the 21st century jobs. Emphasis is placed on project teaching, out-of-class-learning concept, and interdisciplinarity. It demands development and introduction of new teaching methods and contents related to the biggest problems in the world today, from local to global issues. Numerous researches show the effectiveness of the outdoor education as a part of out-of-class learning in which pupils and students interact with the real-world experience in a natural environment. It is also well-known that learning in natural environment affords a wide range of benefits: educational, health, cultural and social. Karst and caves are ideal locations that can serve as outdoor classrooms for learning about natural processes from various aspects but also for application of different knowledge and skills. But besides pupils and students as "end users" of education, it is important to prepare teachers for these new forms of teaching. For the needs of preparing out-of-class geography and physics teaching projects in primary and secondary schools, we formed a working group of scientists and practitioners (geographers, physicists, experts in geography teaching methodology, experts in nature conservation) that developed a programme for teacher education and preparation. A key idea was to highlight the development of programs for formal education and, at the same time, encouraging scientific activities whose results can be included in these programs. We also addressed the importance of collaboration of higher education, schools and nature (cave) management service. This project was realized in cooperation between several institutions: Faculty of Science (UNIZG), Education and Teacher Training Agency, Public Institution for the Management of Geomorphologic Monuments of Nature "Cave Park Grabovača", Croatian Geographical Society and Croatian Geomorphological Society.

Keywords: science education, STEAM, caves, outdoor classrooms

Ključne besede: znanstveno izobraževanje, STEAM, jame, učilnice na prostem

UV-C treatment of Lampenflora proliferating in show caves

UV-C osvetljevanje zelene zarasti razširjene v turističnih jamah

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In recent decades, show caves have begun to suffer from microorganism proliferation due to artificial lighting installations for touristic activity. In addition to the aesthetic problem, light encourages microorganisms that are responsible for physical and chemical degradation of limestone walls, speleothems and prehistoric paintings of cultural value. Microorganisms have previously been described by microscopy or culture-dependent methods, but data provided by new generation sequencing are rare. We have identified, for the first time, microorganisms proliferating in one Swiss and in four French show caves using three different primers. Bacteria, cyanobacteria, micro-algae, diatoms, fungi and mosses were identified. To treat these organisms, a large spectrum treatment should be used such ultra-violet C (UV-C), which is a treatment commonly used in sterilization processes in industry, laboratories and hospitals. In this study, we also have eradicated, for the first time, all proliferating biofilms present in a show cave (the La Glacière Cave, Chaux-lès-Passavant, France). Colorimetric measurements of irradiated biofilms were then monitored for 24 months. Since UV-C can be deleterious for biofilm support, especially parietal painting, we investigated their effects on prehistoric pigment. Results showed that no changes in pigment color nor in chemical and crystalline properties has been demonstrated. The present findings demonstrate that the UV-C method can be considered environmentally friendly and the best alternative to chemicals. Currently, this method is really efficient in the sustainable strategies for cave heritages protection and to preserve the esthetic aspect of the landforms and landscapes in a show cave.

Keywords: lampenflora, UV-C treatment, show cave, sequencing

Ključne besede: zelena razrast, UV-C zatiranje, turistična jama, sekvenciranje

Hydrological data from Herbstlabyrinth-Adventhöhle Cave System, Germany. An essential basis for caving safety?

Hidrološki podatki iz jamskega sistema Herbstlabyrinth-Adventhöhle (Nemčija) – ključna osnova za varnost raziskovanja jam?

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First studies about the hydrogeology in the Herbstlabyrinth-Adventhöhle Cave System (HL) in Breitscheid-Erdbach, Westerwald, Germany, can be traced back to the 1960s (Matthess & Stengel-Rutkowski, 1967) and 1980s (Thüringer, 1981). New passage findings in the last years lead to a better understanding of the cave system (Dorsten, 2016).

From July 2015 to January 2016, continuous hydrological measurements (temperature, conductivity and water level) were measured with automatic data loggers (Hobo-U20) at the Erdbachquelle (EQ) and within the cave system in the „Tiefer Erdbach“ (TE), the nearest point inside the cave to the EQ. Precipitation was measured with the PLUVIMATE logger system above the cave system (Mischel et al. 2015, Mischel et al. 2016).

From July to October 2015 only small precipitation events occurred, whereas, in mid November 2015 a long and huge precipitation event appeared (180 mm during 18 days). The first flush of this event lead to a conductivity drop from 320 µS/cm to 280 µS/cm and water temperature decreased from 10.9°C to 10.5°C in the EQ. After a pause of precipitation (8 mm during 6 days), conductivity increased to 380 µS/cm. Within

4 days, precipitation went on (80 mm), leading to a decrease of conductivity to 200 µS/cm and temperature to 9°C. The water level of the TE was measured continuously from 4th July 2015 to 5th December 2015. During this period, precipitation events are also visible in the water level data. Water level increased by 1 m after a short precipitation event on 19th July 2015 (18 mm during 10 hours) in the TE. A water level increase of 2–3 m is critical to access and to leave the TE.

The prediction of the water level in the TE will help to improve the safety of cavers. Further measurements will improve the precise forecast for high floods and therefore lead to a safety threshold (velocity of water level increase and decrease) for cavers in the HL.

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Keywords: karst hydrology, speleology, caving safety

Ključne besede: kraška hidrologija, speleologija, varnost raziskovanja jam

Terrestrial cave fauna monitoring in touristic part of Škocjan caves, Slovenia

Monitoring kopenskega jamskega živalstva v turističnih delih Škocjanskih jam, Slovenija

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The organized guided tours, which can be considered as the beginning of the real tourism in the Škocjan caves, started in the year 1884. Soon after, the first records of cave fauna were published by various naturalists of the time in various scientific publications. Wolf, in 1938, published the first comprehensive list of Škocjan caves fauna in the world catalog “Animalium caverarum catalogues”. To fill the gap and to prepare the updated list of subterranean fauna of this great show caves, the managers of Škocjan caves started a project Climaparks in 2011 and 2012. The project enabled us to explore at least the touristic part of the cave. In the study, we gathered dispersed historical data on terrestrial cave fauna and started regular faunistical studies. According to a standard protocol, we established 10 reference-observing points across the touristic path, where we inventoried the cave fauna. Bats were studied separately and are, thus, excluded from this study. As a result, more than 38 subterranean invertebrate taxa were recorded, among them 13 taxa were considered as strict or potential troglobionts. In the study, we found and documented some new taxa for this show cave. Some invertebrate groups are still not taxonomically studied in details. The monitoring of fauna at the selected points were repeated at a regular basis to estimate seasonal fauna occurrence. Potential touristic use impact on fauna was estimated and monitored. One beetle species locally vanished from the touristic part of the cave probably due to the touristic use, but it is still common in the non-touristic caves in the vicinity. The lampenflora appeared problematic in the sites artificially lighted, but surprisingly enough some cave invertebrates, namely Collembola and Diplopoda, started to exploit this food source of algae and mosses.

Keywords: troglobionts, tourist impact, monitoring, Škocjan caves

Ključne besede: troglobionti, vpliv turizma, monitoring, Škocjanske jame

Misinformation, magical mystery tours, and extreme adventures: caves and tourist information in British Columbia, Canada

Dezinformiranje, čarobni mistični izleti in ekstremne avanture: jame in turistične informacije v Britanski Kolumbiji (Kanada)

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Sustainable surface karst recreation opportunities are almost absent in tourist information produced in BC. Preliminary research suggests that tourist information materials in British Columbia (BC), Canada, focus mainly on directing visitors into caves. BC's tourist information tends to characterize caves as either "magical" or "mystical" spaces or as venues for "extreme" adventures. Accurate promotional, marketing material and interpretive information for non-commercial caves as natural phenomena explainable by science are lacking.

While some of the errors and misinformation present in BC's tourism information on non-commercial caves make for amusing reading, there can be potentially serious repercussions for cave visitors and cave resources. Higher standards are needed to ensure visitor safety and sustainable recreation and tourism use of non-commercial caves. At a minimum, we suggest that tourist information about caves and karst in BC should: 1) be well-written and free of spelling, grammar and punctuation errors; 2) direct visitors to appropriate cave and surface karst attractions; and 3) provide visitors with accurate site information and interpretation. Tourist information about caves and karst in BC should also avoid encouraging visitor activities that 4) harm sensitive ecosystems and natural resources; and 5) potentially put visitors at risk.

Keywords: caves, tourism, marketing, information standards, British Columbia, Canada

Ključne besede: jame, turizem, trženje, standardi informiranja, Britanska Kolumbija, Kanada

Impact of anthropogenic CO_2 increase on speleothem deposition

Vpliv antropogenega povečanja CO_2 na odlaganje sige

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Due to breathing, visiting of caves results in increased cave air CO_2 concentration; CO_2 rise mostly depends on visitor number, duration of stay, dilution of exhaled CO_2 in passage (volume of cave passage) and processes related to CO_2 removal or "sink" (ventilation introducing outside air, cave air CO_2 uptake by CO_2-low waters). Since cave air CO_2 concentration plays one of the most important roles during calcite precipitation (speleothem deposition) due to its control on CO_2 outgassing from water, reduced rates of calcite precipitation, as well as reversal into dissolution, is one of the most serious concerns in show caves. A parallel phenomenon, where exhaled water vapour condenses on cave walls together with absorbed cave air CO_2 is recognized as human-enhanced condensation corrosion that contributes to dissolution of cave walls and deterioration of cave art.

There are two approaches to study the impact of exhaled CO_2 on calcite precipitation: a theoretical one using geochemical data (cave air CO_2 concentration, pCO_2 of (drip) water, Ca^{2+} hardness of water, saturation index regarding to calcite-SI_{Cal}) and direct observation of calcite precipitation rate during tourist visits. Both approaches were used in Postojna Cave while the theoretical approach was used in some other caves (e.g., Škocjan Caves, Križna Cave) where cave air CO_2 measurements were accompanied by carbonate geochemical characteristics of (drip) water. Case studies indicate that tourist visits indeed results in decreased calcite precipitation rates but it is still far from a reversal into dissolution due to generally high pCO_2 in (drip) water, SI_{Cal} close to 0 and related relatively hard (drip) waters as well as efficient ventilation due to chimney effect being one of the strongest during high season (summer time). Reversal into dissolution by (drip) waters can be

expected only in small extremely weak-ventilated passages with relatively low pCO_2 (drip) water during high visits.

Keywords: carbon dioxide, calcite precipitation, sinter dissolution, cave air, cave tourism

Ključne besede: ogljikov dioksid, odlaganje kalcita, raztapljanje sige, jamski zrak, jamski turizem

Use of Arduino in speleology – Phase 1

Uporaba Arduina v speleologiji – faza 1

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Modern research is often associated with a quantitative approach where portable handheld devices and/or monitoring stations are used to register background environmental parameters and their response to human impact. There is a huge branch of different companies that develop, manufacture and market instruments for environmental measurements, for deep and shallow(er) pockets, but with, more or less, end products that do not allow modifications.

Arduino is small uncommercial microcontroller attracted by a broad community (movement) sharing ideas unselfishly on the WWW. It is a cheap, open-source hardware with numerous digital and analog input/output (I/O) pins that are used to connect different cheap "Chinese" sensors (and actuators), display, clock, battery, SD card, and so on, with jumper wires. It uses IDE language that allows relatively simple programming using Windows (as well as Linux and MacOS) application. With only a shallow knowledge of electronics and programming it is possible to make simple data loggers for air and water temperature, relative humidity, air or water pressure, wind speed and direction, tilting, duration and intensity of illumination (e.g., in show caves), even water conductivity and pH meters, as well as cave air CO_2, etc. Precision, logging interval, battery life, memory capacity, signal transfer, and degree of protection against environmental factors solely depends on user/developer and final version of logger can be completely unique depending on special needs – a final limit is only a place where imagination ends. After use it can be reassembled into new instruments. In case of failure, individual parts can be replaced with new ones. One successful implementation of Arduino in speleology, where commercial instruments do not offer reliable instruments, to monitor water direction and velocity in water-flooded passage was achieved by The Cave Pearl Project (https://thecavepearlproject.org/). The latter project inspired and encouraged us that we, in 2017, started testing different Arduino Boards (UNO-Genuino, Pro Mini) and sensors (listed above) for speleological purposes. Our first experiences will be presented at the 26th IKS.

Keywords: Arduino, open-source hardware, data logger, cave, karst

Ključne besede: Arduino, odprtokodna strojna oprema, registrator, jama, kras

Depositional environment of Čerená travertines (Liptov Basin, Northern Slovakia)

Okolje odlaganja čerenskega travertina (regija Liptov, severna Slovaška)

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The detailed studies of the pre-Holocene Čerená travertine buildup (Liptov Basin, northern Slovakia) have been carried out to determine growth conditions, palaeoenvironment and the age of the travertine. The distinctive

structure of examined lithotypes and their isotopic composition indicate the modification of depositional environment during the growth of travertines. The conglomerates occurring in the base of Čerená mound imply the occurrence of the river valley deposits underlain travertines. Subsequently, the laminated travertine crusts were created on the bottom of the wide and gently inclined river valley. Simultaneously micritic travertines were deposited in the shallow ponds with stagnant water. The further phase of travertines growth included the development of the phytoclastic travertine with additional occurrence of calcareous muds, which include various clay minerals. Together with the quartz they constitute the significant non-carbonate admixtures, which is locally manifested by reduction of calcium carbonate content up to 76%. Deposition of travertines was controlled by migration of deep-circulating water along faults. The presence of ascending water containing geogenic CO_2 has been confirmed by $\delta^{13}C$ values of travertines in the range from 2.22‰ to 5.24‰. However, the depletion of the $\delta^{13}C$ in phytoclastic travertine and calcareous muds (up to 3.08‰ and 2.22‰, respectively), as well as the presence of the detrital impurities, suggest the dilution of deeply circulating water by fresh water, most probably by surface streams draining the Low Tatra Mts to the north.

Čerená travertines developed during the warm, interglacial period, which is pointed out by the presence of rich malacofauna assemblage and high contribution of calcified flora remains. Due to the contamination of the samples with detrital thorium the U/Th dating could provide only the approximate age of deposition.

Keywords: travertine, deep water circulation, meteogenic water, paleoenviroment

Ključne besede: lehnjak, globoko kroženje vode, meteorna voda, paleookolje

Biomineralization in cold caves

Biomineralizacija v mrzlih jamah

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This project aims to examine the extent of microbiological control in the formation of secondary minerals in "cold" cave environments. Such processes are well documented in temperate and tropical cave environments, but less studied in caves of the sub-arctic and arctic zone where freezing or near-freezing temperatures prevail during the year. In our case, where we have studied the formation of sulphate (gypsum, jarosite) and carbonate (moonmilk) minerals, our hypothesis is that the main process is bio-induced mineralization where H^+ is released to the environment in conjunction with redox reactions of sulphur species. The resulting release of acid can then cause karstification, and thus, provide a pathway for early speleogenesis (inception) that is independent of the ambient CO_2 supply. This is particularly important when considering subglacial speleogenesis during Pleistocene stadials, when basal glacial water was depleted in CO_2 and also largely saturated with respect to calcite.

To examine if biomineralization is in fact happening, samples of the sulfate mineral jarosite, as well as samples of calcite moonmilk, were collected from several caves in the Rana and Fauske areas, Northern Norway. The samples are examined using both classical microbiological methods, like culture enrichment and DNA sequencing, as well as different geochemical methods. Since this project is in its initial phase most of the work lies ahead. The plan is to examine the samples using scanning electron microscope (SEM), energy dispersive x-ray (EDX), x-ray diffraction (XRD) as well as isotopic analyses of chemical species. A supplementary field trip to the study area is also being planned for this summer, in order to collect in situ geochemical measurements and collect more material.

Keywords: biomineralization, cold caves, Norway, DNA sequencing, microbiology

Ključne besede: biomineralizacija, mrzle jame, Norveška, sekvenciranje DNA, mikrobiologija

Antibiotic resistant *Escherichia coli* strains in karst waters and on tourist footpaths in show caves in Slovenia

Antibiotično odporni sevi *Escherichia coli* v kraških vodah in na poteh po slovenskih turističnih jamah

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Microbial indicators are commonly used to monitor the status and pollution in the environment. A bacterium *Escherichia coli*, one of the primary intestinal commensal microorganisms in man and endothermic animals, is often regarded an indicator for faecal pollution. Some strains can be pathogenic for their hosts. A set of *E. coli* strains has been isolated from five karst rivers (Črni potok, Malenščica, Pivka, Rak, Unica) from SW Slovenia during monitoring of flood pulses in September, October and November 2017. Additional strains were isolated from swabbing the tourist footpaths in four tourist caves (Škocjan Caves, Predjama, Postojna Cave, and Županova Cave). Strains were identified using MALDI-TOF (Matrix-Assisted Laser Desorption/Ionization Time-Of-Flight) and according to EUCAST (European Committee on Antimicrobial Susceptibility Testing) tested for the presence of antibiotic resistance to ampicillin (AM), chloramphenicol (CL), ciprofloxacin (CI), nalidixic acid (NA), tetracycline (TC) and trimethoprim (TR). Maximum prevalence of antibiotic resistance (12.5%) was against AM, NA and TR in strains from karst waters. On the other hand, surface swabs of tourist footpaths had the lowest percentage of CI-resistant *E. coli* strains (2.6%). At the ponor of the Pivka River into Postojna Cave, a strain was isolated resistant to all tested antibiotics. Additionally, in river samples, a positive correlation has been observed between the dissolved oxygen concentration and *E. coli* counts, and a negative correlation between electric conductivity and *E. coli* concentrations. Results showed that karst underground harbours microbes carrying antibiotic resistance, which are directly related to human interventions. Additional studies are needed to follow the fate and role of antibiotic resistances in microbes, and the natural background of these genetic determinants in karst.

Keywords: karst, caves, water, *E. coli*, antibiotic resistance

Ključne besede: kras, jame, voda, *E. coli*, antibiotična odpornost

Monitoring of the cave environmental settings in Modrič show cave (Croatia)

Monitoring jamskega okolja v turistični jami Modrič (Hrvaška)

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Modrič Cave is the only Croatian show cave open for the adventure tourism, thus, without any man-made construction or other intervention. Small guided tourists groups (usually 2–20 people) equipped with caving gear spend usually one to two hours within the one of two channels, so major impact from the visitors is not expected. However, cave morphology also plays an important role in cave atmosphere settings. The cave is 829 m long and completely horizontal, with a relatively thin overburden (1–30 m). Nevertheless, it maintains a stable cave atmosphere in terms of air temperature and relative humidity (Rudzka et al., 2012; Surić et al., 2017). As for the cave air CO_2, measurements have started in 2017 in order to reveal natural temporal and spatial variations of cave air CO_2 concentrations. Recorded winter and summer pCO_2 values of the innermost part of the Right Channel vary significantly between 1400 ppm and 7600 ppm, respectively, while additional anthropogenic CO_2 influence recorded after the tourist groups is notable, but minor in comparison to the natural pCO_2 values.

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Keywords: CO_2 concentration, cave environment, show cave, Modrič Cave, Croatia

Ključne besede: koncentracija CO_2, jamsko okolje, turistična jama, jama Modrič, Hrvaška

Scientific research in Modrič Cave (Croatia) – an overview

Pregled znanstvenih raziskav v jami Modrič (Hrvaška)

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After the discovery in 1985, Modrič Cave (near Starigrad, Croatia) came into the focus of different scientific disciplines, with researches undertaken by several institutions and individuals. Upon the initial topographic (1985) and palaeontological studies (1987), thorough speleological and geological survey and partial geochemical and hydrogeological (1999) investigations were conducted. As the cave has been open for the adventure tourism since 2004, radon activity in the cave air was also monitored, along with cave microclimatic settings (2009–2011), and the basic karstological settings related to deposition and dissolution within the surface-to-cave system (2012–2013). For the purpose of palaeoclimate reconstruction, speleothem and cave water stable isotope analyses were conducted within several campaigns (2003–2011, 2008–2010, 2014–2018). The latter, as the most comprehensive one, aimed at the overall reconstruction of palaeonvironment and supported by monitoring of recent surface and cave air and water parameters is a part of the project Reconstruction of the Quaternary environment in Croatia using isotope methods - REQUENCRIM (HRZZ-IP-2013-11-1623) financed by the Croatian Science Foundation.

Keywords: cave environment, show cave, Modrič Cave, Croatia

Ključne besede: jamsko okolje, turistična jama, jama Modrič, Hrvaška

Nearly 10-years of air temperature monitoring in Postojnska Jama and Predjama (2009–2018)

Skoraj 10 let monitoringa temperature zraka v Postojnski jami in Predjami (2009-2018)

Stanka Šebela

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Karst Research Institute ZRC SAZU acts as expert cave guardian on the use of Postojnska Jama and Predjama Caves for tourist purposes since 2009. At both show caves, climatic and biological monitoring accompanying expert control visits are organized and annual reports are presented to the Ministry of the Environment and Spatial Planning of the Republic of Slovenia. In the period 2010–2017 at Velika Gora (Postojna 1) collapse chamber in Postojnska Jama, mean air temperature is 11.15 °C, at Lepe Jame (Postojna 2) 10.39 °C and in Koncertna Dvorana 10.93 °C. For the same period, mean outside air temperature is 9.73 °C. At Postojna 1 monitoring site, we registered an increase of air temperature for +0.66 °C (+6%) since 2010, at Lepe Jame (Postojna 2) an increase is for +0.58 °C (+5.7%) and in Koncertna Dvorana an increase represents +0.41 °C. Outside cave increase of air temperature for the period 2010–2017 is +1.61 °C (+19.18%). Velika Gora, Lepe Jame and Koncertna Dvorana are all impacted by an increase of visitor numbers for +36.48% since 2010. At Predjama, which receives much less visitors than Postojnska Jama, mean air temperature for the period 2010–2017 is 8.99 °C for Konjski Hlev site (near cave entrance) and 7.07 °C for Velika Dvorana chamber. Air temperature rise of +0.54 °C at Konjski Hlev site and +0.14 °C at Velika Dvorana is determined for the period 2010–2017. At Predjama, temperature rise at both sites can be attributed to natural climate conditions outside the cave that proceed into the cave. Heating of the air in Velika Dvorana can be a reference value for impact of natural conditions on the cave climate. In Postojnska Jama, due to strong increase of visitors since 2010, part of

the warming cannot be only due to natural conditions but must be attributed to anthropogenic impact (visitors, lights) on cave climate too.

Keywords: air temperature, Postojnska Jama, Predjama, Slovenia

Ključne besede: temperatura zraka, Postojnska jama, Predjama, Slovenija

Abundance of troglobites on surfaces with lampenflora in show caves: case study of Škocjan Caves, Slovenia

Številčnost podzemnih vrst v turistični jami na površinah obraslih z zeleno obrastjo (lampenfloro): primer iz Škocjanskih jam

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Škocjan Caves with accompanying karst features rank among the most important karst phenomena not only in Slovenia's Karst region, but worldwide with international importance; caves are recognized on the UNESCO list of world heritage sites and on the Ramsar list of wetlands. Altogether, 29 stygobiotic and troglobiotic organisms have been identified in Škocjan Caves so far. Epikarst fauna (i.e., Copepoda) is particularly abundant. In addition, two species with troglomorphic cave populations (*Alpioniscus strasseri*, *Androniscus stygius tschameri*) were found.

Sixteen monitoring sites (between 2-6 m^2) were established in passage used for tourism in 2015; 15 of them were covered with lampenflora, which was growing more than 20 years. Six sampling sites were no longer exposed to light during the monitoring period while the rest were still lighted. In 2014, lampenflora was partly removed from all monitoring surfaces, although some moss thalli and algal mat still remained. After initial detailed inspection of sampling sites, another check was performed after 3 weeks to observe changes. The purpose of the study was to identify the troglobites and relate their presence with the remains of lampenflora after partial removal.

Nine cave taxa were found on the sampling surfaces; three troglobites (*Titanethes dahli*, *Zospeum spelaeum*, Onichiuridae –Troglopedetes) and a troglomorphic cave population of *Androniscus stygius tschameri*. Maximum six taxa were found at one sampling site, three of them were troglobites. *A. s. tschameri* was present at 14 of total 16 sites and was also the most abundant species found during the study. Abundance of cave species in Škocjan caves on surfaces covered with lampenflora was significantly higher than on the surfaces not subjected to lampenflora colonization. In conclusion, proper conservation measures of troglobite and troglomorphic organisms should be included in a management plan along with proper restriction of lampenflora growth.

Keywords: Škocjan Caves, show cave, lampenflora, troglobionts

Ključne besede: Škocjanske jame, turistična jama, lampenflora, troglobionti

The cave database of SK Zlatovrv - an attempt for creating a cave registry of Macedonia

Register jam Jamarskega kluba Zlatovrv – poizkus vzpostavitve makedonskega registra jam

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After more than 90 years of history of speleological research in Macedonia, still no official cave registry exists. Cavers remain the only carriers of systematic cave exploration and documentation, but their results are generally not shared and are only rarely and partially published. There is one published list of explored caves in Macedonia from 1981, reporting 140 caves, with another publication from 2001 reporting 221 caves

being registered in the literature, but generally the unofficial number of explored caves, as reported in the literature and in the media, is considered to be approximately 500. The cave database of the Speleological club "Zlatovrv" from Prilep (SK Zlatovrv) is an unofficial, internal attempt of creating, as comprehensive as possible, database of caves in Macedonia, using previously published information, information from our own explorations, as well as unpublished information shared by other cavers/researchers. The current registered number of caves within the database is 427 (April 2018), with Slatinski Izvor (3942 m) being the longest, and Slovačka Jama (−650 m) the deepest explored cave. The published information in the literature usually lacks precise cave location data, so only 70% of the caves in our registry have entrance coordinates data, thus, producing a slight spatial bias in the cave distribution map, under representing certain areas (e.g., north-western or central parts of Macedonia). Information on cave dimensions (length/depth) is registered for 86% of the recorded caves, with cave maps obtained for 63% of them. Cave bedrock lithology is also included in the database, with most of the caves developed in Precambrian marble (37%) followed by Mesozoic limestone (33%) and Paleozoic marble (22%). Few caves, developed in travertine, carbonate breccia and gypsum can also be found. In addition, the same basic information will be presented on the most important caves in Macedonia.

Keywords: caves, registry, Macedonia, Zlatovrv

Ključne besede: jame, register jam, Makedonija, Zlatovrv

Brittle tectonics and endokarst geometry in marble caves: A case study from Aspfjordsgrotta, Fauske, North Norway.

Prelomna tektonika in endogena geometrija v jamah v marmorih – primer iz Aspfjordsgrotta (Fauske, North Norway)

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Solutional caves are usually formed when chemically aggressive, aquatic solutions are moving through the surrounding carbonate rock following low resistance paths like cracks and fissures. The formation of these discontinuities is most of the times closely connected to the tectonic activity. Depending on the stress type, the fissures are formed either parallel, perpendicular or oblique to the stress fields.

In this study, we aim to decipher to which extent the tectonic setting of an area controls cave architecture. We use Aspfjordsgrotta in Fauske, Northern Norway, as an analogue and we perform an extensive literature overview to reconstruct the regional stress field. Furthermore, we use a series of geographic information system (GIS) techniques on the 2D cave survey and the surrounding landscape in order to determine the cave architecture and the general fracture pattern of the area. This data set will be, in turn, combined with accurate 3D mapping of the cave void and geologic structures in the surrounding rock mass. The total data set will be used to work out a plausible model for tectonic history and hydraulic selection of individual structures during speleogenesis. This is a MSc. project where field observations will commence later this year, and preliminary results of our GIS analysis will be presented at the conference.

Keywords: speleogenesis, marble caves, tectonic history, hydraulic selection, glacial history, passive continental margin

Ključne besede: speleogeneza, jame v marmorjih, zgodovina tektonike, vodilne strukture, zgodovina poledenitve, pasiven kontinentalni rob

Tourists impact on air quality in Postojna Cave and Škocjan Caves (Slovenia)

Vpliv turizma na kvaliteto zraka v Postojnski jami in Škocjanskih jamah (Slovenija)

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Aerosols in cave are natural tracers and, together with parameters of cave climate, give a detailed view of conditions in the atmosphere, responses to climatic changes and impact of man. Aerosols are formed by air currents, animals, people and splashing water. Besides inanimate particles, cave airborne microbiota is also a quantitative measure of human impact in show caves. Air was sampled in 2017 along tourist footpaths in Postojna Cave and in Škocjan Caves before and during tourist visits. Tourist presence significantly increased the concentration of carbon dioxide. The highest concentration of airborne microbes was during the tourist peak season in August 2017, ranging from 6.2–7.0 × 10^4 /m^3 at all sampling sites, with the documented impact of tourist presence of 264 tourists in Postojna Cave, 154 tourists in Postojna Cave/Vivarium and 182 persons in Škocjan Caves during sampling campaigns. The concentration of airborne microbes impacted on nutrient agar plates was the highest in Postojna Cave/Vivarium; 425 CFU/m^3 cultivated at 37 °C and 829 CFU/m^3 at 20 °C. The concentration of beta-glucans, a typical compound of fungal cell walls, in the air did not follow this trend as it was the highest in the off-season in October/December 2017 when at all sites occasionally exceeded 3.3 ng/m^3. In the air, a mix of bacteria typically associated with humans and other natural habitats, including a large percentage of non-identified isolates, was found. Frequently encountered isolates belonged to the following genera: Acinetobacter, Aerococcus, Arthrobacter, Bacillus, Cryptococcus, Micrococcus, Pseudomonas, Rahnella and Staphylococcus. SEM analysis of impacted airborne particles pointed out the presence of various organic (different microbiological features, textile particles, etc.) and inorganic particles. During tourist visits, the quantity of airborne particles was clearly elevated. Tourist presence is reflected further in higher quantity of larger aerosol particles and particles of organic origin. Results showed a significant impact of tourists on the quantity and quality of airborne particles, and this is also an additional significant factor that contributes to the dynamics of atmospheric conditions in tourist caves.

Keywords: tourist caves, airborne particles, aerobiology, tourist impact

Ključne besede: turistične jame, delci v zraku, aerobiologija, vpliv turizma

Evaluation of the speleological geoheritage of Serbia – Case study of the show cave Petnička Pećina (Petnica Cave)

Vrednotenje jamske geodediščine Srbije – primer turistične Petničke jame

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The inventory of Serbian Geoheritage Sites in this moment includes 26 caves, but not all Serbian show caves are among them.

Petnica Cave, the most famous cave of Valjevo karst area, is one of the ten speleological natural monuments in Western Serbia that have been declared as elements of the geoheritage. It is an example of a cave with diverse values. Partly arranged for touristic visits, which have never been officially recorded, the Petnica Cave was, since its official opening in the year 1988, unfortunately devastated in terms of tourist infrastructure.

The need to develop the clear criteria for the evaluation of geoheritage objects has been emphasized since the very beginning of work on the inventory of the geoheritage of Serbia. However, to date, there are few examples of evaluation or assessment of geoheritage objects in Serbia, especially caves, in scientific literature. This paper briefly analyzes examples of methodologies used for evaluation of caves in some other countries, for the purposes of assessing scientific values, protection, potentials for recreation and tourism, and the impact of visitors on caves and their surroundings. The intention is to assess the applicability and relevance of these methodologies for the caves in Serbia. The aim of the paper is to suggest an initial model for evaluating caves in Serbia on the example of the Petnica Cave.

One of the basic challenges is to define and quantify indicators of values. This is essential for decision making regarding nature protection, planning and management. Serbia has a tendency of increasing the number of protected natural assets. With the open issues related to nature protection and the ecosystem services approach, there are new fields of concern for scientists and speleologists. The tourist caves in Serbia are certainly one of those fields that have to be thoroughly revised.

Keywords: speleological geoheritage of Serbia, evaluation methods, Petnica Cave

Ključne besede: jamska geodediščina Srbije, metodologija evaluacije, Petnička jama

Start of project implementation "Center of excellence - Cerovačke caves; sustainable management of natural heritage and karst underground"

Začetek implementacije projekta »Center odličnosti – Cerovačke jame; trajnostno upravljanje naravne dediščine in kraškega podzemlja«

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The project "Center of excellence - Cerovačke caves; sustainable management of natural heritage and karst underground" (MIS code: KK.06.1.2.01.0011) was submitted for Competitiveness and Cohesion operational programme 2014–2020 (Theme 62C) and successfully passed the evaluation procedure. The main goal of the project is to improve sustainable use of natural heritage, primarily in Nature park Velebit with focus on Cerovačke caves (Upper and Lower Cerovačke caves). The main problems that were identified through the project preparation were that these show caves are located in the undeveloped Lika region, near the town of Gračac, which has poor tourist infrastructure in general, and that the lack of proper long-term development plan for show caves and complementary activities resulted in poor management of the caves and, in the end, a degradation of cave inventory and its surrounding landscape. The caves had inadequate approach trails, obsolete lighting system, poorly planned tourist trails, and generally were not sufficiently explored (archaeology, biology, geomorphology etc.). The core activities of the project involve development of a new "state of the art" regional scientific/educational center and revitalization of show-caves Cerovačke caves. To be able to revitalize Cerovačke caves and secure long-term sustainability, various activities were planned to enrich the tourist offerings of the region. Aside from the show caves and educational and hiking trails around the caves, a big part of the planned activities focuses on education programmes and scientific explorations (schools in nature, trainings for cavers, various workshops and courses, on-site laboratory etc.) and creation of a strong network of potential users from many communities - public, caving, scientific, as well as public or private institutions that can use these facilities and programmes. For this to be possible in the project activities, the whole caving community of Croatia and its regions will be involved, as well as numerous experts and scientists, because the project needs to be identified by this community as their own so its activities continue after the formal end of the project implementation. To achieve sustainable use of the caves and the surrounding area, modern solutions in IT visitor management will be implemented, monitoring of tourist impact will be done and the newest technical solutions for show cave inventory will be

used. The start of project implementation is planned for April 2018 and the duration of the project is 3.5 years.

Keywords: Cerovačke caves, Lika region, show-caves, sustainable use, education programmes, scientific explorations, tourism

Ključne besede: Cerovačke jame, Lika, turistične jame, trajnostna raba, izobraževalni programi, znanstvene raziskave, turizem

Photogrammetric mapping of complicated cave rooms: structural, morphological and speleogenetic information

Fotogrametrično kartiranje zapletenih jamskih prostorov: strukturne, morfološke in speleogenetske informacije

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Accurate mapping of cave voids is an essential pre-requisite for any further scientific study of the cave or its contents. Cave mapping techniques have evolved trenmendously over the last two decades, from traditional tape-and-compass polygon surveys, via laser distance meters and portable total stations (DistoX) to complete Lidar-type point-cloud scanning. Simplified, hand-held scanners are also available, but all this equipment is quite costly. A point-cloud survey almost always needs to be supplied with photographic documentation. Another and much more economic approach is photogrammetry, which can generate 3D point clouds as well as high resolution photographs. In connection with archaeological and palaeoclimatic studies of caves in the deHoop Natural Reserve, South Africa, we have applied this technique to mixed quartzite/calcarenite sea caves along the coastline. This is a part of the SapienCE CoE project on early human behavior.

During the course of three days in February 2018, digital photogrammetry was used to map Bloukrans Cave and its immediate surroundings. Digital photogrammetry is a method of visual and spatial recording, which utilizes overlapping still images to generate high-resolution 3D surface models of features and objects. The mapping of Bloukrans Cave was preformed using a conventional DSLR camera (Nikon D4) with an attached flash, scaled and oriented using a standard spirit level and processed on a laptop using a photogrammetric software solution. The entire recording process was performed by a single individual, capturing over 2000 images in a systematic order. The preliminary results show that a minimum of equipment and a simple but flexible recording strategy can be used to capture a complex and hard to access cave system during a short span of time. A scaled photorealistic 3D model of the cave interior, floorplan and profile view were created using the collected data. These datasets provide unique and intuitive structural, morphological and speleogenetic information.

Keywords: cave, mapping, technology, photogrammetry, morphological analysis

Ključne besede: jama, kartiranje, tehnologija, fotogrametrija, morfološka analiza

The Chauvet Pont d'Arc Cave Replica: a technical, scientific and territorial challenge for a new way to enhance underground heritages

Replika jame Chauvet Pont d'Arc: tehničen, znanstveni in prostorski izziv za nov način varovanja podzemne dediščine

Christophe Vigne
SMERGC (Chauvet Pont d'Arc Cave Replica Mixed Union)

The Chauvet Pont d'Arc Cave is among the major "sanctuaries" of Palaeolithic art, perfectly protected from the outside world by the collapse of the cliff above the entry 21,000 years ago. Since its discovery in 1994, the cave is just accessible to a few technicians and scientist. The public do not have access in order to preserve paintings. Then, French local authorities, supported by the European Union, decided to create a replica of the cave with two main objectives:

- To share a World Heritage site with people (Chauvet Pont d'Arc cave has been nominated a World Heritage site in 2014);
- To enhance both the cultural and economic development of Ardèche.

To design, build-up the replica and reproduce such an amazing heritage, we needed to gather scientists, digital engineers and artists. We had to invent new methods and train engineers in order to help them to reproduce precisely a word famous place.

However, Chauvet Pont d'Arc Replica "Caverne du Pont d'Arc" is not only a cultural and touristic site. It is also the driving force of a global project to develop the territorial activity by the promotion of its natural and cultural heritages.

Since April 2015, more than 1.5 million people have visited the Chauvet Pont d'Arc Cave Replica. They were made aware to such a sensitive and hidden Palaeolithic sanctuary located 3 km away from the Caverne du Pont d'Arc.

Keywords: palaeolithic art, cave paintings, cave replica, Chauvet Pont d'Arc Cave, Ardèche

Ključne besede: paleolitska umetnost, jamske slikarije, replika jame, Chauvet Pont d'Arc Cave, Ardeche

An attempt to reconstruct paleohydrological changes on the basis of speleothem studies in a show-cave (Szemlő-hegy Cave, Buda Thermal Karst, Hungary)

Poizkus rekonstrukcije paleohidroloških sprememb na osnovi raziskav sige v turistični jami Szemlő-hegy (termalni kras Buda, Madžarska)

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Hypogenic caves of the Buda Thermal Karst developed in Pleistocene times as a result of interaction of the host Eocene limestones with thermal waters rising along pre-existent fractures and discharging at the local base level of erosion. Because of subsequent tectonically controlled uplift, most caves are now dry and far above the

actual base-level. There has been a general consent among speleologists, that the passage from the hypogenic (phreatic) to the epigenic (vadose) zone must have left its imprints on the speleothem assemblage of the caves. The Szemlő-hegy Cave, open for the public since 1986, offered the best opportunity for a study to prove or disprove the above hypothesis. Freshly-cut rock surfaces generated by underground constructions revealed the inner structure of speleothems, thus facilitating problem-oriented sampling. Also long-ago available detailed maps served as a reliable basis for 3D plotting and evaluating our results.

Exact positions (including altitude) of the collected speleothems were measured by classical geodetics, and plotted on the above mentioned maps. Samples were studied petrographically and classified using Frisia's terminology. Five major groups (mammillary crusts, cave rafts, cave-coralloids/popcorns, dripstones) were identified and their paragenetic order recorded at each sampling point. Following Frisia's classification scheme, mammillary crusts were considered as phreatic precipitates, cave-rafts as water-table indicators, whereas cave-coralloids/popcorns and dripstones as vadose zone features.

Mineralogical (XRD, SEM) and geochemical analyses (major and trace elements and stable C, O and S isotopes) were also undertaken. Minerals like (Mg, Sr and Ba-rich) aragonite needle/frostwork, gypsum crust, and associated small crystals of barite, dolomite, other high-Mg-carbonates, celestite and sepiolite were identified. Age-datings of calcite speleothems representing petrographically established stages of the paragenesis were carried out by the U/Th series method.

Results: The oldest cave-rafts precipitated more than 500 ka suggesting that, already at that time, as a result of the uplift, in the formerly water-filled cave already a water-table became established (i.e., the cave has reached the vadose zone). The age-spread (360 to 77 kyrs) of phreatic speleothems showed that smaller or larger thermal water pools have still existed in the cave for a long time after the establishment of that first water-table. Paleo-temperature of these thermal water pools was calculated on the basis of $\delta^{18}O$ data measured on carbonates from mammillary crusts and cave rafts. They show a general cooling trend (from 58°C to 25°C), though with some anomalies. Also the paragenetic order of the identified speleothems is anomalous. To the contrary of what was expected, they do not follow the simple phreatic-vadose transition, which would have been: mammillary calcite → cave rafts → cave-coralloids → popcorns and dripstones. Mammillary crust → cave raft or mammillary crust → cave-coralloid successions are at places followed by mammillary calcite again suggesting that the phreatic → vadose transition was followed by another phreatic event, implying water-table fluctuations superimposed on the monotonous uplift of the cave. Age-dating of these "anomalous" paragenesis showed that at least one of the observed fluctuations of the paleowater-table must have taken place ca. 280 ka.

Keywords: thermal-water, speleothems, Szemlő-hegy Cave, Buda Thermal Karst

Ključne besede: termalna voda, siga, jama Szemlő-hegy, termalni kras Buda

Fractal dimension of the longest cave of Dinaric Karst

Fraktalna dimenzija najdaljše jame dinarskega krasa

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Fractal analysis addresses an important problem in the study of nature. Natural phenomena are complex, and their understanding requires many years of scientific research. There are no methods that can be described quantitatively in a faster way. Determining the fractal dimension is one of the prospective techniques if appropriate a way to connect with geological, hydrological and physical processes in nature. Dimensions in the case of regular geometric figures, such as lines, squares and cubes integer: 1, 2, 3. However, in nature there are structures (fractals) that do not have the whole spatial dimension. The technique presented in this work is aimed at the determination the fractal dimension and analysis of the longest cave of Dinaric Karst (length is 32

km). For the Cave system Kita Gaćešina (Velebit Mt., Croatia) fractal dimension up to 2.4 was determined, which confirms that the network of cave channels has a fractal structure. This is a significant result that requires further interpretation in framework of geological studies.

Keywords: fractal analysis, caves, Dinaric Karst

Ključne besede: fraktalna analiza, jame, dinarski kras

History of exploration and perspectives of new discoveries in the Bobačka Cave (Muránska plateau, Slovakia)

Zgodovina odkrivanja in perspektiva novih odkritij v jami Bobačka (Muránska planota, Slovaška)

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The Bobačka Cave represents the most important endokarst phenomenon within the Muránska plateau and one of the most important caves within Slovakia. The length of surveyed cave spaces reaches 4.7 km and the cave still continues (Vlček et al. 2017). The cave was created at least in two speleogenetical phases, both of them suppose an attendance of several allochtonous water streams. The horizontal main corridor from the entrance to the terminal sump is a wonderful experience for all visiting cavers – spaces are great, well-decorated and half of the cave has an active water stream at its base. The few sumps can be easily bypassed by higher developed corridors, which are richly decorated.

The entrance of cave is situated near the resurgence and it was known from time immemorial (Kámen 1955; Vlček 2011). The cave ended after 120 m in a sump. In 1973, speleodivers dived to the opposite side and climbed a chimney to the cave's continuation in length of 1250 m (Sasvári 1976). Further exploration and discoveries followed between 1985 and 1989, in 2001 and 2016–2018. Many of the chimneys are still untouched by climbers and some cave corridors have not yet been surveyed. We suppose the continuation of the cave deeper inside the massif, where the water streams and air draught directions lead the cavers to. There are geological and hydrological indices of possibility for discovering one of the longest cave systems of Slovakia.

In 1970's, cavers were thinking about opening the cave to the public (Hlaváč 1994). It could be the essential step towards starting the tourism in relatively weekly developed region of Slovakia. Because the water from the cave is still used as a source of drinking water for adjacent settlements, this idea is still a future venture.

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Keywords: Bobačka Cave, Muránska plateau, cave exploration, regional karst hydrology

Ključne besede: jama Bobačka, Muránska planota, raziskovanje jam, regionalna kraška hidrologija

Results of Veternica Cave monitoring as a basis for sustainable visitor management, Zagreb, Croatia

Rezultati monitoringa v jami Veternica kot osnova trajnostnega upravljanja obiska, Zagreb, Hrvaška

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Veternica Cave, within the protected area of Medvednica Nature Park and Natura 2000 Ecological Network (POVS HR2000583 Medvednica), represents an underground object with special geomorphological and biospeleological values. It has been protected as a geomorphological monument of nature since 1979 and has long been considered as a valuable tourist destination near to the city center of Zagreb. "Medvednica Nature Park" Public Institution has been actively managing Veternica Cave since the year 2000. The number of Veternica Cave visitors is monitored through the number of tickets sold during the visiting season. Biodiversity monitoring and population density of cave invertebrates, hibernating and maternal bat colonies monitoring, as well as monitoring of habitat conditions in Veternica Cave have been ongoing since 2005, while continuous monitoring of green fodder (lampenflora) and protozoan population (Protozoa) have been continuously carried out since 2012. Microclimatic measurements carried out are: the temperature of substrate, air and water; relative air humidity, air flow, and CO_2 share; organoleptic and physico-chemical and biological analysis of water at 30 parameters. The troglobiont taxa of invertebrates and the population of the protozoa, as well as the specially studied bat fauna, indicate a satisfactory stable condition of species diversity and individuals number. The cave monitoring results are the basis for determining guidelines for sustainable use and management of cave visitors. It has been established that Veternica Cave has not yet been endangered by the tourist function although there is a tendency of tourist number increase in the Park as well as in the Veternica Cave. Established monitoring of cave habitat and its biological components is shown as an example of good practice for other caves with tourist function for the purpose of sustainable management.

Keywords: Medvednica Nature Park, Veternica Cave, tourism, monitoring, bats, troglobionts, visitors, sustainable management

Ključne besede: Naravni park Medvednica, jama Veternica, turizem, monitoring, netopirji, troglobionti, obiskovalci, trajnostno upravljanje

Interpretation of karst science – Postojnska Jama EXPO

Interpretacija znanosti o krasu – EXPO Postojnska jama

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The monitoring of impacts of tourist visits in show caves is important and needed. Sustainable management in show caves with large visitor numbers is a big challenge. But the basis for understanding and protecting caves and karst is still their scientific research. The scientific study of karst phenomena including the surface, caves, waters, biology and ecology has been the aim of the Karst Research Institute ZRC SAZU in Postojna since 1947. With the aim of spreading the knowledge of scientific research and of protecting and raising awareness of the importance of landscapes, caves, water and biodiversity in the karst areas, the Institute carries out numerous activities. The education of various target groups, from the youngest children in schools to the adult population, life planners, legislators, and potential visitors, is especially important due to the exceptional geological, geomorphological and archaeological content of the caves, their vulnerability, specific environment and habitats. Karst science can be interpreted for a public through publications, lectures, excursions, workshops, exhibitions, educational trails, projects, etc.

One of the best examples of the Institute's involvement in the scientific presentation of the development of a natural cave as a tourism product was the design and preparation of content for the interpretative exhibition at show cave Postojnska Jama. In 2012, the new concessionaire Postojnska Jama, d.d. decided to invest in interpretation of the Postojnska Jama story. Prior to that, Postojnska Jama was a historically well-known show cave with numerous and famous visitors from all over the world, but any permanent exhibition or interpretation on the cave was lacking. A leading idea was to present cave regarding natural and tourist development and its significance in space and time with the use of innovative technologies and interpretation. A big challenge was how to provide enough information for the average visitor, without over-simplifying or overloading; to avoid this problem, a multi-level exhibition was set up. The exhibition was opened in 2015 under the marketing name "EXPO Postojna Cave Karst". In 2017, the exhibition got the award for the most creative and exciting achievements in Slovenian tourism "Sejalec 2017" from the Slovenian Tourist Board.

Keywords: karst phenomena, scientific research, show cave, exhibition, tourism, Slovenia

Ključne besede: kraški pojavi, znanstveno raziskovanje, turistična jama, razstava, turizem, Slovenija

Have you thought about publishing your presentation?

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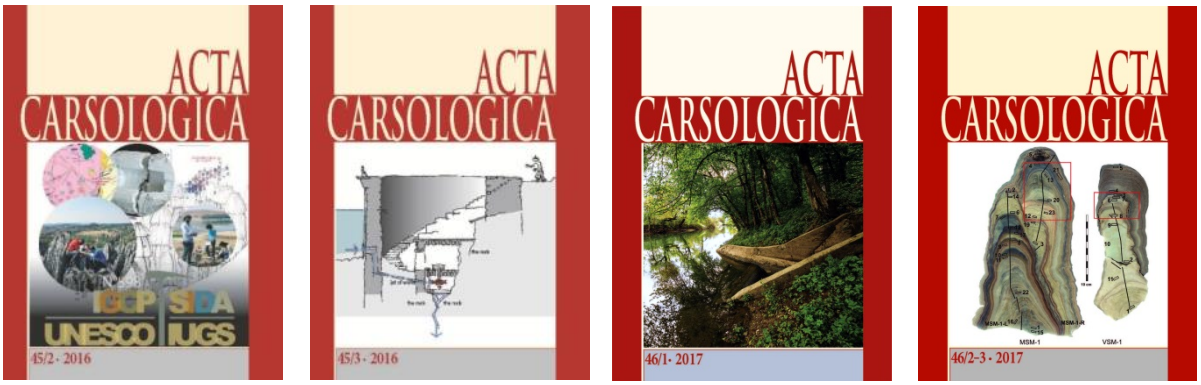
Acta Carsologica publishes original research papers and reviews, letters, essays and reports covering topics related to specific of karst areas. These comprise, but are not limited to karst geology, hydrology and geomorphology, speleology, hydrogeology, biospeleology and history of karst science.



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The Karstology doctoral study programme is a world-wide unique programme which provides a comprehensive study of karst science, combining the study of the karst landscape, karst caves, karst hydrogeology, biology and ecology of karst in one course of study. It was designed for students who wish to gain deeper insight of this broadly integrated system of karst sciences. The fundamental objective of the programme is to produce two types of karstologists. The first is the karstologist-researcher who can conduct independent research on karst and karst phenomena from multiple aspects.The second type is the karstologist- manager who can apply the full knowledge of karst conveyed by narrowly specialized experts for different applications (economy, education, protection).

The programme was developed with researchers of the Karst Research Institute at Research Centre of the Slovene Academy of Sciences and Arts (ZRC SAZU) and is carried out by professors and researchers from Karst Research Institute and invited foreign professors, and is coordinated and managed by the University of Nova Gorica. Lectures and research take place in the premises of the Karst Research Institute in Postojna where students are provided all necessary professional and scientific support for their own research work. Successful functioning of doctoral study programme Karstology resulted in naming it in 2014 as the **UNESCO Chair on Karst Education**.

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