



31st INTERNATIONAL KARSTOLOGICAL SCHOOL
“Classical Karst”

31. MEDNARODNA KRASOSLOVNA ŠOLA “KLASIČNI KRAS”

DATA ACQUISITION and ANALYSIS in KARST SYSTEMS

PRIDOBIVANJE in ANALIZA PODATKOV v KRAŠKIH SISTEMIH



ABSTRACTS & GUIDE BOOK
POVZETKI & VODNIK

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Postojna
2024

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Blaž Kogovšek, Astrid Švara, Franci Gabrovšek, Nadja Zupan Hajna

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GENERAL INFORMATION

SPLOŠNE INFORMACIJE

PROGRAM

Monday, June 17 th , 2024 Ponedeljek, 17. junij 2024		Cultural Centre Postojna Kulturni dom Postojna
08:00–13:00	REGISTRATION / PRIJAVA UDELEŽENCEV	
09:00–09:15	OPENING CEREMONY / OTVORITVENA SLOVESNOST	
	SESSION 1 SKLOP 1	
09:15–09:45	<i>Keynote lecture / Plenarno predavanje</i> I. D. Sasowsky: The diversity of karst geo-data and challenges for acquisition, management, analysis, and storage	
09:45–10:00	N. Zupan Hajna et al.: From pilot samples to high-resolution approach (to methodology of paleomagnetic sampling of karst sediments)	
10:00–10:15	N. Lončar et al.: Monitoring of water-level fluctuations in a coastal cave: methods and implications for POS based sea-level reconstructions	
10:15–10:30	D. Brunović et al.: Imaging the submerged karst landscapes in the eastern Adriatic Sea using acoustic methods	
10:30–11:00	<i>Coffee break / Odmor za kavo</i>	
	SESSION 2 SKLOP 2	
11:00–11:30	<i>Keynote lecture / Plenarno predavanje</i> M. Ćuk Đurović: Qualitative and quantitative approach for understanding karst hydrodynamics in artificial and natural conditions	
11:30–11:45	L. Durand et al.: Characterization of the hydrogeological role of weathered rock in karst aquifer using a multidisciplinary and multiscale approach	
11:45–12:00	L. Keim & H. Class: Integrative analysis of long-term CO ₂ measurements and weather patterns in the Swabian Jura: Insights into karst processes and potential speleogenesis	
12:00–12:15	A. Švara et al.: Post-Miocene tectonically induced hydrological changes revealed by cave sediments (Loza Cave System, W Slovenia)	
12:15–14:00	<i>Lunch break / Odmor za kosilo</i>	
	SESSION 3 SKLOP 3	
14:00–14:30	<i>Keynote lecture / Plenarno predavanje</i> M. D. Covington: Leveraging open data and open source software to study karst processes	
14:30–14:45	I.-K. Giannopoulos et al.: First approach on the multiparametric study for the development and evolution of a karstic environment: The case of Petroto karstic system (Northern Greece)	
14:45–15:00	D. Paar et al.: Challenges of non-periodic behaviour in cave climate and other karst processes due to climate change	
15:00–15:15	F. Šarc et al.: Dedolomitization in the cave environment – link to speleogenesis and geomorphological development of the carbonate-siliciclastic area in Central Slovenia	
15:15–15:30	V. Mai Yung Sen et al.: Late Miocene to Quaternary relief evolution, cave networks development, and tectonic/climatic forcing in the Western French Alps	
15:30–15:45	<i>Break / Odmor</i>	
	SESSION 4 SKLOP 4	
15:45–16:15	<i>Keynote lecture / Plenarno predavanje</i> R. Mihevc: Building a doline map with applied machine learning	
16:15–16:30	C. Baral et al.: GIS in 3D: A tool for karst reservoir studies - Example of Larzac Causse, southern France	

16:30–16:45	C. Denizman: Spatial Data Acquisition and Analysis in Karst by GIS: Examples from Florida and Turkey	KRI IZRK
16:45–17:00	N. Bočić et al.: Making a geomorphological map in karst area based on high resolution DEM - experiences from the Plitvice Lakes National Park (Croatia)	
17:00–17:15	M. Torab & N. Fayad: LiDAR Scanning's 3D mapping of Abu Sariye Alabaster Cave, Assiut Governorate, the Eastern Desert of Egypt	
17:15–17:30	<i>Break to move / Odmor za premik</i>	
	POSTER SESSION POSTERJI	
17:30–19:00	Quick poster presentations / Hitra predstavitev posterjev	
19:00–21:00	Poster display / Ogled posterjev	
19:00–21:00	ICE BREAKER and KARST JAM UVODNO DRUŽENJE in KRAŠKE DEBATKE	

Tuesday, June 18th, 2024 Torek, 18. junij 2024		
08:30–11:00	REGISTRATION / PRIJAVA UDELEŽENCEV	Cultural Centre Postojna Kulturni dom Postojna
	SESSION 5 SKLOP 5	
09:00–09:30	<i>Keynote lecture / Plenarno predavanje</i> M. Perne et al.: Data acquisition for analysis through modelling	
09:30–09:45	P. Bosák & P. Bella: Sulfuric Acid Speleogenesis in the Plavecký Karst, Slovakia (model developed during data acquisition)	
09:45–10:00	A. Stachnik et al.: Patterns of precipitation $\delta^{18}\text{O}$ through the Iberian Peninsula: Machine Learning dynamic modeling for climate proxy calibration	
10:00–10:15	M. Temovski et al.: Neogene-Quaternary karst and landscape evolution in Crna Reka basin constrained by geochronological data from caves based on U-Th and cosmogenic nuclide burial age dating	
10:15–10:45	<i>Coffee break / Odmor za kavo</i>	
	SESSION 6 SKLOP 6	
10:45–11:15	<i>Keynote lecture / Plenarno predavanje</i> S. Jaillet: 3D analysis and geomorphology of Upper Palaeolithic decorated caves (Grotte Chauvet, Grotte aux Points, Grotte des Deux Ouvertures, Ardèche, France)	
11:15–11:30	P. Herich & M. Budaj: On Sustainable Cave Mapping	
11:30–11:45	G. Cazes et al.: Achieving full scale high resolution 3D cave mapping using action cameras and photogrammetry	
11:45–12:00	J. Littva et al.: A comparison of the structural data acquired in the Okno Cave (Slovakia) from field research versus the laser scanner 3D models – a case study	
12:00–12:15	J. Obu et al.: Quantification of hourly particle movements on sorted circles in a karst cave in Slovenia	
12:15–14:00	<i>Lunch break / Odmor za kosilo</i>	
14:00–14:15	S.-E. Lauritzen: Analytic methods in structural speleology and deducing the “unit cell” of stripe karst caves	
14:15–14:30	F. Morelli & T. Piacentini: New approaches to identifying and classifying karst landforms in the Central Apennines (Abruzzi, Central Italy)	
14:30–14:45	<i>Break / Odmor</i>	
14:45–15:00	B. Rožič et al.: Provenience of limestones used for Stečki Tombstones in the Dinaric Karst, Bosnia and Herzegovina	
15:00–15:15	A. Entrena et al.: Phreatic overgrowths on speleothems (POS) from coastal caves: classification and characterization	
15:15–15:30	K. Karbowski et al.: The Pleistocene remains horses (genus Equus) from Slovenian Karst - the preliminary results	

17:00–19:30	Afternoon field trip (A) / Popoldansko terensko delo (A) Acquisition and processing of cave air physical parameters in Postonjska jama. <i>Walk (several km).</i> Zajem in obdelava fizikalnih parametrov jamskega zraka v Postonjski jami. <i>Hoja (nekaj km).</i>	
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Wednesday, June 19 th , 2024 Sreda, 19. junij 2024		
08:30–09:30	REGISTRATION / PRIJAVA UDELEŽENCEV	Cultural Centre Postojna Kulturni dom Postojna
	SESSION 7 SKLOP 7	
09:00–09:30	<i>Keynote lecture / Plenarno predavanje</i> T. Olarinoe : Building FAIR data for karst hydrology and applications to foster research advances	
09:30–09:45	L. Soto et al. : Cave and Karst Data Management at the USDA Forest Service, USA	
09:45–10:00	B. Miklavič et al. : Contrasting occurrence of karst in Alpine and tropical environments and challenges of their analysis	
10:00–10:15	A. Piquerez & J. Thierrin : Investigations volatile organic compound contamination in a Swiss karst system used for drinking water supply	
10:15–10:45	<i>Coffee break / Odmor za kavo</i>	
	SESSION 8 SKLOP 8	
10:45–11:15	<i>Keynote lecture / Plenarno predavanje</i> L. E. P. Travassos et al. : Microclimatic characterization of tourist caves in Cavernas do Peruacu National Park, Minas Gerais, Brazil	
11:15–11:30	W. Chen et al. : Occurrence of Organochlorine Pesticides (OCPs) in Multimedia Environment from Zigui Karst Area, China	
11:30–11:45	M. Kazmer et al. : Karst evolution in Borneo, Malaysia	
11:45–12:00	D. Cailhol & B. Gely : The Ebbou cave in Ardèche, France, an archaeological site confronted with karst evolution	
12:00–12:15	D. Szieberth et al. : Anthropogenic effects in the thermal springs of the Transdanubian Mountains	
12:15–14:30	<i>Lunch break / Odmor za kosilo</i>	
15:00–19:00	Afternoon field trip (B) / Popoldansko terensko delo (B) Groundwater flow in the Ljubljana recharge area. <i>Bus drive and walk (several km).</i> Tok podzemne vode v porečju kraške Ljubljane. <i>Vožnja z avtobusom ter hoja (nekaj km).</i>	

Thursday, June 20 th , 2024 Četrtek, 20. junij 2024		
08:30–18:00	Whole-day field trip (C) / Celodnevno terensko delo (C) Radensko polje. <i>Bus drive and walk (several km).</i> Radensko polje. <i>Vožnja z avtobusom ter hoja (nekaj km).</i>	KRI IZRK
18:00–19:30	<i>Break / Odmor</i>	
19:30–	Reception at the Karst Research Institute Sprejem na Inštitutu za raziskovanje krasa	

Friday, June 21 st , 2024 Petek, 21. junij 2024		
9:00–16:00	Whole-day field trip (D) / Celodnevno terensko delo (D) Reka-Timava flow system. <i>Bus drive and walk (several km).</i> Sistem Reka-Timava in njen tok vode. <i>Vožnja z avtobusom ter hoja (nekaj km).</i>	

LIST OF POSTER PRESENTATIONS

The following list presents the order of the 2-min long flash presentations. Authors are kindly invited to prepare 1–2 slides to attract attention to the content of the poster. Flash presentation and poster showing will both take place at Karst Research Institute ZRC SAZU.

Na spodnjem seznamu je abecedni red 2-minutnih kratkih predstavitev. Avtorje vljudo vabimo, da pripravijo 1–2 prosojnici, da pritegnejo pozornost na vsebino plakata. Kratke predstavitve in predstavitev plakatov bodo potekali na Inštitutu za raziskovanje krasa ZRC SAZU.

1 st AUTHOR		TITLE
1	Bajo Petra	Seasonality in cave air and drip water properties – implications for speleothem palaeoclimate studies, Nova Grgosova cave (Croatia)
2	Bajraktari Fadil	Necessity of establishing geoinformation for speleological heritage objects in Kosovo
3	Bania Dominika	Morphostructural and geomorphometric properties of the Rovte karst (Central Slovenia)
4	Błaszczak Marcin	Paleoclimatic implications of The Tatra Mountains in Central Europe during MIS 11-6 based on multi-proxy speleothem records
5	Calabrò Laura	POS-based MIS 5e Relative Sea Level for Mallorca and Sardinia
6	Class Holger	Convective Mixing of CO ₂ in Fractures: Small Scale Investigation and Large Scale Implications?
7	Čeligoj Biščak Jasmina	Library of the Karst Research Institute ZRC SAZU
8	Čonč Špela	Modelling the relationship between micro-relief characteristics and the occurrence of cave entrances: the example of the Slovenian Dinaric Karst
9	Čremožnik Zupančič Jerneja	Occurrence of antimicrobial resistant and pathogenic <i>Escherichia coli</i> from the water of two karst springs in Slovenia
10	Džaferagić Ahmed	Cave diving researches of karst springs in the Una river cathment (Bosnia and Herzegovina)
11	Gebus-Czupyt Beata	Sulfur and oxygen isotopes in waters and cave gypsum of the Rovte karst area (central Slovenia)
12	Johnston Vanessa E.	Basic hydrogeochemical methods in karst research
13	Kaminsky Eva	Monitoring of water infiltration into an Alpine karst system during snowmelt events
14	Knez Martin	Karren of Gréolières
15	Kropczyk Aleksandra	Remains of Canidae (Fischer de Waldheim) from the Niedźwiedzia Cave
16	Kure Karin	Morphogenesis of the Čepovan dry canyon

17	Kurečić Tomislav	Building up a depositional model of clastic sediments in the enclosed cave system as a proxy for landscape evolution (Grgos Caves, Croatia)
18	Lončarić Robert	Challenges and obstacles during cave monitoring programs in Modrič Cave (Croatia)
19	Matoušková Šarka	U-series dating of speleothems using ICP-MS – case studies
20	Miklavc Primož	Small, sparsely preserved outcrops of unroofed cave sediments: are they worth investigating?
21	Molero-Monsonis Andrea	Response of dripwaters to Mediterranean climate in Don Juan Cave (E Spain)
22	Mulec Janez	Microbiological exploration of underground environments, ethical and legal dilemmas with implications for extraterrestrial research in role of education
23	Nagl Michael	Quantification of near-surface cave drip-water by combining different measurement approaches
24	Novak Uroš	Dinaric Faults: do they creep
25	Novak Uroš	The Slovenian Near Fault Observatory: SLO KARST NFO
26	Palatinuš Iva	Chronology building using fluorescence in Late Holocene stalagmite from Nova Grgosova cave, NW Croatia
27	Pawlak Jacek	The sampling problem in the construction of a speleothems age distribution curves – introduction for the conception of growing phases
28	Peugnet Guillaume	The impact of subsurface life on ghost-rock karstification processes
29	Pipan Tanja	20 years of LTER Slovenia: from challenging beginnings to successful national long-term research infrastructure
30	Rispal Nathan	Element of a pluri-disciplinary project on karstic reservoir characterization: first results of cave sediments paleomagnetic dating in Dévoluy Massif, France
31	Sierpień Paula	“Dirty calcite” and the search for suitable correction coefficient – an experimental approach
32	Skok Sara	Microbial load and community composition on cave surfaces, and the impact of organic pollution from cattle slurry: A case study of Postojnska jama, Slovenia
33	Stanišić Andrijana	The influence of geotectonics on the hydrogeological conditions and regime of the karst aquifer in the Ravanica zone – Eastern Serbia
34	Stienss Jacek	Dripstone formation from Gigant Cave – one of the oldest caves in Prokletije Mountains (Montenegro)
35	Stokes Tim	Analysis of karst springs data to aid in the understanding karst aquifer processes, disturbances in the karst catchment and longer-term climate change effects
36	Stremțan Ciprian C.	In situ, sequential $\delta^{13}\text{C}$ measurements in speleothem calcite via Laser Ablation Cavity Ring Down Spectroscopy – a novel method
37	Surić Maša	Evolution of twenty-year monitoring in Modrič Cave (Croatia)
38	Szieberth Dénes	An Arduino based tracer detector and flow rate logger for community science and large scale applications
39	Šturm Samo	Introduction of regular monitoring of critical environmental stressors for <i>Proteus anguinus</i> in Škocjan Caves, Slovenia

GENERAL INFORMATION

Registration

- Registration is possible on Monday (8:00 – 13:00), Tuesday (8:30 – 11:00), and Wednesday (8:30 – 09:30) in the Cultural Centre Postojna (Gregorčičev drevored 2a, Postojna) in a separate space in front of the main entrance to the Cultural Centre on the right. **Registration is obligatory for all participants.**

Oral presentations

- Lectures will take place in the Cultural Centre Postojna (Gregorčičev drevored 2a, Postojna).
- PowerPoint presentations **should be given to the organizers** during the break before the Session with the presentation.
- Maximum duration of the lecture is 15 min (12 min for talk and 3 min for discussion). Invited lecturers (keynote speakers) have 30 min for the lecture. Due to a tight schedule, we ask you to please be punctual!

Posters

- Poster size: mandatory max. format is A0 – 841 x 1189 mm (portrait layout).
- Poster presentation and display will be held at the Karst Research Institute in the hall and the stairway.
- Flash presentation session will be organized at the beginning of the poster session. For this, each author(s) is asked to prepare a 2-minute-long flash presentation with 1–2 slides to attract attention to the content of the poster. After the flash session, 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 17th, before the lunch break.
- Stand by your poster during the poster display.

Meals

- Lunches are not organized during the session days and afternoon field trips (Tuesday and Wednesday).
- During whole-day field trips (Thursday and Friday) simple lunches will be provided. Due to the length of the Thursday's and Friday's excursions (Excursion C and D) we suggest you take with you some additional snacks.
- Lunch breaks are timetabled into the schedule during the session days (Monday, Tuesday and Wednesday). You can go for lunch to e.g. Štorja pod stopnicami, Bar Bor, Pri kaminu, Čuk, Bistro Perspektiva, etc.
- On Thursday a reception dinner will be provided.

Field trips

- All fieldtrips, except on Tuesday, will be combined with a bus drive and walk (several km per day).
- Registration for each field trip will be possible only on Monday, 17th June 2024 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).
- Because of visits of caves, walking shoes, field clothes and headlamps are obligatory. At most excursions, a lot of walk is expected. Please, be ready for possible hot weather or/and rain.
- Insect repellents are recommended as we will be walking in areas populated with ticks (Ixodes ricinus) that transfer mainly lyme disease 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 organizers 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 comply with the instructions of the organizers.

OSNOVNE INFORMACIJE

Prijava

- Registracija je mogoča v ponedeljek (08:00 – 13:00), torek (08:30 – 11:00) in sredo (8:30 – 09:30) v Kulturnem domu v Postojni (Gregorčičev drevored 2a, Postojna), v ločenem prostoru pred glavnim vhodom v Kulturni dom, desno. **Registracija je obvezna za vse udeležence.**

Predavanja

- Večina predavanj poteka v Kulturnem domu v Postojni (Gregorčičev drevored 2a, Postojna).
- Prosimo, da PowerPoint predstavitev **oddete organizatorjem** v odmoru pred začetkom tematskega sklopa, v katerem imate predstavitev.
- Dolžina predavanja je omejena na 15 minut (12 minut za govor in 3 minute za razpravo). Vabljeni predavanja so omejena na 30 minut. Prosimo vas, da se strogo držite predpisanega časa!

Posterji

- Velikost posterjev: obvezen največji format je A0 – 841 x 1189 mm (pokončna lega).
- V začetku predstavitve posterjev bo potekala hitra predstavitev v obliki diapozitivov. Pri tem vse avtorje vabimo k pripravi 2 minuti dolge predstavitve - napovednika (1–2 diapozitiva), v kateri pritegnete pozornost na vsebino posterja. Hitri predstavitvi bo sledil klasičen ogled posterjev, kjer bodo avtorji lahko odgovarjali na morebitna vprašanja udeležencev.
- Posterje in kratke predstavitve (.ppt, .pdf) pustite pri mizi za prijavo udeležencev, in sicer v ponedeljek, 17. junija, do odmora za kosilo.
- Med ogledom posterjev stojte poleg svojega posterja.

Obroki

- Kosilo med predavanji in popoldanskim terenskim delom (torek in sredo) ni organizirano.
- Med celodnevni terenski delom (četrtek in petek) organiziramo enostavne obroke. Zaradi dolžine četrtkov in petkov ekskurzije (Ekskurzija C in D) priporočamo, da si s sabo vzamete še kakšen dodaten prigrizek.
- Odmori za kosilo so v času predavanj (ponedeljek, torek in sredo) vključeni v program. Jeste lahko v Štorji pod stopnicami, Bar Boru, Pri kaminu, v Čuku, Bistro Perspektiva, itd.
- V četrtek je v večernem delu programa planirana pogostitev.

Strokovne ekskurzije

- Vse ekskurzije, razen torkove, bodo kombinirane z avtobusno vožnjo ter hojo (nekaj km/dan).
- Prijave za strokovne ekskurzije bodo mogoče le še v ponedeljek, 17. 6. 2024 pri mizi za prijavo udeležencev.
- Odhod avtobusov je z glavne avtobusne postaje Postojna (označeno s št. 3 na karti Postojne).
- Zaradi predvidenih obiskov jam je obvezna primerna oprema (pohodni čevlji, terenska oblačila, svetilke). Na vseh ekskurzijah pričakujemo precej hoje. Pripravite se tudi na možno vročino ali/in dež. Na ekskurzijah bomo veliko hodili – bodite pripravljeni.
- Priporočamo uporabo repelentov proti insektom. Hodili bomo po območjih, kjer se nahajajo populacije klopov (*Ixodes ricinus*), ki so lahko prenašalci povzročiteljev Lyme bolezni ali meningitisa.
- 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 terenskim 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

ZEMLJEVID POSTOJNE



- 1 Karst Research Institute ZRC SAZU / Inštitut za raziskovanje krša 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: KARST JAM

(Monday, 17th June 2024)

This year's school will be as always a great meeting point between experienced and new researchers from different parts of the globe.

In the past, a Special Session on Mysteries in Karst science was held which was a successful way to present open research questions and ideas in a form of a short PPT presentation.

This year, for the second time, we will hold a "Karst Jam" session, where a debate will be challenged by the moderator and attendees, where different karst topics will be addressed. The idea is to talk about some open/unresolved/ambiguous/problematic topics in a friendly environment with a lot of fun. Young researchers and students will get the possibility to hear both (or several) answers to the unresolved questions within karst science, where recognized scientists will get the possibility to mingle.

No contribution is needed, just your presence, goodwill and constructive ideas.

See you on Monday, 17th of June in the evening at the Karst Research Institute ZRC SAZU!

POVABILO NA POSEBNO SEKCIJO: KRAŠKE DEBATKE

(ponedeljek, 17. junija 2024)

Letošnja šola bo kot vedno odlično stičišče izkušenih in novih raziskovalcev iz različnih koncev sveta.

V preteklosti je potekala posebna sekcija o skrivnostih krasoslovja, ki je bila uspešen način za predstavitev odprtih raziskovalnih vprašanj in idej v obliki kratke PPT predstavitve.

Letos bomo že drugič vpeljali sekcijo "Kraške debatke", kjer bo debata potekala s pomočjo moderatorja in udeležencev, kjer bodo obravnavane različne kraške teme. Ideja je, da se o nekaterih odprtih/nerešenih/dvoumnih/problematičnih temah pogovarjamo v prijaznem okolju z veliko zabave. Mladi raziskovalci in študentje bodo imeli možnost slišati oba (ali več) odgovorov na odprta krasoslovna vprašanja, kjer bodo dobili možnost druženja s priznanimi krasoslovci.

Prispevek ni potreben, le vaša prisotnost, dobra volja in konstruktivne ideje.

Se vidimo v ponedeljek, 17. junija zvečer na Inštitutu za raziskovanje krasa ZRC SAZU!

FIELD TRIPS
TERENSKO DELO

Afternoon field trip (A):
ACQUISITION AND PROCESSING OF CAVE AIR PHYSICAL PARAMETERS
IN POSTOJNSKA JAMA

Tuesday, June 18th 2024, 17:00–19:30

Franci Gabrovšek, Boštjan Grašič, Primož Mlakar, Marija Zlata Božnar

Značilnosti podzemnega toka v zaledju Ljubljane

Popoldansko terensko delo (A); torek, 18. junij 2024;

Jamska klima je ključni kazalnik jamskega okolja. Spremembe jamskih klimatskih vzorcev so lahko posledica intenzivne turistične rabe jame in zunanjih klimatskih sprememb. Razlikovanje med obema je ključno, vendar ni enostavno. Prvi korak je postavitve razpršenega, zanesljivega in dolgoročnega opazovalnega sistema z učinkovitim zajemanjem, prenosom podatkov, kontrolo kakovosti in podatkovno bazo. Meritve in opazovanja fizikalnih parametrov jamskega zraka v Postojnski jami so bila vzpostavljena že pred stoletjem. Šebela (2022) daje temeljit pregled preteklih in novjših meritev. Cilj ekskurzije je predstaviti elemente jamskega informacijskega sistema, ki zagotavlja podatke za znanstveno preučevanje jamske mikrometeorologije in mikroklima, ki temeljijo na kakovostnih avtomatskih meritvah na štirih postajah v jami.

INTRODUCTION

Cave climate is a key indicator of cave environment. Changes of cave climate patterns may result from intensive touristic use of cave and external climate changes. To distinguish between both is critical, yet not easy. The first step is to set-up distributed, reliable and long-term observation system with efficient data acquisition, data transfer, quality control and data base. Measurements and observations of cave air physical parameters in Postojnska Jama were already established a century ago. Šebela (2022) gives a thorough review of past and recent measurements. The aim of field trip excursion is to present elements of cave information system, which provides data for the scientific study of the cave micrometeorology and microclimate, based on quality automatic measurements at four meteorological stations in the cave. Participants will learn what we measure, how we measure, how is data being transferred, handled and stored, and (shortly) what we have learned so far.

THE CAVE

The total length of known passages of Postojnska Jama is more than 24 km (Fig. 1.1) and the calculated volume of all cave passages is 1.7 million cubic meters. The passages have formed in two levels. The upper dry part of the cave is located between 520 and 530 m. The ponor is at an altitude of 511 m .a.s.l. There are several cave entrances located at an altitude of 529 m above the ponor of the Pivka. Other entrances to the cave are Otoška Jama (Otok Cave), Magdalena Jama (Magdalena Cave), Pivka Jama (Pivka Cave) and Črna Jama (Black Cave). In the past, all of these entrances were known as separate caves and were later connected to the Postojna Cave system through research and exploration. The interconnected passages form a single cave, which is why the cave is also called Postojnska Jama. The calculated volume of all cave passages is 1.7 million cubic meters. The distance from the ponor of Pivka into Postojnska Jama to the siphon in Pivka Jama is about 3.5 km. The difference in altitude between the highest point at the entrance to Magdalena Jama and the lowest

point at the siphon in Pivka Jama is 115 m. The known section of the Rov podzemne Pivke (Passage of the Subterranean Pivka) ends about 500 m before reaching the passages of the Planinska Jama.

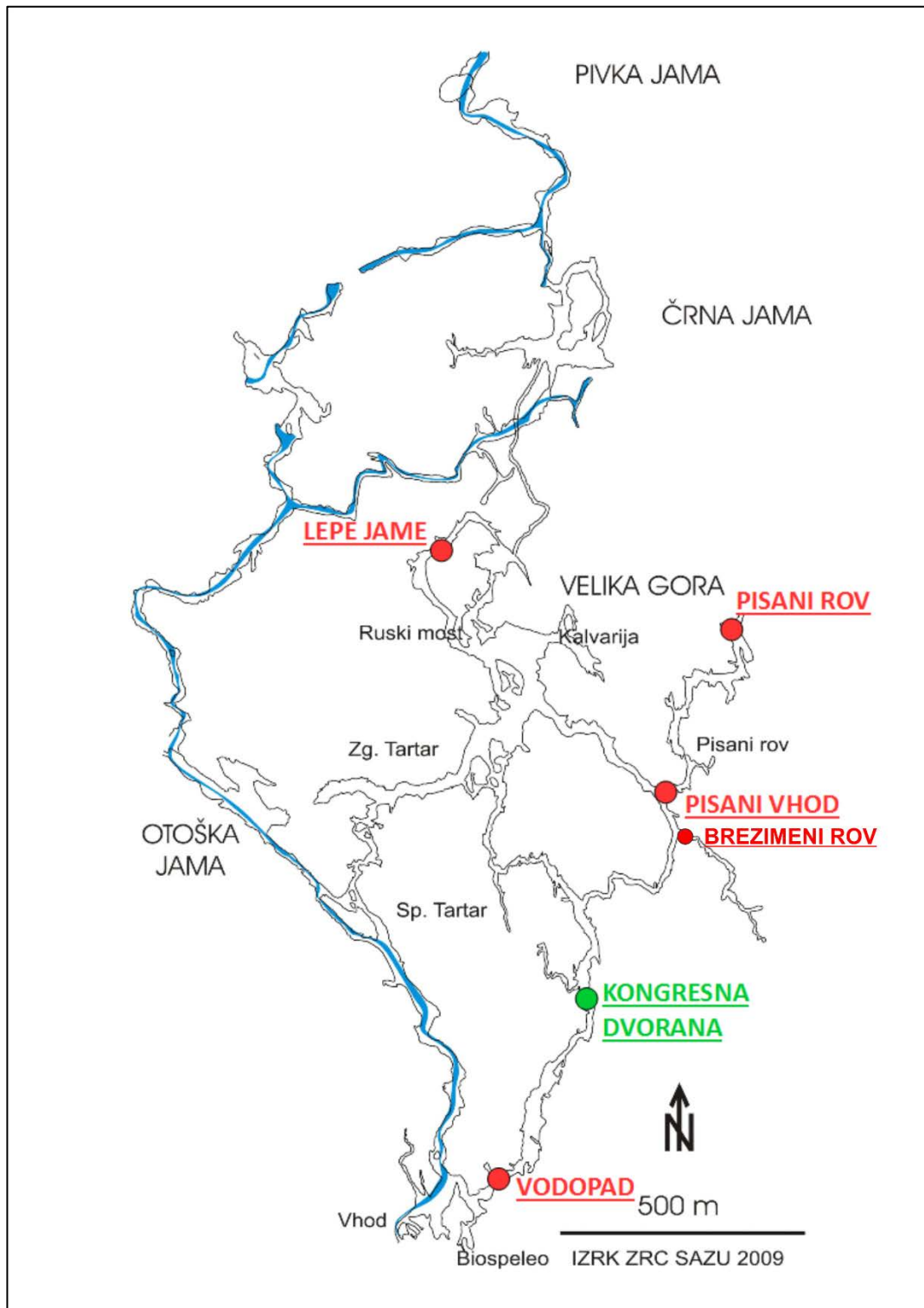


Figure 1.1: Map of Postojnska Jama (parts north of Pivka Jama are not shown). Red dots and text show locations of automatic cave measuring stations. DTN gateway is shown in green.

The cave has a network of hydrologically and morphologically very different passages in terms of their origin and enlargement. The active water passages are on average smaller than the passages in the dry sections. The dry passages up to an elevation of 520 m can be reached only by

the highest water levels. Passages in the present dry section are large - up to 10 m high and wide. Their profiles are rounded here and show traces of paragenesis, such as levelled ceilings and side notches on the walls. The largest chamber, Velika gora (Big Mountain), has a volume of about 100,000 m³. The thickness of bedrock above the cave passages ranges from 30 to 120 m.

The currently active water passages are about 20 m lower than the dry sections and run along the western part of the cave. The underground river Pivka flows behind the ponor towards north along the passages of the Rov podzemne Pivke (Passage of the Subterranean Pivka). In the northern direction, the riverbed slopes slightly - in the entire cave from 511 m at the ponor (Fig. 1.1) to 477 m at the syphon in Pivka Jama.

“JAM'CA” – CAVE INFORMATION SYSTEM OF POSTOJNA CAVE

Cave information system (referred as Jam'ca) is based on the guidelines given Mlakar *et al.* (2020). The map of the Postojnska jama cave (Fig 1.1) shows the locations of automatic cave measuring stations in the Postojnska jama cave, which have been operating since 2010. The locations were chosen in accordance with the purpose and the financial resources available. The “Vodopad” station describes the conditions near one of the cave entrances; the “Lepe jame” station describes the conditions in the part of the cave that is most visited by tourists; while the “Pisani rov” station describes the conditions in the part of the cave that is the most remote and free of the impact of tourists in the cave. Additionally, another gateway station is also located in the cave in the “Kongresna dvorana”, where a fibre-optic Internet connection is available; the station is used above all as the main node for transferring data from the cave to the central unit outside the cave. The diagram (Fig. 1.2) shows the main building blocks of the “Jam'ca” environmental information system in the Postojnska jama cave.

AUTOMATIC CAVE MEASURING STATION

The main modules of the automatic measuring station are shown in the diagram (Fig. 1.2) and are the same for all stations in the “Jam'ca” system except for the selection and number of sensors, which is why we will give a detailed description of only the “Pisani rov” station, and its description will apply to all other stations.

The station for measuring individual environmental variables within the cave is equipped with the following sensors:

- Air temperature: PT100 sensor, type “Pt100 Thermometer 1/5 DIN”, accuracy ± 0.10 °C, range from -65 °C to $+70$ °C, response time < 20 seconds, long-term stability 0.1 °C/year, manufacturer MicroStep-MIS;
- Air flow: ultrasonic wind sensor, type “WindSonic”, wind speed accuracy $\pm 2\%$ at 12 m/s, wind direction accuracy $\pm 3\%$ at 20 m/s, wind speed ranges from 0 m/s to 60 m/s and wind direction range from 0° to 359° , manufacturer Gill Instruments Limited;
- Carbon dioxide CO₂: CO₂ probe, type “GMT 200 series”, accuracy $\pm (1.5\% \text{ of range} + 2\% \text{ of reading})$, a range from 0 ppm to 10000 ppm, response time < 20 seconds, long-term stability $< \pm 5\%$ of range /2 years, manufacturer Vaisala.

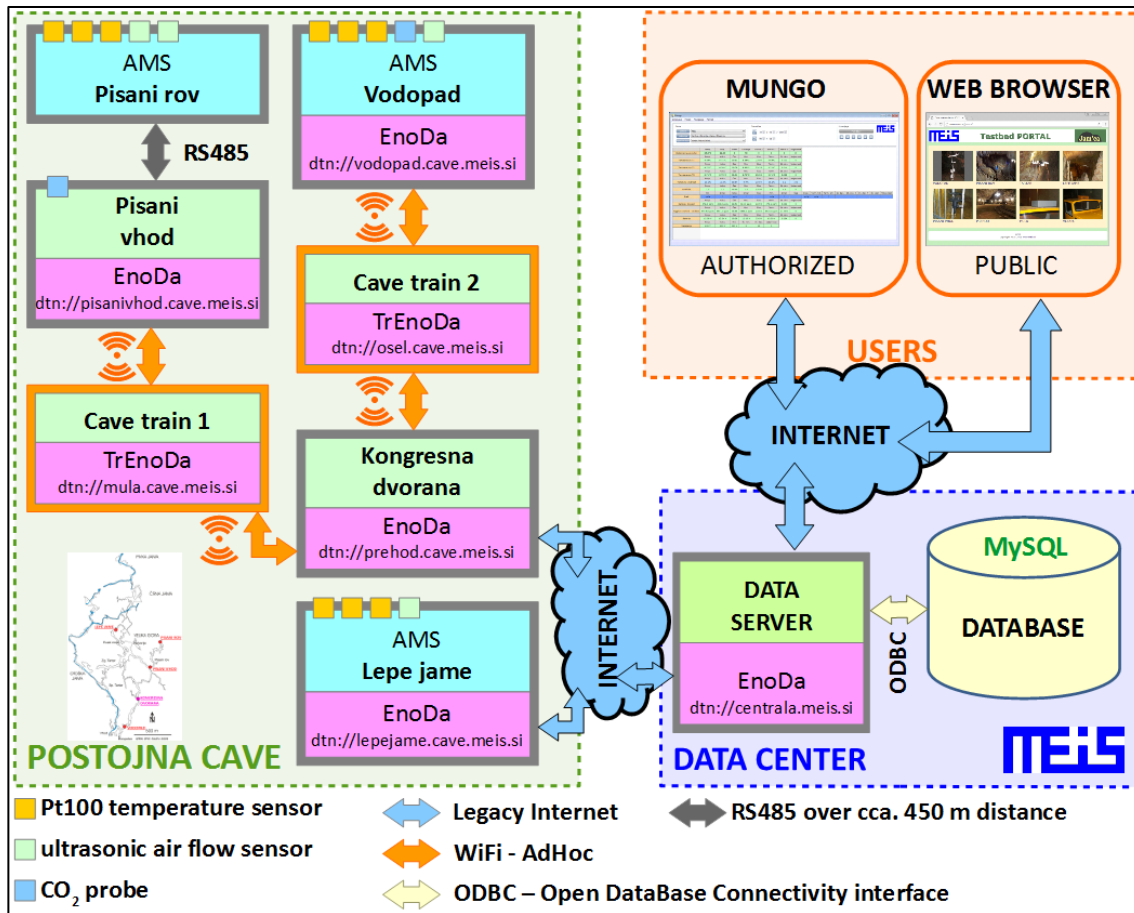


Figure 1.2: Diagram of the main building blocks of the “Jam’ca” environmental information system in the Postojnska jama.

The measured data are captured (sampled and basically statistically elaborated) by the MicroStep-MIS AMS 111 data logger via the RS485 communication interface. The capture, collection, statistical processing, control, local storage and transfer to the central unit is provided by the MEIS Enoda environmental node. The Enoda device is based on the Arduino Yún embedded computer, which provides relatively good performance in light of its consumption (under 2 W), a quality WiFi connection, and a permanent microSD memory medium. The Enoda device is also equipped with quality uninterruptible power supply based on a 12 V lead-acid battery, which enables continuous operation during a power outage up to 12 hours long or longer, depending on the battery’s capacity; it also enables a controlled shut down of the device to protect the data on the memory medium. The software of the MEIS Enoda environmental node complies with all the properties described in the subchapter “Automatic Cave Measuring Station”; a detailed description is available in the paper (Grašič *et al.* 2011).

All of the electronics of the cave measuring station, apart from the sensors, are installed in a suitably thermally insulated housing that prevents condensation on the housing. A simple styrofoam box originally designed for food delivery is used. Enoda environmental nodes in the “Vodopad” and “Lepe jame” locations in such a thermally insulated housing with open lid are presented on Fig. 1.4. For station in Pisani Rov, a 500 m long (UTP) cable was laid for energy supply and data transfer between the measuring interface in the “Pisani rov” location and the Enoda environmental node in the “Pisani vhod” location. The Enoda has been placed in that location because of the vicinity of the cave’s railway line, which the tourist cave train occasionally passes by, equipped with a data mule for data transfer based on DTN technology (Gabrovšek *et al.* 2014).

The sensors have been installed in accordance with the possibilities and needs in individual locations. Whereas in the locations of “Pisani rov” and “Pisani vhod” they have been mounted on existing brackets using plastic cable ties, in the locations of “Vodopad” and “Lepe jame” a removable portable tower has been used instead (Fig. 1.5).

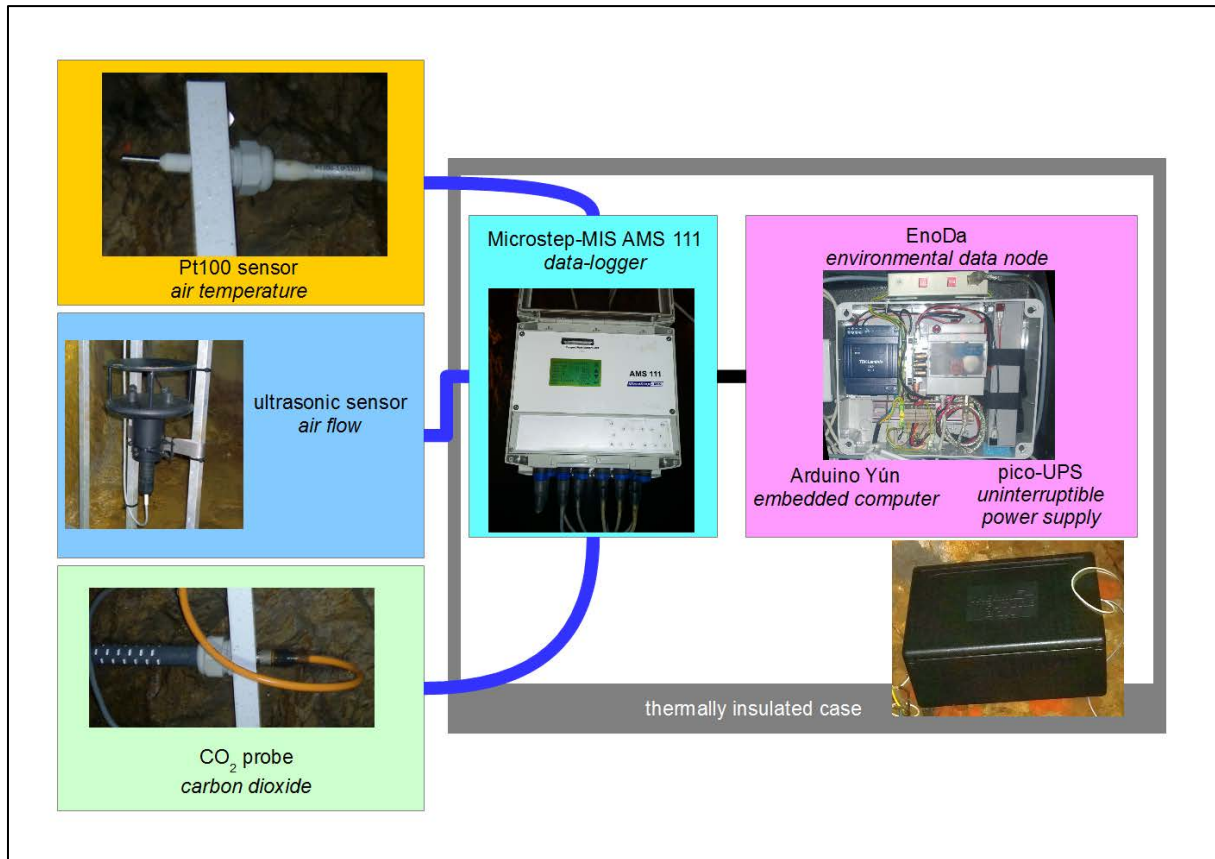


Figure 1.3: Diagram of the main building blocks of the automatic cave measuring station.

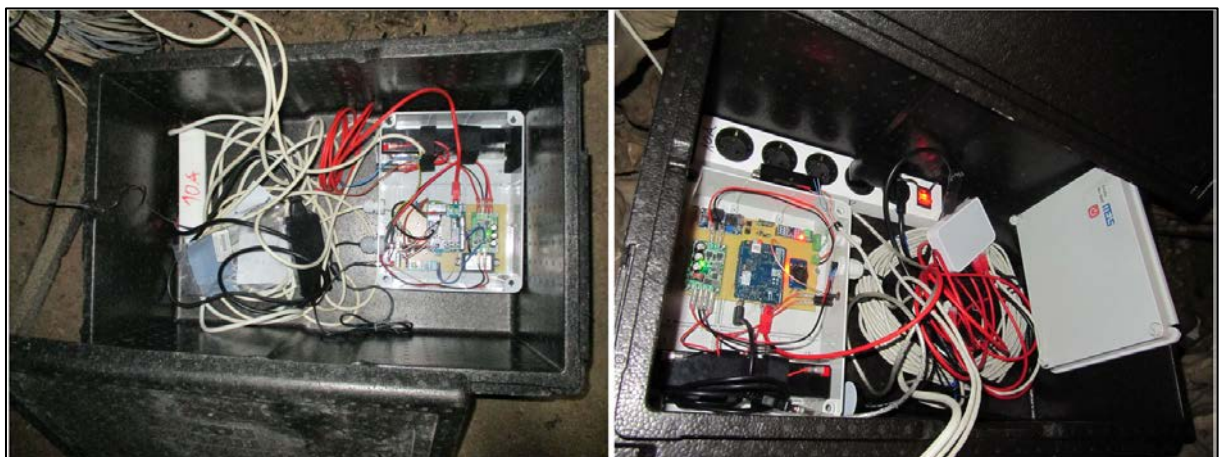


Figure 1.4: Pictures of the EnoDa environmental nodes in the “Vodopad” location (left) and “Lepe jame” location (right) both in a thermally insulated housing with open lid (Photo: B. Grašič).

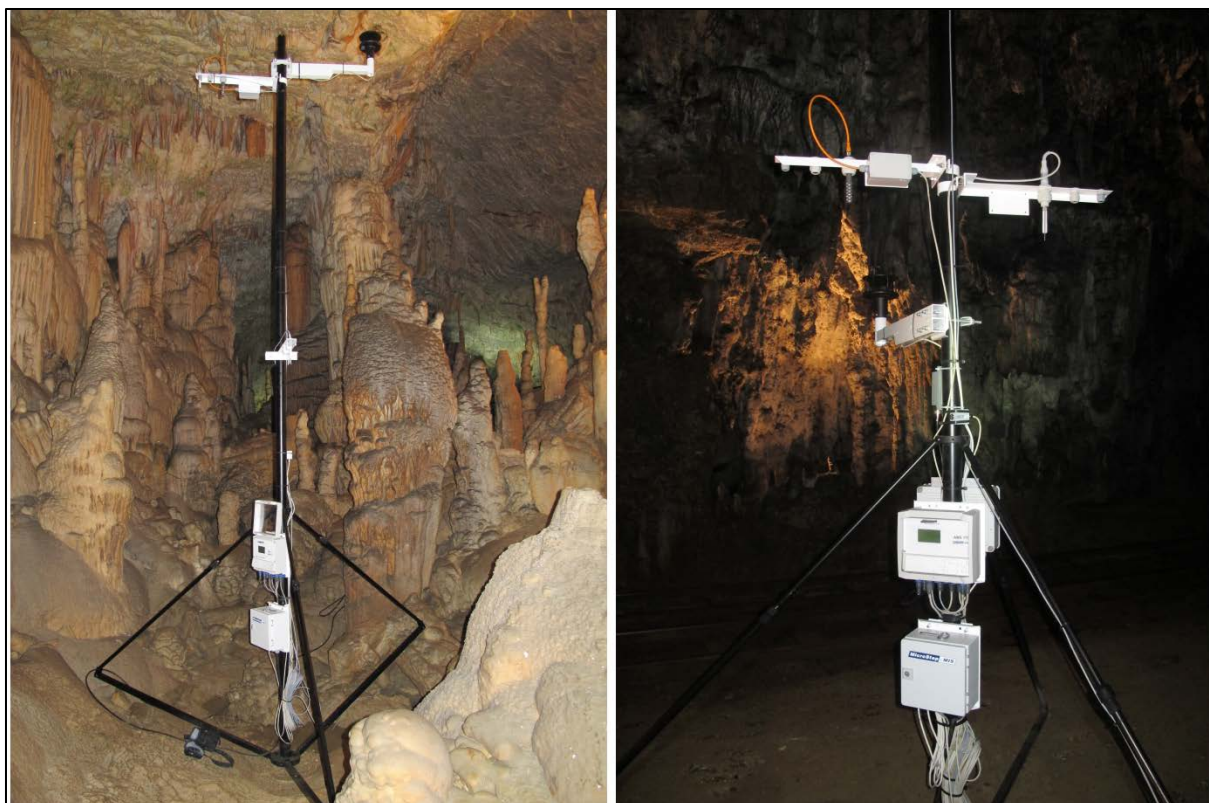


Figure 1.5: Pictures of the mounting of sensors on portable removable measuring towers (left in the location of “Lepe jame”, right in the location of “Vodopad”) (Photo: F. Gabrovšek).

CENTRAL UNIT OF THE “JAM'CA” ENVIRONMENTAL CAVE SYSTEM

The central unit of the “Jam'ca” cave system is located on the premises of MEIS. It is made up of several computers of suitable performance:

- The EnoDa environmental node, which is the main node for receiving data via the World Wide Web (Internet) based on an Arduino Yún embedded computer, or via an Ad-Hoc wireless connection with the TrEnoDa data mule;
- A high-performance server computer, based on an Intel I7 microprocessor, 16 GB of RAM and 1 TB hard drive, with installed software for the additional control and saving of data received from the stations to the MySQL database; this computer also has installed software for accessing the archived data and transferring the measured values for the last 5 days from all stations in the form of graphs to the public website (Fig 1.6);
- Rented server space outside the premises of MEIS for hosting the public website;
- And a personal computer, equipped with a system for automatic warning (alarming) of detected outages or errors in the “Jam'ca” system via emails and short text messages.

Access to all current and historical data is enabled by means of a dedicated “Mungo” display program, which enables reviews, graphic presentations and statistical displays for scientific purpose even outside the internal MEIS network on personal computers. Other dedicated tools are also available for visualisation and statistical processing, such as the “webSolarRose” program for drawing sunflower diagrams (Fig. 1.6).

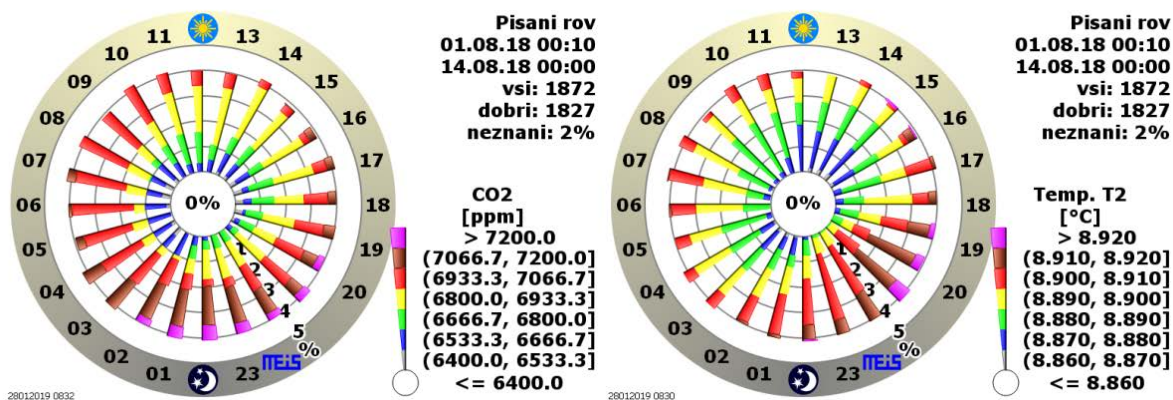
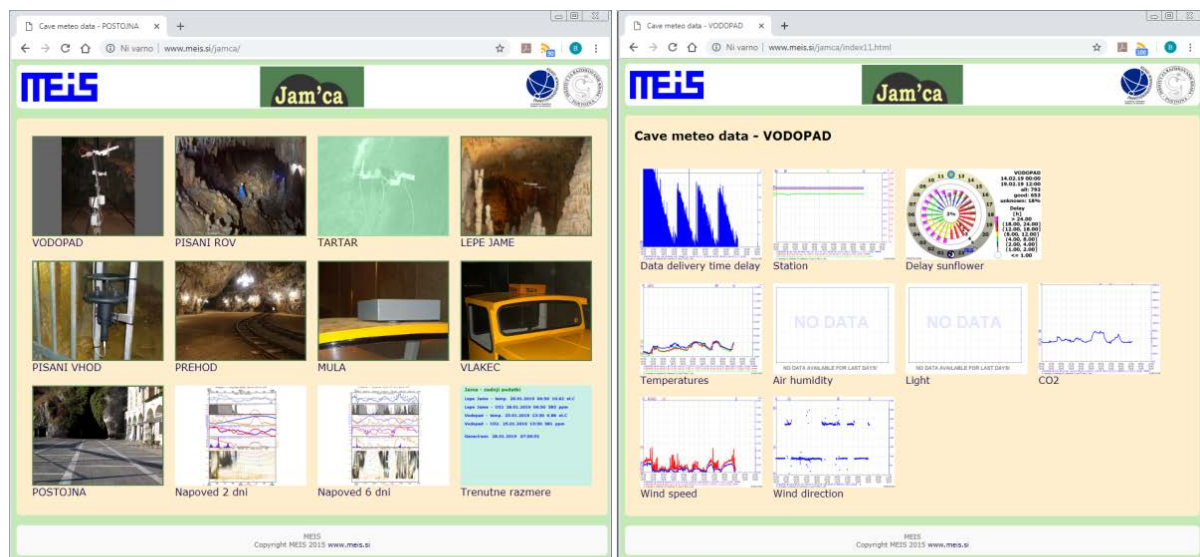


Figure 1.6: Top left: The entry page of the publicly accessible website of the “Jam’ca” environmental system on the website: <http://www.meis.si/jamca/>. **Top right:** The publicly accessible website of the “Jam’ca” environmental system presents last five days of data. **Bottom:** Analysis of measurement data from Pisani rov using the “Sončnica/Sunflower” tool. Left: average CO₂ concentration. Right: average temperature T2. The graphs are made with “webSolarRose” program. The graph shows 14 days of statistically elaborated data to find daily patterns: note that for this period the CO₂ has higher values during nights, particularly between 7:30 p.m. and 2:00 a.m. The temperature shows highest values between 6:30 p.m. and 8:30 p.m.

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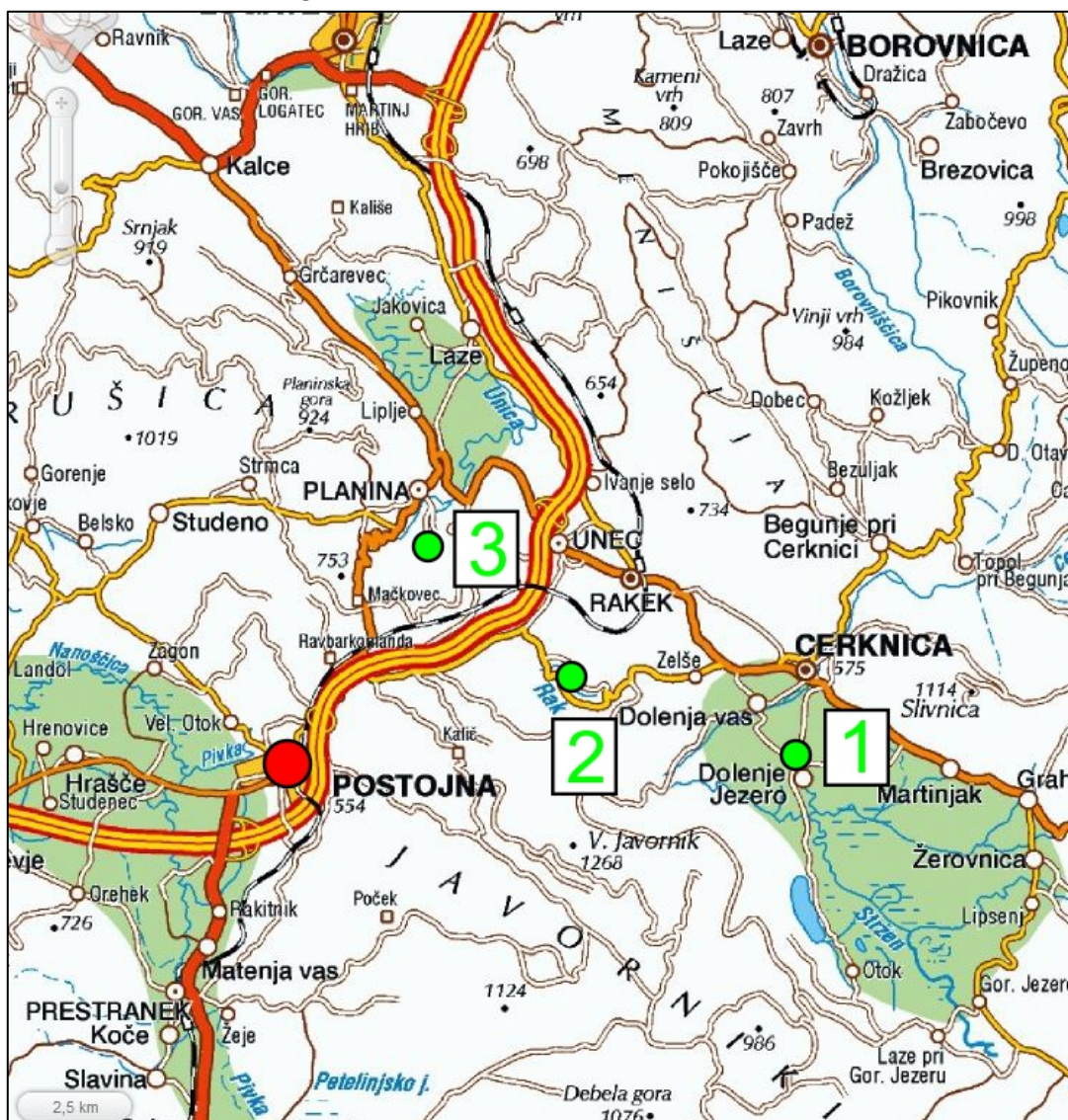
Afternoon field trip (B):
GROUNDWATER FLOW IN THE LJUBLJANICA RECHARGE AREA

Wednesday, 19th June 2024, 15:00–19:00

Franci Gabrovšek, Cyril Mayaud, Blaž Kogovšek, Matej Blatnik, Nataša Ravbar, Metka Petrič

Stops:

- 1 – Outflow zones of Cerkniško Polje
- 2 – Hydrology of the Rakov Škocjan karst valley
- 3 – Planinska Jama with underground confluence of rivers



Značilnosti podzemnega toka v zaledju Ljublanice

Popoldansko terensko delo (B); sreda, 19. junij 2024;

Za kraško zaledje izvirov Ljublanice je značilno menjavanje kraških polj in kraških planot. Niz kraških polj s ponikalnicami ima dinarsko smer (SZ–JV), del voda pa se priključi z JZ, s Pivške kotline. V prvem delu ekskurzije predstavimo Cerkniško polje ter Rakov Škocjan z značilnimi kraškimi pojavi (kraški izviri, požiralniki, jame, vodotoki). Drugi del je posvečen izvirom Unice. Poudarek je na predstavitvi zadnjih raziskav, kjer smo raziskovali tok vode v Rakovem rokavu Planinske jame in določili prostorske in časovno spremenljivost vodnega toka. Prepoznali smo tudi prelivne kanale in potencialne geološke pregrade, ki lahko vplivajo na dinamiko pretakanja podzemne vode in poplavljanje na površju.

GENERAL INTRODUCTION: HYDROGEOLOGY OF THE LJUBLJANICA RIVER RECHARGE AREA

The central part of the Slovenian Dinaric Karst drains to the springs of the Ljubljana River, located on the southern edge of the Ljubljana Basin (Fig. 2.1). Although the area is about 26 km of straight-line distance close to the Adriatic Sea, intense tectonic activity has triggered drainage into the Sava-Danube river basin, which flows to the Black Sea. The estimated total size of the Ljubljana recharge area is almost 1800 km², of which about 1100 km² are karstified. The karst catchment area was delineated during an extensive tracing campaign in the 1970s (Gospodarič & Habič 1976).

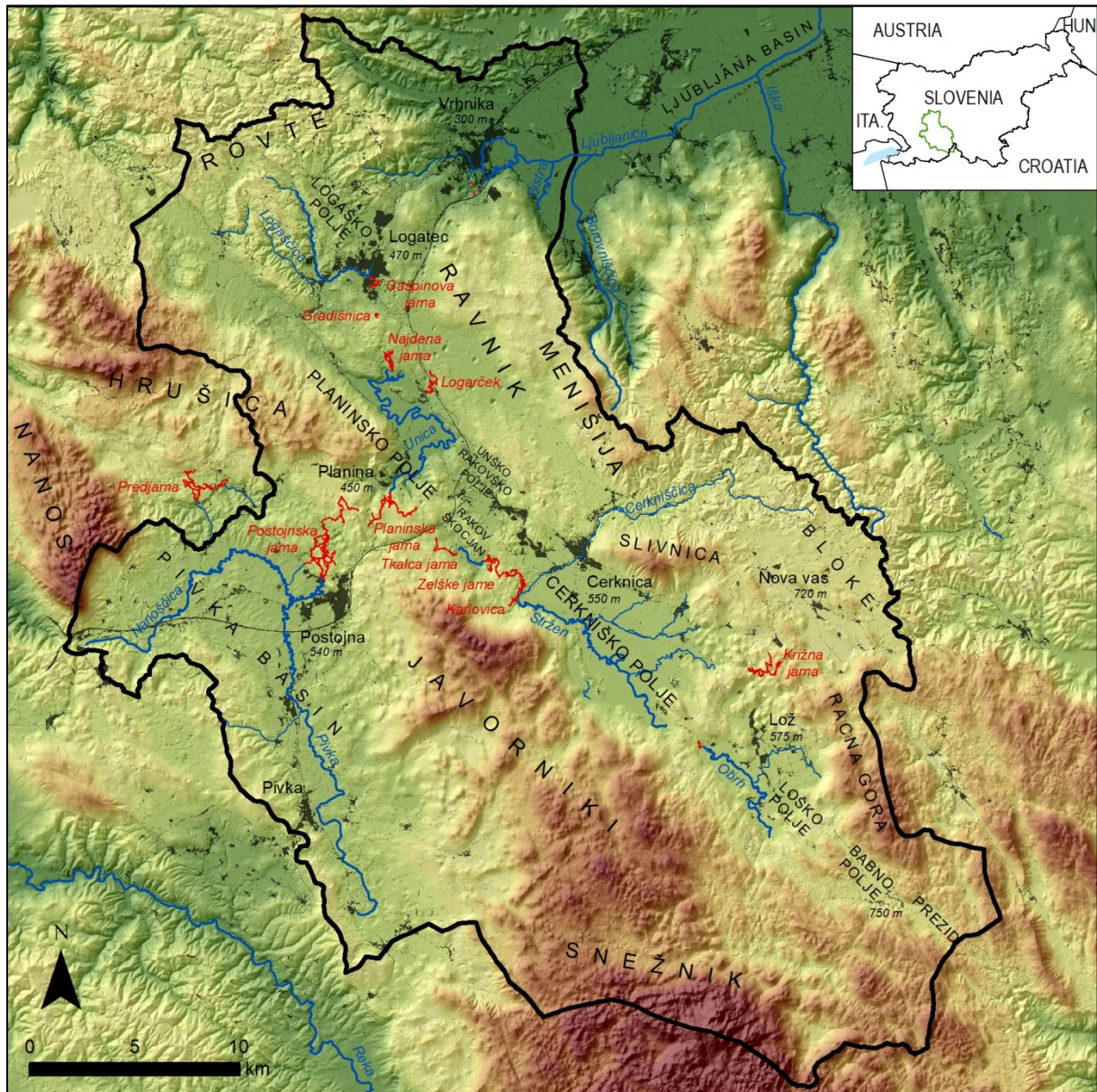


Figure 2.1: Ljubljana River recharge area with high karstic plateaus, karst poljes and surface rivers. The main caves are shown with red lines.

The karst rocks are mostly of Mesozoic age. They are generally micritic, locally oolitic limestones and predominantly late-diagenetic dolomites. They formed on the Dinaric platform under conditions of continuous sedimentation that allowed high rock purity, generally with less than 5%, locally even only 0.1%, insoluble residues. The total thickness of the carbonate sequence is almost 7 km.

Structurally, the entire Ljubljana catchment belongs to the Adriatic Plate. The area consists of several nappes that were overthrust during the peak of the Alpine orogeny in the Oligocene in a NE to SW direction (Placer 2008; Placer *et al.* 2010). A later change in the direction of plate movement led to the formation of the Idrija Fault Zone, a dextral strike-slip fault that crosses the area in the direction of NW-SE (Fig. 2.2) (Vrabec 1994). The Idrija Fault Zone largely determines the direction of regional flow (Fig. 2.2). In general, the steepest hydraulic gradient is oriented northwards, from the Notranjska region towards the Ljubljana Basin, which represents a regional base level. However, the fault zone acts as a barrier to groundwater flow and forces the water to surface in the poljes. At the same time, it diverts the flow in the Dinaric direction (SE-NW) (Šušteršič 2006).

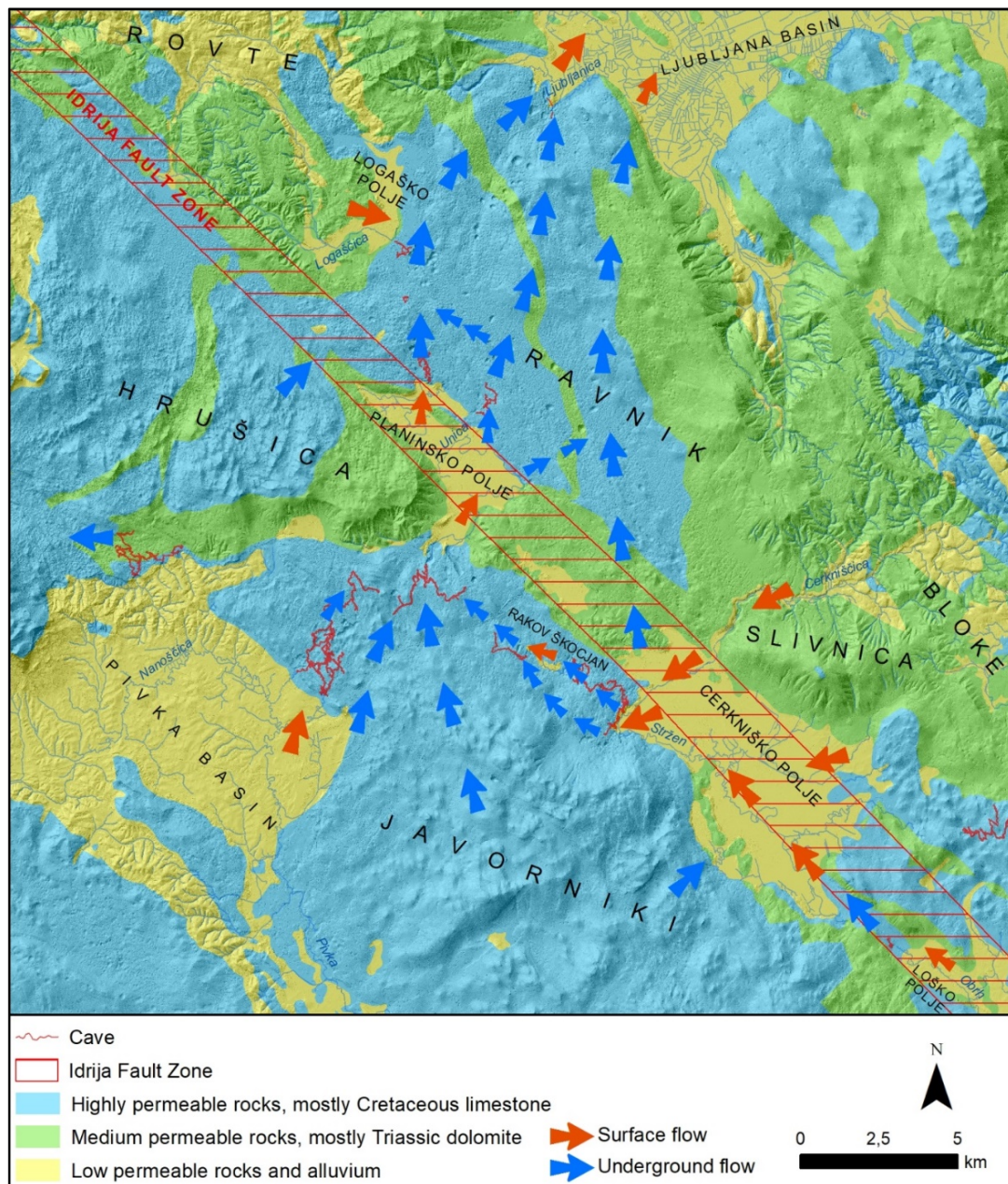


Figure 2.2: Geology and hydrology of the Ljubljana recharge area (adapted from Krivic *et al.* 1976).

Several poljes have developed along the Idrija Fault Zone (Gams 1965, 1978; Šušteršič 1996). These large flat-bottomed depressions are regularly flooded and are often the only areas where water appears at the surface. The formation of poljes is preconditioned by tectonics, in this case by the structures within the Idrija strike slip fault (e.g. pull-apart zones), but the forming mechanism is the corrosional planation at the groundwater level.

In general, the water follows the SE-NW direction with surface flow on the poljes and groundwater flow in-between (Fig. 2.3). Additional water enters the flow system at numerous springs draining the areas of the Snežnik and Javorniki mountains in the south of the Idrija Fault Zone. Several sinking rivers draining dolomite or flysch areas also contribute to this system (Gams 2004). The altitude of the poljes drops from about 750 m to 450 m. The streams that flow through them have different names: Trbuhovica, Obrh, Stržen, Rak, Pivka and Unica. Apart from a relatively small amount of water flowing directly from Cerkniško Polje to the springs of Ljublanica, most of the water comes to the surface along the southern edge of Planinsko Polje. Along its eastern and northern edges, the water sinks back underground and flows northwards to several large and many small springs aligned along the southern edge of the Ljubljana Basin, which is connected to the gradual tectonic subsidence of the area (Krivic *et al.* 1976; Gams 2004). The average annual discharge of the Ljublanica springs is 38.6 m³. An additional amount of water drains from the low- to medium-permeable Rovte plateau and contributes to the Ljublanica springs by sinking into the ponors of Logaško Polje (Mihevc *et al.* 2010).

There are almost 1600 known caves located in the recharge area of the Ljublanica River (Cave register 2019). Most of them are accessible fragments of a fossil underground drainage system (Habič 1973; Gospodarič 1981; Šušteršič 1999, 2002). The average cave length is 48 m and the depth 18 m. However, the largest cave systems are water-active and sum a total of about 80 km of epiphreatic channels (Fig. 2.3).

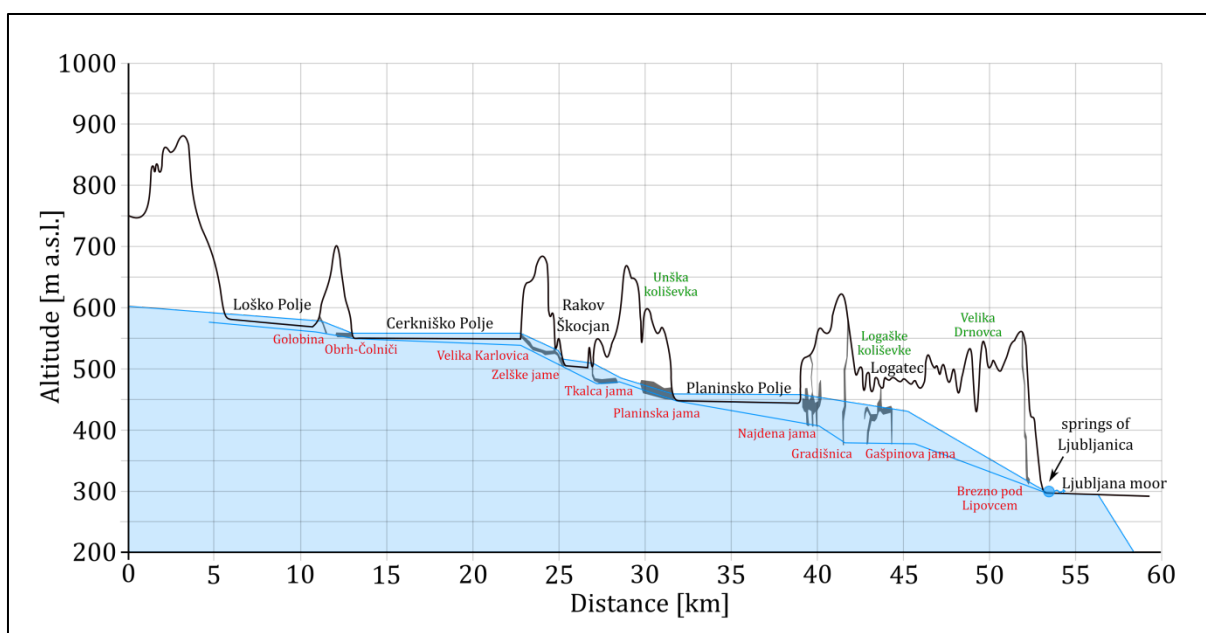


Figure 2.3: Cross section of Ljublanica River recharge area following an initially SE-NW trend along the Idrija Fault Zone between Loško and Planinsko Polje, and turning N from Planinsko Polje toward the Ljublanica springs near Vrhnika. The major caves are indicated in red, large collapse dolines in green.

CERKNIŠKO POLJE

Cerkniško Polje is the largest karst polje in Slovenia (Gams 1978, 2004). It is often called Cerkniško Jezero (Lake of Cerknica) because of its regular floods (Fig. 2.4a). When full, the intermittent lake covers up to 26 km² out of 38 km² of the polje's total area. The bottom of the lake is at an altitude of 550 m. Its intermittency has attracted many scholars since the beginning of the New age including the polihistorian Valvasor, who published his famous study of the Cerkniško Jezero in 1689 (Shaw & Čuk 2015). The main part of the polje is underlain by Upper Triassic dolomite at its N, E and SE borders. The areas to the W and NW, on the other hand, are mainly underlain by Cretaceous limestone (Fig. 2.2).



Figure 2.4: (a) Flooded Cerkniško Jezero (Spring 2013); (b) Ponors of Rešeta during low flow conditions (Summer 2017).

The polje is regularly flooded for several months (Fig. 2.5), mostly in autumn, winter and spring (Kovačič & Ravbar 2010). On average, the water is above the level of 550.3 m a.s.l. on 10.2 days per year, which corresponds to a flooded area of 21.84 km² (Ravbar *et al.* 2021). The main inflows into the polje come from a series of karst springs called Žerovniščica, Šteberščica and Stržen, located on its eastern and southern borders. The springs on the SW side (e.g. Suhadolca, Vranja jama) add a lot of water during floods. In addition, an important allogenic component comes from the Cerknjšica River, which drains a dolomitic area of about 44 km² in the east (Gams 2004). Finally, several estavelles (e.g., Vodonos) also contribute to the inflow into the polje.

In addition to the estavelles, several ponor zones located in the inner part of the polje drain a certain amount of water directly to the springs of Ljubljana (Krivic *et al.* 1976) (Fig. 2.4b), while the main ponors are aligned along the W side of the polje, with Velika and Mala Karlovica being the most prominent. Both caves extend for over 8.5 km between Cerknjško Polje and the Rakov Škocjan karst valley. So far, only a small section between Velika Karlovica and Zelške Jame (located in Rakov Škocjan) is unexplored as an important collapse zone is located there. Recent studies have shown that at low to medium water levels (Gabrovšek *et al.* 2010; Ravbar *et al.* 2012, Kogovšek 2022), a large part of the water sinking into the ponor of Mala Karlovica reaches the Kotliči springs in the middle of Rakov Škocjan and a smaller part reaches Zelške Jame, which would be the most logical direction.

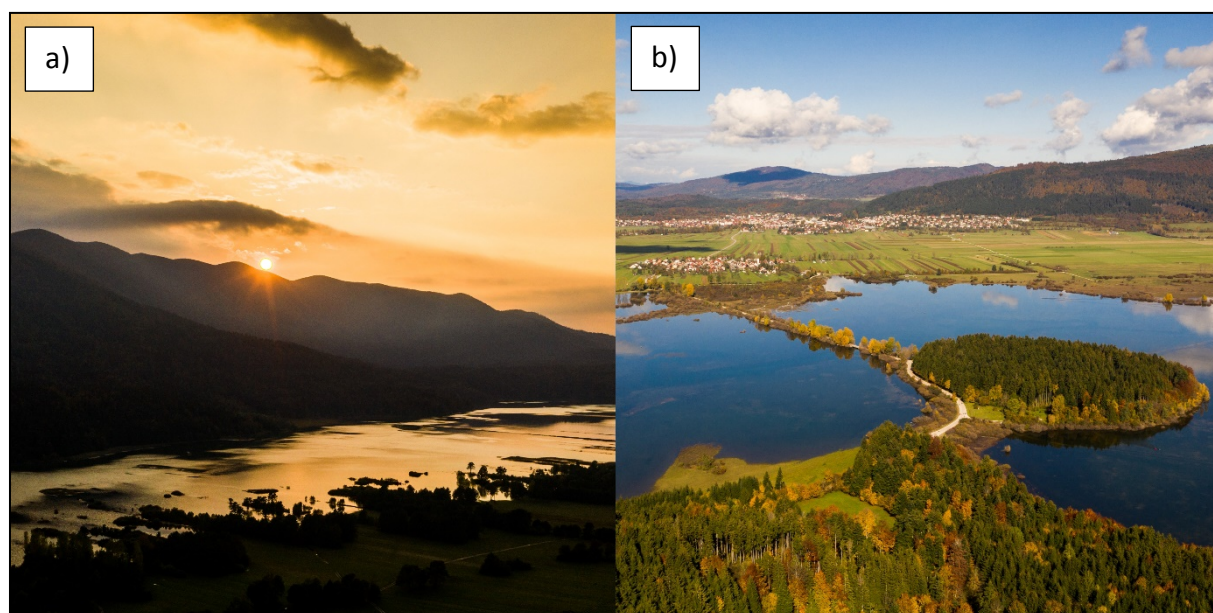


Figure 2.5: Cerknjško Jezero. a) Lake and Javorniki Mountains at sunset. b) View toward the village of Dolenje jezero.

In the last centuries, several plans were made to change the hydrological behaviour of the polje, but none was completed. In the 1960s, a plan to transform the Cerknjško Jezero into a permanent lake was initiated. The entrances to the caves Velika and Mala Karlovica were closed with concrete walls and a 30 m tunnel was built to connect Karlovica to the surface. However, a minor impact on water retention during dry periods was found assessed (Shaw & Čuk 2015).

RAKOV ŠKOCJAN KARST VALLEY

Before reaching Planinsko Polje, the water sinking in the main ponors of Cerknjško Polje surfaces in an about 1.5 km long and 200 m wide karst valley called Rakov Škocjan (Fig. 2.6). On the upstream side (SE) the water emerges as the Rak River from the cave Zelške Jame. Zelške Jame is about 5 km long and ends in the large collapse doline of Velika Šujca, where the water arrives from Cerknjško Polje via the Karlovica cave system. The entrance area of Zelške Jame is a fragmented system of channels and collapse dolines. The most prominent feature is Mali Naravni Most (Small Natural Bridge; Fig. 2.7a), where an impressive narrow arch, which was part of the former cave ceiling, crosses the collapse doline (Gams 2004).

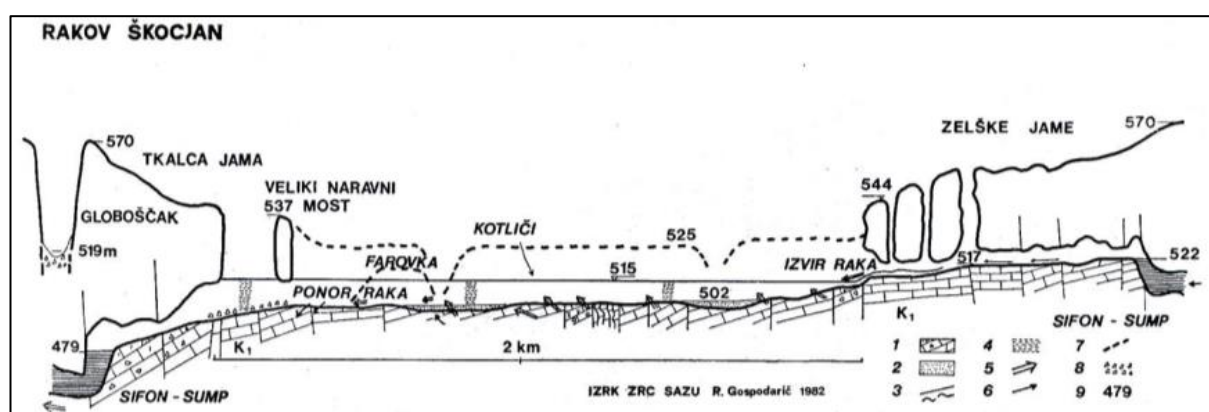


Figure 2.6: Cross-section of the Rakov Škocjan karst valley between the Rak spring at Zelške Jame and the terminal ponor in Tkalca Jama. Legend: 1. rocky bottom; 2. alluvia; 3. fault zone; 4. flood level in 1982; 5. karst spring; 6. water flow directions; 7. terraces; 8. boulder rocks; 9. altitude.

Downstream, the valley widens and several springs (Fig. 2.7b) located along the SW side of the valley (e.g. Kotliči, Prunkovec) form perennial or intermittent tributaries of the Rak River. The valley narrows an impressive natural bridge called Veliki Naravni Most (Big Natural Bridge; Fig. 2.8). The height of the bridge is comprised 9.5 and 17 m, its width is between 15 and 23 m and the length is of 56 m. The rocky arch is made of thick-bedded and anticline-folded Lower Cretaceous limestone.



Figure 2.7: Rakov Škocjan karst valley. a) The arch of Mali Naravni Most. b) Kotliči spring at the beginning of a hydrological event.

After Veliki Naravni Most, the channel opens into a 150 m long canyon that ends at the entrance to Tkalca Jama, an almost 3 km long cave that drains the water towards Planinsko Polje. The connections of the Rak with the water from Cerkniško Polje and with the Unica springs at Planinsko Polje have been proven by several tracer campaigns under different hydrological conditions (Gabrovšek *et al.* 2010; Ravbar *et al.* 2012). An important flow constriction is present before the first siphon of Tkalca Jama and allows flooding to occur regularly. The floods can reach a height of 19 m above the cave entrance (located at 496 m a.s.l.), and large parts of the Rakov Škocjan karst valley are frequently inundated (Drole 2015; Fig 2.8a). Before World War 1, Rakov Škocjan was a private park owned by the Windischgrätz family, while between the First and Second World Wars the Italians used it as a military site. Since 1949 Rakov Škocjan has been is a Landscape Park open to the public.

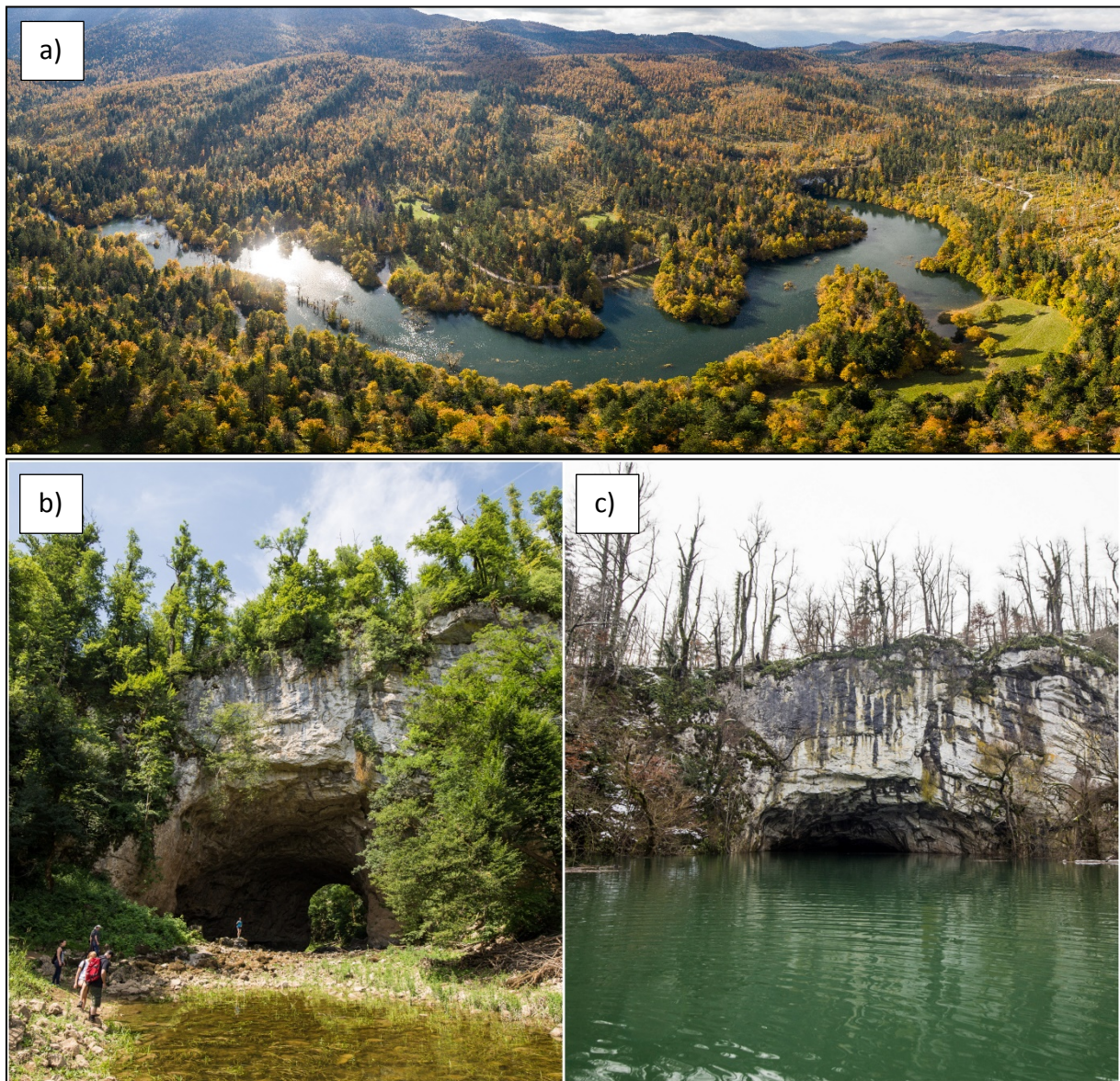


Figure 2.8: a) Flooded Rakov Škocjan Karst Valley in October 2020, b) Veliki Naravni Most (Big Natural Bridge) during dry period in summer; and c) during high water event in winter.

PLANINSKA JAMA

Planinska Jama (Planina Cave) is a large spring cave located on the southern edge of Planinsko Polje (Fig. 2.9a). The cave is about 6.6 km long and consists mostly of large active river passages with cross-sections often larger than 100 m² (Fig. 2.11 left). The cave is known to be the confluence of two important regional rivers (Fig. 2.9b; Fig. 2.10): the Pivka River, which drains a large allogenic catchment through the Postojnska Jama (Gabrovšek *et al.* 2010; Kaufmann *et al.* 2016, Kogovšek 2022) and reaches the confluence with the cave via the Pivka Branch, and the Rak River, which carries water from Rakov Škocjan and Cerkniško Polje via the Rak Branch. Finally, a large amount of water also flows into the Rak Branch via the siphon of the Javornik Current, which is located below the Mysterious Lake (Fig. 2.10) (Kaufmann *et al.* 2020). The water exits the cave under the common name Unica River with a discharge between 0.2 and 90 m³/s (Kogovšek 2022).

The different parts of the aquifer that feed the Unica spring show considerable differences in water contribution (Savnik 1960, Kogovšek 2022). During high water conditions, there is a groundwater divide in the Javorniki Mountains. The water discharges through the western, eastern and northern edges of the massif. Then the nearby Malenščica spring (Fig. 2.10), which is mainly fed by the the autogenic Javorniki water and allogenic water from the Rakov Škocjan reaches a maximum discharge of 9-10 m³/s (Kogovšek 1999; Kovačič 2010, 2011). As the spring is damped, the Rak Branch is activated and acts as an overflow, while the Unica spring also receives water from the Pivka Branch. At low-flow, after the Cerkniško Jezero is drained, the outflow is solely directed towards the Malenščica spring, while the Unica spring is fed exclusively by the Pivka Branch (Kaufmann *et al.* 2020, Kogovšek 2022). The inversion of the flow direction between the Mysterious Lake and the Malenščica spring was numerically simulated with a pipe flow model (Kaufmann *et al.* 2020).

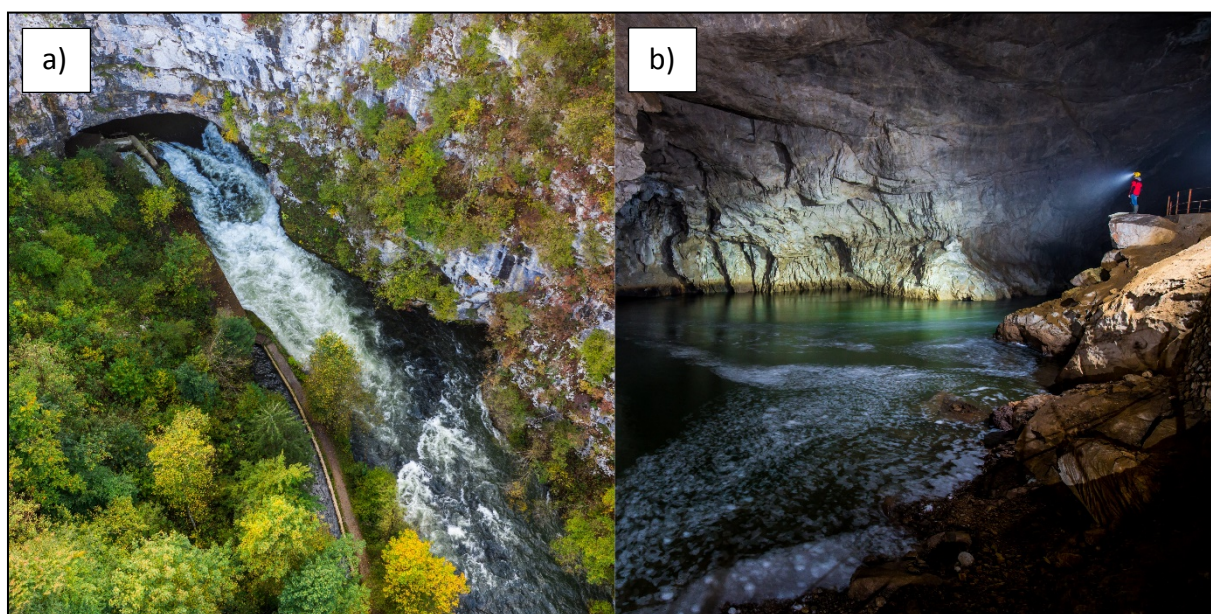


Figure 2.9: Planinska Jama. a) Cave entrance. b) Confluence of the Pivka and Rak Branches.

There are also differences in flow velocities between low and high flow conditions (Petrič *et al.* 2018). In general, the apparent dominant flow velocities in the karst aquifer are five times higher during high water (between 20 and 25 m/h) than during low water conditions (~ 4 m/h). In the well-developed conduit networks of Karlovica-Zelške Jame, Tkalca-Planinska Jama and Postojnska-Planinska Jama, flow velocities were up to fifty or even ninety times higher during high water

(between 170 and 1000 m/h) compared to the velocities observed during low water ($\sim 4\text{--}23$ m/h) (Petrič *et al.* 2018).

The research conducted in Planinska Jama over the last three years focused mainly on studying the hydrological behaviour of the Javornik Current (Gabrovšek *et al.* 2019), a partially explored siphon that connects to the Rak Branch in the so-called Mysterious Lake (Figs. 2.10 & 2.11). For this purpose, water pressure, electrical conductivity and water temperature were automatically recorded in both Mysterious Lake and the Javornik Current sump. The main objective was to find out whether the water coming out of the siphon is suitable for human consumption, to be used as a back-up reservoir for the municipalities of Postojna and Pivka (Gabrovšek *et al.* 2019).

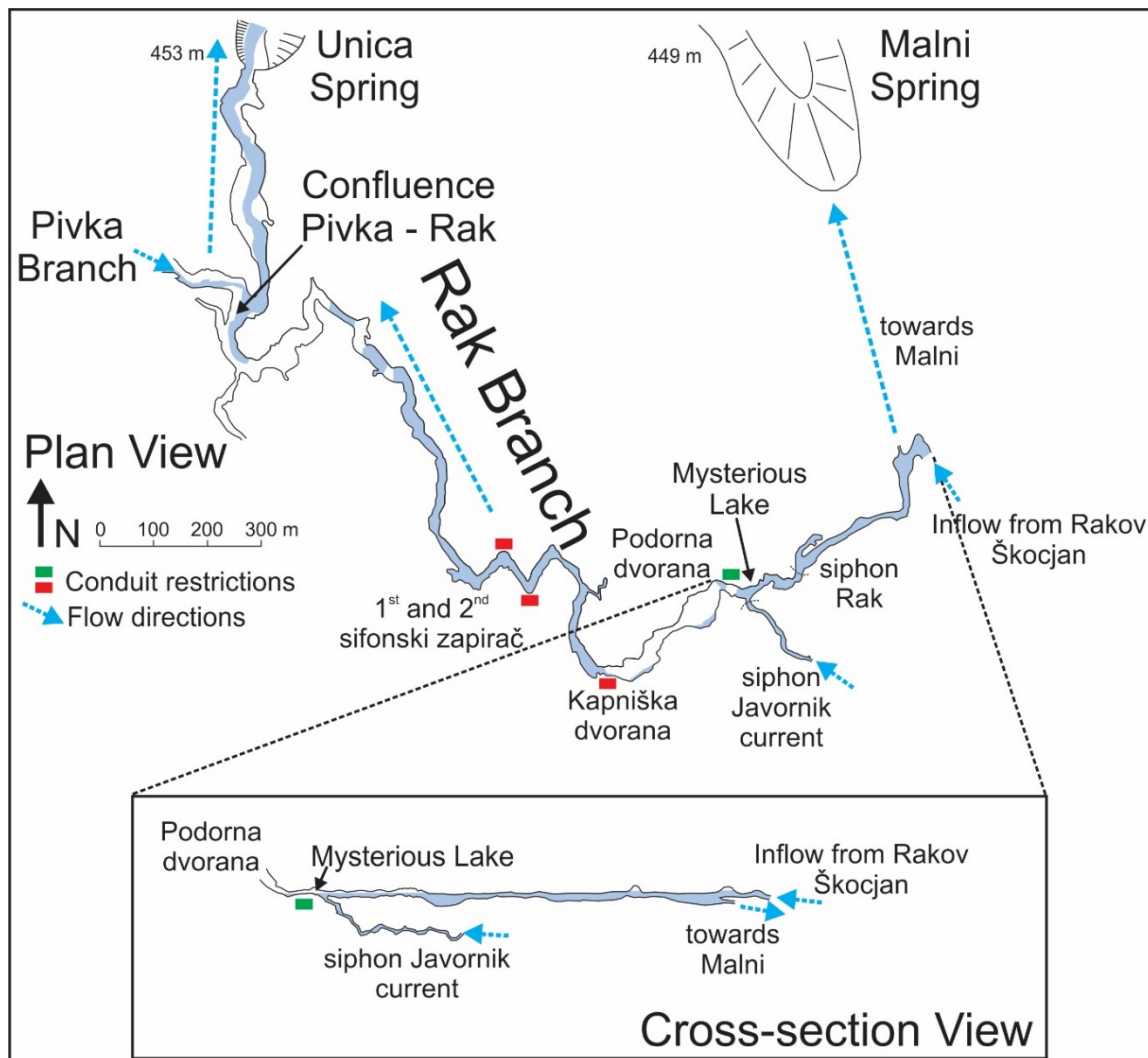


Figure 2.10: Plan and cross-section view of the explored passages of the Rak Branch. The constrictions described in the text are indicated in red and green (Gams 2004; Kaufmann *et al.* 2020).

Rak Branch & Mysterious Lake in Planinska Jama

The Rak Branch (Channel) is a 1.5 km long open-flow channel extending between its junction with the Pivka Branch and its most remote part called Misteriozno Jezero (referred as Mysterious Lake (labelled ML in graphs (Fig. 2.10). The channel has a large cross-section ($> 10\text{ m} \times 10\text{ m}$) along most of its length. Few relatively short constrictions - marked in red on Figure 2.10, show signs of occasional pressurised flow, but are not known to cause substantial backflooding. Minor breakdowns

cause ponding, but do not hinder the flow along the channel. However, two large breakdown chambers divide the continuous stream of the Rak Branch from the Mysterious Lake.

There are two known inflows and two known outflows into/from the Mysterious Lake (Figs 2.10 & 2.11):

- The water from Rakov Škocjan and Javorniki Mountains enters Mysterious Lake along two channels that are submerged and only partially explored.
- The water from Mysterious Lake is diverted towards the Malni Spring and into the Rak Branch further toward the Unica Spring. The conduits toward the Malni Spring are submerged and unexplored.

The flow convergence/divergence at Mysterious Lake has been long known. During low water conditions, the inflow from Javorniki Mountains prevails. The flow along Rak Branch is minimal. The contributions from Cerknjsko Polje and Rakov Škocjan become dominant during medium and high events. The water is diverted between Malni Springs and Rak Branch from Javorniki Channel dominates water and medium-flow conditions, most of the water from the Mysterious Lake is diverted towards the Malni Spring as large breakdowns in Podorna dvorana (marked green in Fig. 2.10, see also Fig. 2.11) prevents outflow along the Rak Branch (Fig. 2.11a). At high water (Fig. 2.11b), the level in the Mysterious Lake rises to accommodate increasing head loss in the conduits connected to the Malni Spring. When the level is above the position of the breakdown pile, the water starts to overflow into the large Rak Branch channel towards the confluence with Pivka Channel.

This mechanism also explains the flow distribution between both Malni Spring and Rak Channel. During low water conditions, the Malni Spring is the main outlet of the system and the flow along Rak Channel is minimal. However, the discharge at Malni is limited to about 9-10 m³/s during high water conditions, where most of the flow is along the Rak Branch to the Unica Spring. This implies a change of the main flow direction due to the activation and deactivation of an overflow, which leads to a spatial and temporal variation of the catchment size and reserves.

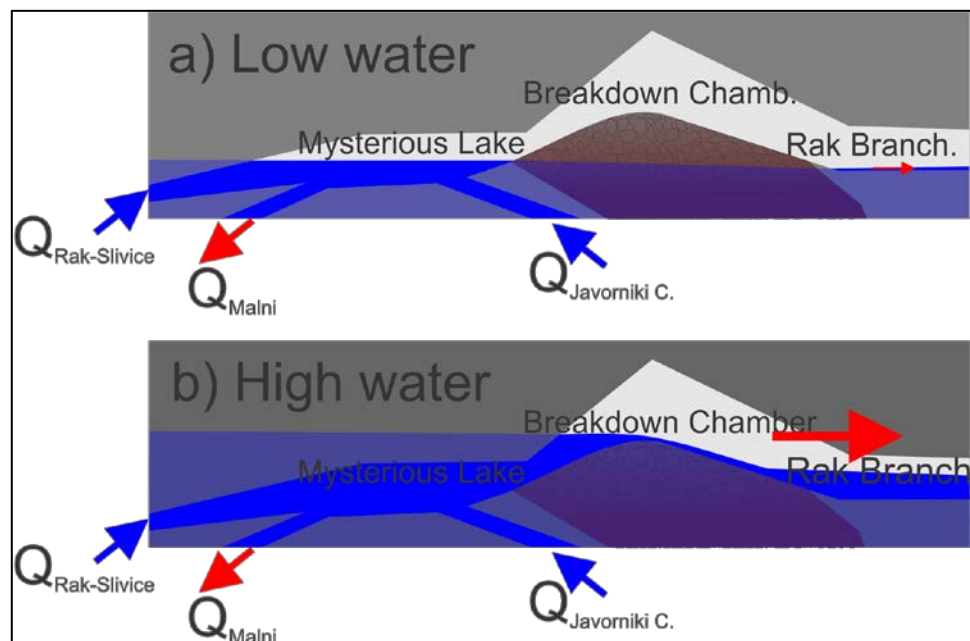


Figure 2.11: Conceptual hydrological model of the Mysterious Lake leading to overflow into the Rak Branch at high water situations; (a) low-flow, (b) high-flow conditions (Kaufmann et al. 2020).

The convincing fit of Kaufmann et al. model left not much space for further exploration. However, it was noted that during diving expedition 1990s at medium water level, the divers report flow direction from the Mysterious Lake into Javorniki Channel, which is also supported by their spot temperature observations. Although, this may be considered non-reliable information, we took it seriously and continued the work.

Figure 2.12 shows the level/temperature hydrograms at Mysterious Lake (ML), Javorniki Channel (JC) and the temperature hydrogram of Tkalcja jama (TJ) during the transition from medium water to high water and recession to low water conditions between the end of April and mid-July 2019.

Initially (Region 1), the water level (red line) in the lake fluctuates between 470 m and 477 m a.s.l. Temperatures at ML and JC are almost equal and follow the temperature at TJ; the diurnal character of the signal is well preserved; the flow through time between the two points estimated from the peak-to-peak temperature shift is 15-25 hours between. The green line presenting the head difference between ML and JC indicates the flow direction ML-> JC.

When the water rises above 477 m a.s.l. (Region2) the temperature curves separate. The temperature in the channel (TJC) drops to a stable value of 8.5 °C, while the temperature in the lake follows that of Tkalcja Jama, albeit shows more noisy character.

If H_{ML} drops below 477 m, the direction of flow reverses to ML-> JC. The T-curves at JC and ML meet again and follow that of TJ. A further drop leads to a further rapid drop in the temperature of the T mass T at JC and ML and to a further reversal of the flow direction towards JC-> ML at $H_{ML} = 470$ m.

The present event is no exception, because each time the level passes the 470 m or 477 m, during the rise or recession, the flow direction reverses. Summarised: The flow has the direction JC-> ML for $H_{ML} < 470.5$ m and direction ML-> JC for $470 \text{ m} < H_{ML} < 477$ m.

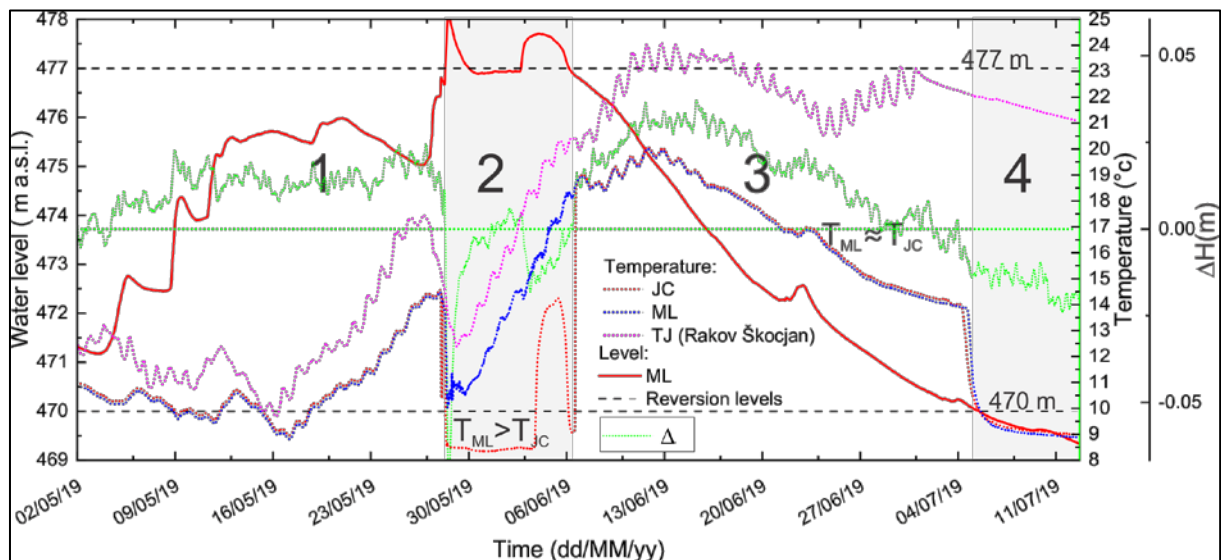


Figure 2.12: Water level and temperature in Mysterious Lake (ML), Javorniki Channel (JC) and Tkalcja Jama (TJ) in spring/summer 2019.

It is surprising that the flow reversal occurs at the same water levels in the lake during the rise and recession for all events.

The above conclusions were further verified by a Doppler velocimeter installed in 2021. Figure 2.13 shows the recorded flow velocities and H_{ML} in autumn 2022. The filled parts of the curves show the situation with the flow direction JC-> ML. As already assumed, the flow velocity at $H_{ML} < 470.5$ m and $H_{ML} > 470$ m is directed from the channel into the lake and vice versa for the heads in between. For some events, this direction is also briefly present for the levels in between, e.g. the spike at the end of the September.

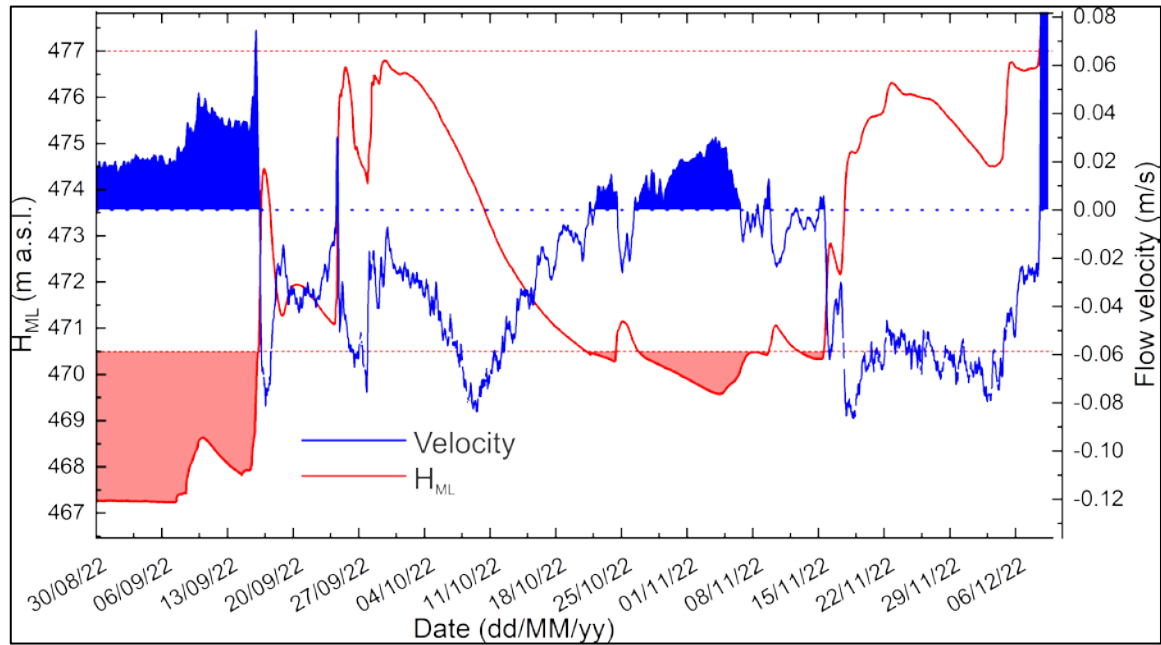


Figure 2.13: Water level in Mysterious lake (H_{ML}) and flow velocity in Javorniki Channel in autumn 2022. Filled curves present periods with flow direction JC->ML.

For a more general picture, Figure 2.14 shows the flow velocity as a function of the water level in lake (H_{ML}). Despite the scatter, the plot shows a clear trend and confirms the above conclusions. Note that the flow velocity through the channel is relatively low. The peak flow in the ML-> JC direction is about twice as large as in the opposite direction, except during the large flood events when the flow from the channel rises above $1.5 \text{ m}^3/\text{s}$ (Fig 2.14a); note that extreme events were not recorded.

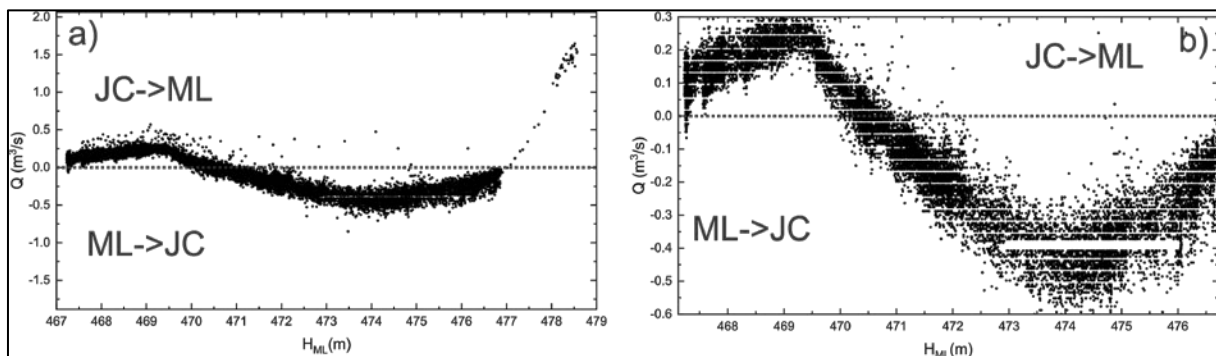


Figure 2.14: Flow rate through Javorniki Channel calculated from the records of Doppler velocimeter; a) Whole range of measurements. b) Zoomed section $467 > H_{ML} < 476$.

The question remains what is on the other side of the channel. On the ML side we have the inflow from the Tkalca Jama (TJ), an outflow into the Malni or Rak Channel and the inflow/outflow into/from the Javorniki Channel. The flow in the Javorniki Channel is controlled by the head difference between ML and the other side (JA). Our knowledge of the head on the other side is based on the observed HML and QJC. We know that the events are diverse enough to produce a wide range of ratios between the inflow from the Rakov Škocjan (TJ) and the Javorniki Mountains. The reason why the flow reversals are tied to a specific water level in the Mysterious Lake must therefore lie in the channel geometry.

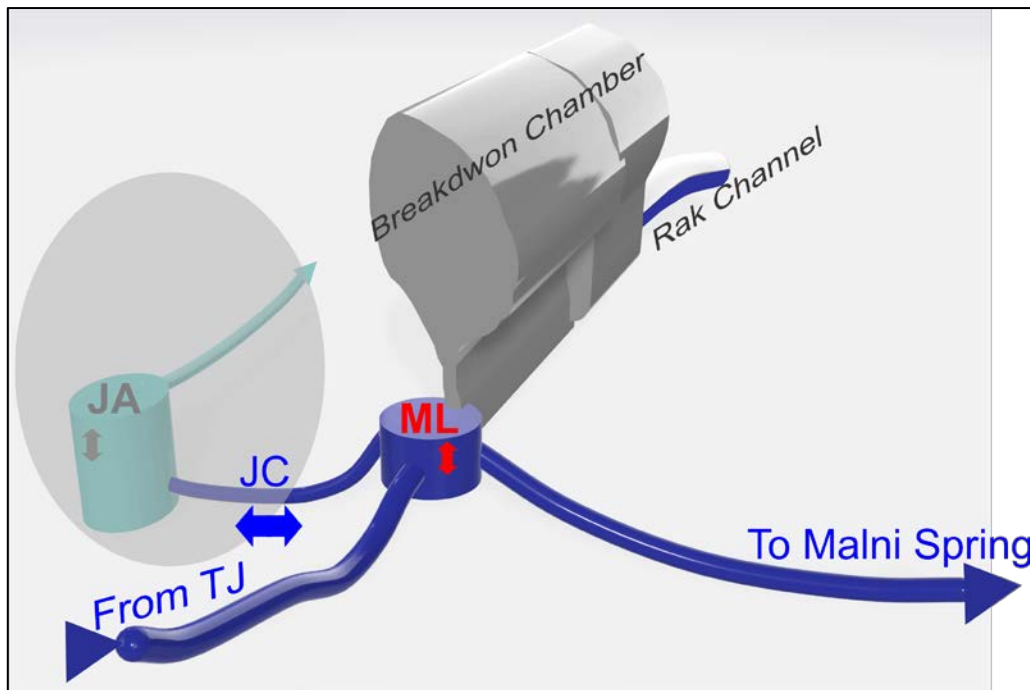


Figure 2.15: A 3D conceptual view of Mysterious Lake and surrounding system. See text.

We speculate on a robust arrangement of channels that would lead to such observations under a variety of inflow conditions. We propose a simple model, shown in Figure 2.15. The model is based on the known settings around the ML as described above. The tributaries to the springs of Malni Springs and inflow conduits from Rakov Škocjan (Tkalca Jama, TJ) are only partially explored. It is possible that their geometry is complicated; we cannot even claim that there is a single connecting channel. The Javorniki Channel is partially known, but not yet fully explored. Between the Mysterious Lake and the Rak Channel, a series of breakdown chambers prevent the free flow from the ML to the Rak Channel. There, the flow is constrained between the boulders and the other breakdown material, only when the level in the lake rises above 477 m, the flow cross-section becomes large, so that the water level does not react to a further increase of in the inflow. The shaded region on Figure 2.15 is speculated. We may assume a water body (lake?) connected to ML via JC; the logical element that assures a flow reversal in JC at 470 m is a conduit at this level, which drains the water efficiently.

Flood pulse propagation between Cerkniško Polje and Planinsko Polje

Combining autonomous long-term monitoring and novel analytical tools allows better insight into the dynamics of groundwater flow. However, a precise look at the data can reveal »hidden gems« which are hard to find by computational techniques; but thorough look at the data may help.

Although the flow between Cerkniško Polje, Rakov Škocjan and Planinska Jama has been studied for centuries, many details are still hidden. An example is shown on Figure 2.16. Figure shows hydrographs at several stations with two distinct events in spring 2019. The first peak was clearly triggered by a series of rain events between May 27th and May 30th. High water level persisted until June 3rd when additional rise of water level at all stations appeared out of the »blue sky«. The peak could not be a response to a rain event. In fact, all regional rain stations show no precipitation, except one which registered 11 mm of rain, which could not have caused the recorded event. It turns out that the peak was caused by the opening of a flood gate that caused additional runoff from the Cerkniško Jezero.

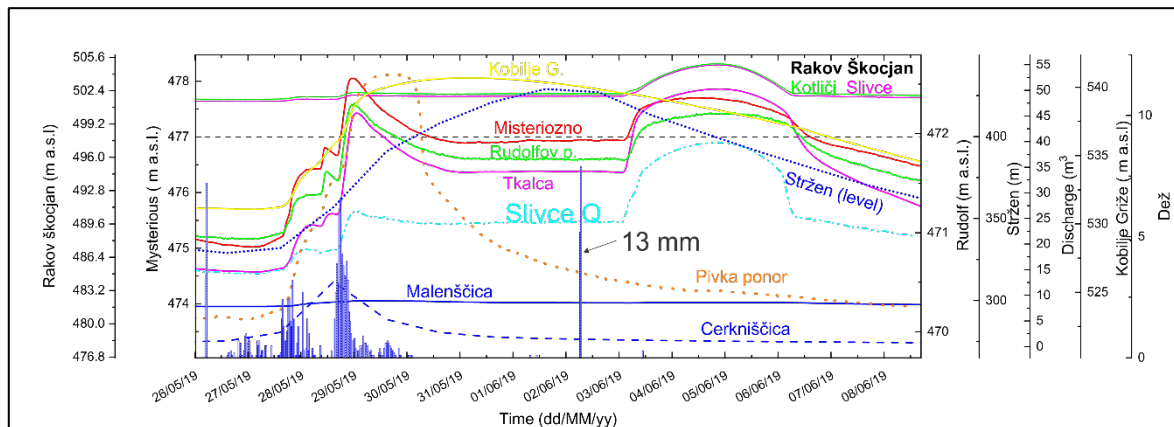


Figure 2.16: Groundwater level and discharge of streams in late May, early June 2019.

The solution came from poorly documented fact that the outflow from Cerkniško Polje is still controlled by opening and closing of the gate at Rakovski Mostek (Nova Karlovica) ponor, which is close to and connected to the Karlovica Cave (Figure 2.17), the main ponor cave of Cerkniško Polje. The gate is opened from late spring till the late autumn and closed in-between. This way farmers have assured grassland in summer and fish has some assured water in winter. At the time of late spring opening, the water level is often relatively dry, so opening of the gate has no or minor effect to the situation downstream. In case of spring 2019 this was not the case.

The transition of flood pulses was fast, it reached the Rakov Škocjan in 2-5 hours and one hour later the rise started at Mysterious Lake and Rudolfov Pristan in Planinska Jama (Figure 2.18). Fast transition indicates that the large part of the flowpath is hydraulically connected.

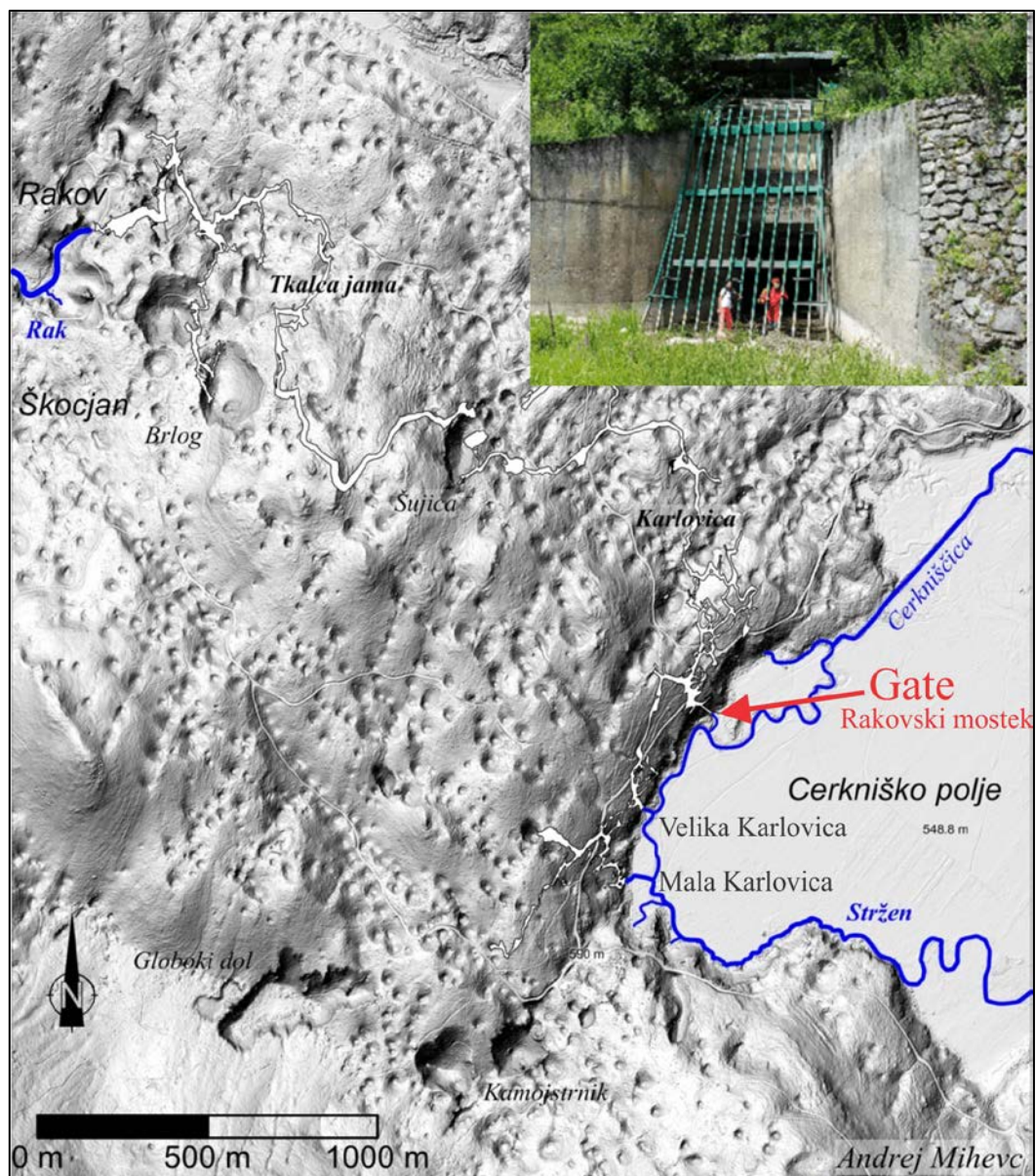


Figure 2.17: Flood gate at the W border of Cerknjško polje, leading to Karlovica Cave.

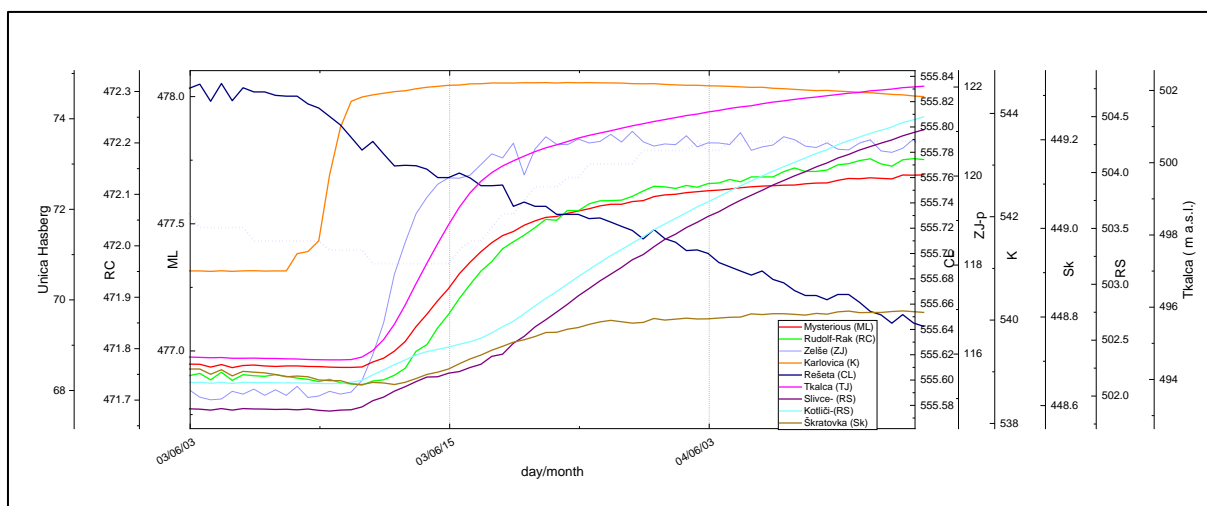


Figure 2.18: Onset of a flood event caused by flood gate opening in Cerknjško Jezero.

The situation in Cerkniško Jezero as recorded in Rešeta Station (CL) was stable before the opening, which means that the inflow to the polje equals the outflow. After the opening the level starts to drop with initial rate of 0.3 m/day. Taking this rate and lake area of about 20 km², we estimate that initial additional outflow due to gate opening in the order of 70 m³/s.

The reaction is visible along the Cerkniško Polje-Rakov Škocjan-Planinsko Polje line. The travel time of lake water to observation points can be evaluated from the phase shift of diurnal maxima and minima. In the Javorniki Channel the temperature changes about 25 hours after the water level rise and 28 hours after the gate opening.

The relative size of two peaks depends on location (Figure 2.19). While the first peak is the result of rain event in the entire catchment, the latter is the result of increased discharge from the lake alone. The second peak is dominant in Rakov Škocjan (where the first peak is minimal), but not at Mysterious Lake, Rak Channel and Škratovka. Second peak is also visible in Unica discharge curve, however the discharge increases for about 3 m³/s.

The level rise along the Karlovica- Rakov Škocjan-Tkalca Jama is much higher during second peak, indicating that Cerkniško Polje is the main contributor to this site.

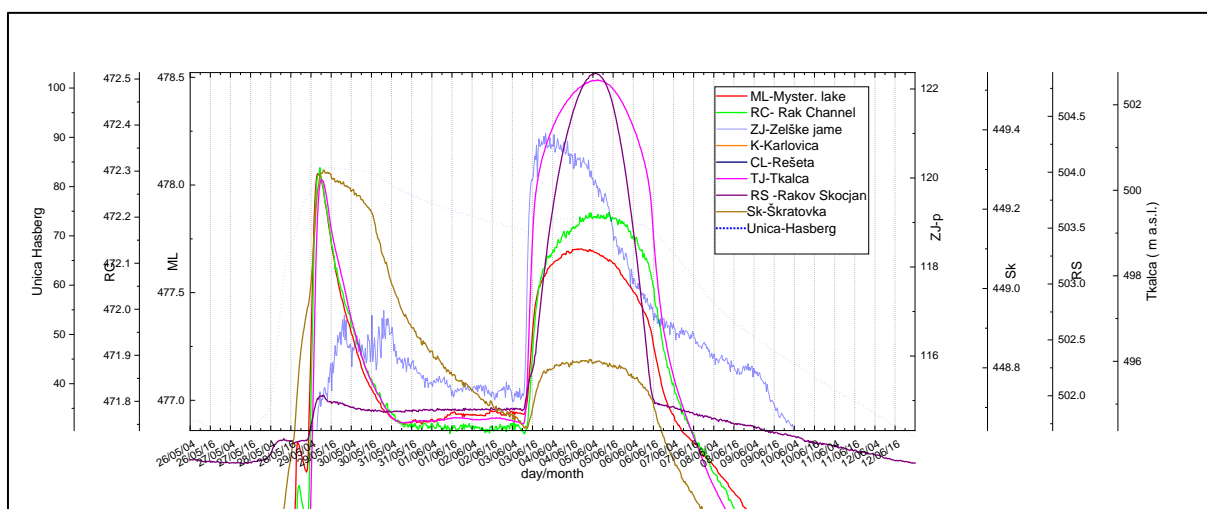


Figure 2.19: The relative size of peaks gives new insights into the distribution of recharge areas.

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Whole-day field trip (C):

RADENSKO POLJE

Thursday, June 20th 2024, 08:30-18:00

Nataša Ravbar, Blaž Kogovšek, Cyril Mayaud, Matej Blatnik, Metka Petrič

Stops:

- | | |
|------------------|---------------------|
| 1 – Ponikve | 4 – Dobravka ponors |
| 2 – Mala Račna | 5 – Krka spring |
| 3 – Zatočne jame | |



Obisk Radenskega polja

Celodnevno terensko delo (C); četrtek, 20. junij 2024;

The Radensko Polje lies on the south-eastern outskirts of the Grosuplje Basin. It covers an area of over 4 km² at an altitude of around 325 m and is one of the smallest karst poljes in Slovenia. It is surrounded by steep slopes, only the north-western edge is open to the Grosuplje Basin. From this side, the Grosupeljščica River flows into the Polje, which is renamed Dobravka at its confluence with the Podlomščica River. In the northern part of the Polje, it sinks already at low water level, and when the water level rises, it continues its course for a little more than a kilometer and sinks into the ponors on the eastern side of the Polje (Fig. 3.1).

There are numerous estavelles in the western part of the Polje, such as Tinčetov Rep, Novljanovo Retje, Špeharjevo Retje and Zelenka. At higher water levels, the water of the Zelenka overflows into the riverbed and flows two kilometers to the ponors on the eastern edge of the Polje. During dry periods, the estavelles dry out. Between Novljanovo Retje and Zelenka there is a small stream and the Pirka marshland. In the southern part of the Polje, the Šica appears in the form of several karst springs, crosses the Polje in a west-easterly direction and meanders for three kilometers to the ponors on the southeastern edge of the Polje.

In the Polje at different water levels, the water sinks either in its northern part or on its eastern edge. At high water, the Dobravka, Zelenka and Šica watercourses merge and flow towards Zatočne Jame. These are part of the biospeleologically important Viršnica cave system with three

entrances – Viršnica, Lazarjeva Jama and Zatočna Jama (No. 569, 570, 571; Cave Registry 2023). The rising waters of Radensko Polje normally flow directly to the springs of the Krka River, which are only about five kilometers away. At high water levels, they reappear on the surface in the form of the Radenščica River in Lučke Dol. The extremely high water level in Radensko Polje forms an intermittent lake that reaches as far as the first houses in the villages of Zagradec and Velika Račna.

Lithologically Radensko Polje consists of very pure carbonate rock from the Jurassic period. Its western edge consists of gray and dense oolite limestone and granular dolomite, while the eastern edge consists of gray, dense limestone with lithiotides. Triassic dolomite occurs only on the north-eastern edge around Boštanj. The bottom of the Polje is covered with 5 to 10 m thick layers of clay with gravel, underneath are Holocene layers with a larger amount of dolomite gravel and sand. The Polje is intersected by a fault of the Dinaric direction (Meze 1981, eGeologija 2023). In the middle of the Polje, the solitary dolomite hum named Kopanj rises 70 meters above the plain.

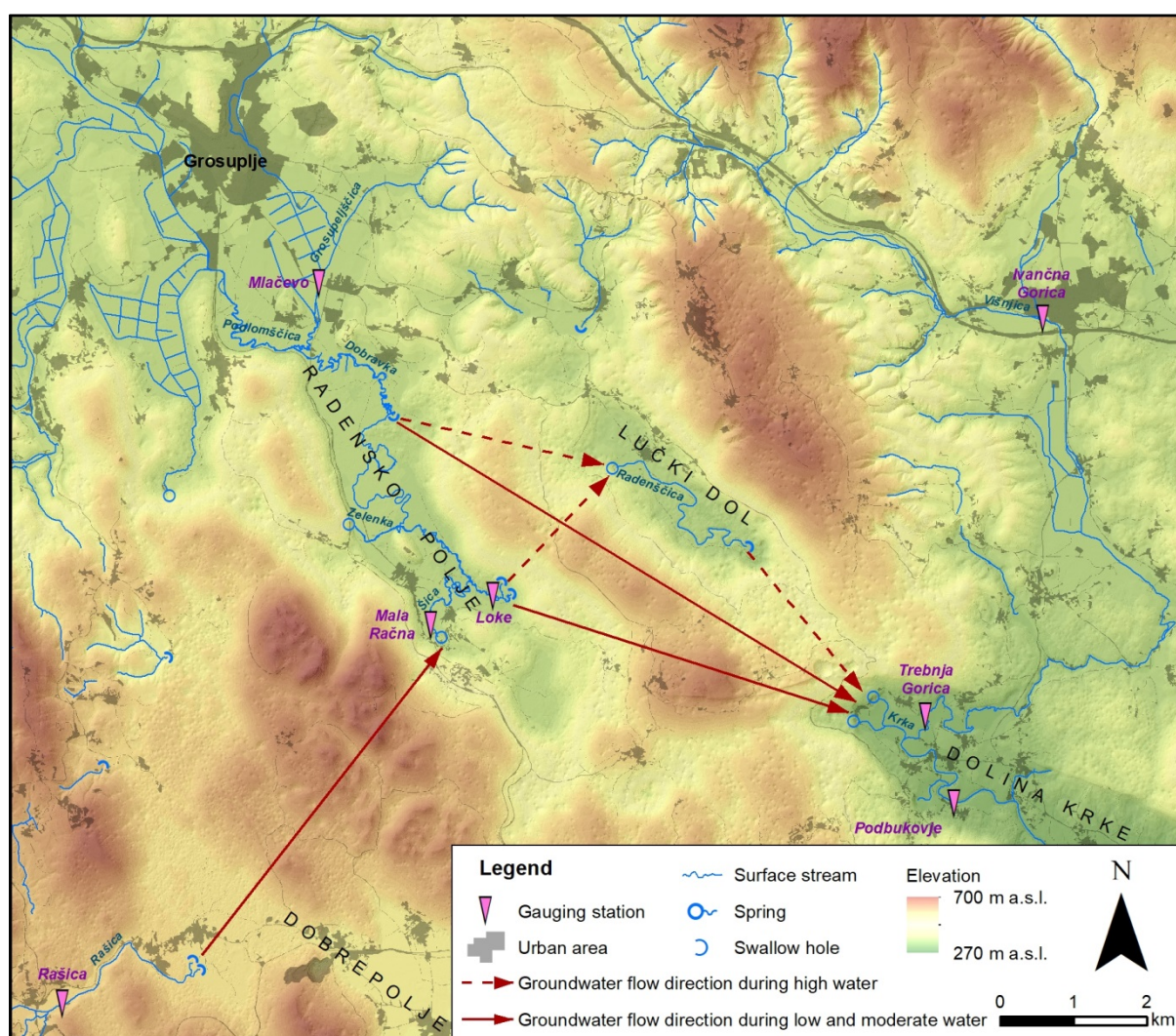


Figure 3.1: Geomorphology and hydrology of the Grosuplje Basin and Radensko Polje.

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Whole-day field trip (D):

REKA-TIMAVO FLOW SYSTEM

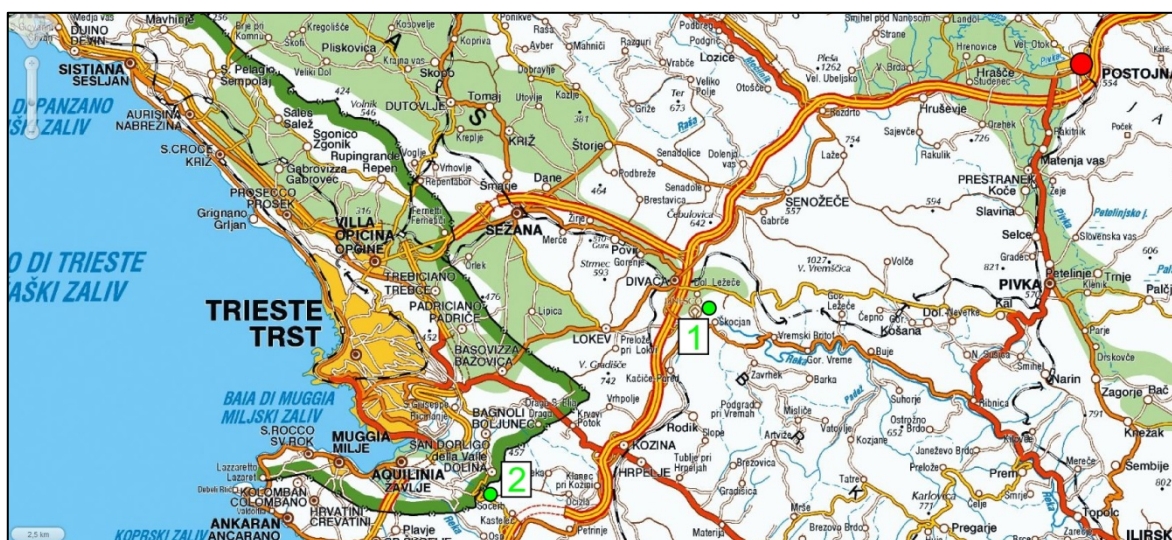
Friday, 21st June 2024, 9:00–16:00

Franci Gabrovšek, Andrej Mihevc

Stops:

1 – Škocjan Caves

2 – Socerb



Sistem Reka-Timava in njen tok vode

Celodnevno terensko delo (D); petek, 21. junij 2024;

Kras se razteza med Škocjanskimi jamami, Sočo, Vipavsko dolino in Tržaškim zalivom. Zaradi specifičnega razvoja in strukturne zgradbe, je vodonosnik Krasi izjemno kompleksen, kar se kaže tudi v veliki dinamiki podzemne vode. To v veliki meri pogojuje režim reke Reke, ki ponira v Škocjanskih jamah. Izjemna spremenljivost pretoka Reke povzroča veliko in hitro spreminjanje nivoja podzemne vode v celotnem vodonosniku. Iz dolgo časovnih zapisov nivojev in temperature lahko sklepamo tudi o strukturi vodonosnika. V Škocjanskih jamah smo februarja 2019 zabeležili največji poplaveni dogodek po letu 1964. Poplavne dogodke lahko zaznavamo tudi z geofizikalnimi in natančnimi geodetskimi meritvami. Vodonosnik Krasi izteka skozi številne izvire med Nabrežino (Aurisina) in Tržičem (Monfalcone). Največji so izviri Timave pod vasjo Štivan (San Giovanni di Duino), ki ob nižjih vodostajih večino vode dobijo iz Soških naplavin, ob poplavnih dogodkih pa je prevladujoč dotok Reke. Izviri Timave so tudi vhod več kot 2 km dolgega jamskega sistema.

THE AQUIFER OF KRAS/KARSO PLATEAU

Geological and hydrogeological settings of the Kras/Carso plateau

The Kras/Carso Plateau extends in a northwest–southeast (NW–SE) direction between the Bay of Trieste in the southwest (SW) and the Vipava Valley in the northeast (NE) (Fig. 4.1). The plateau is ~40 km long and 13 km wide. Apart from the some higher mountains in the central part, it has a low relief and is covered by numerous dolines and other karst features, with about 4000 known caves. The surface generally dips from SE to NW, between 400–500 m a.s.l. in the SE, down to 100 m a.s.l. in the NW.

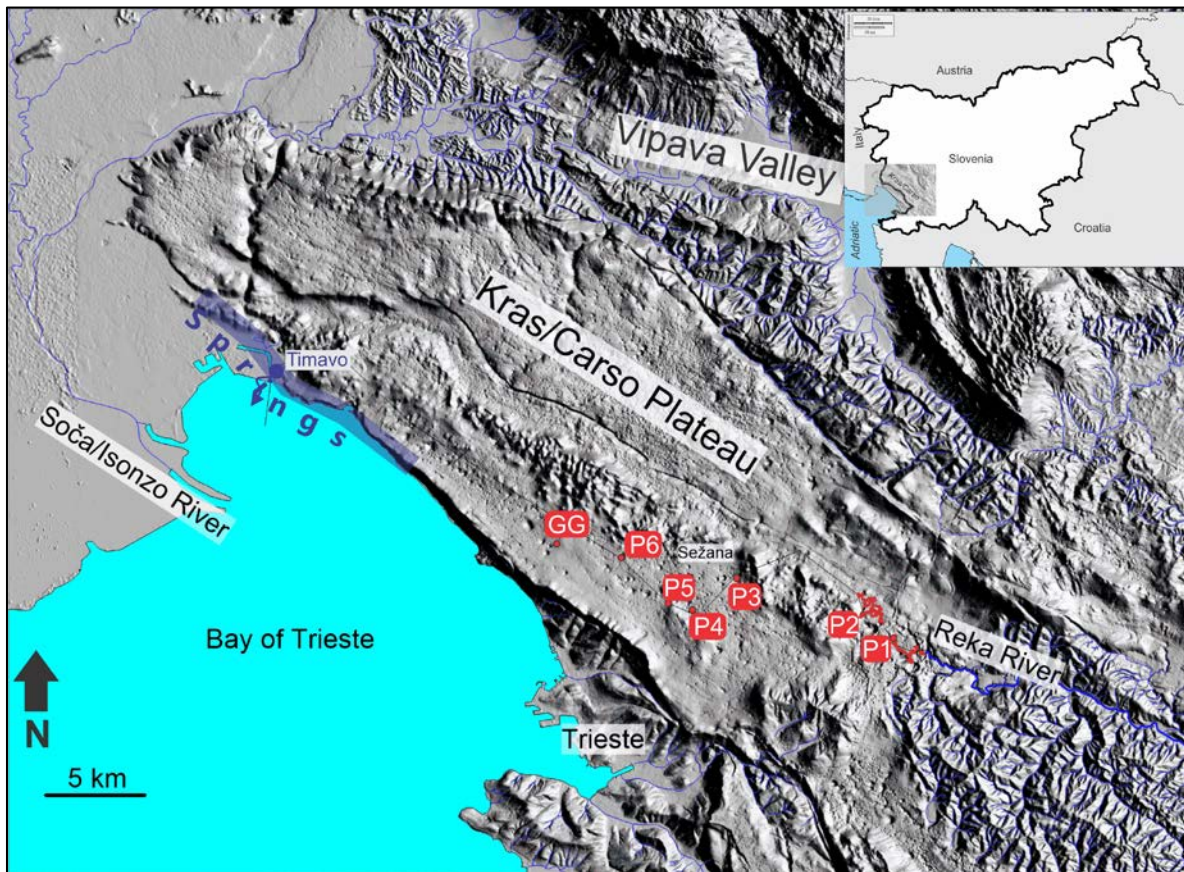


Figure 4.1: A relief map of Kras/Carso Plateau limited by the Soča River alluvium in the west, the Adriatic Sea in the south and southwest and flysch areas with clear fluvial network (blue lines) on other borders. Points P1–P6 denote the main reaching the groundwater flow; 1. Škocjan Caves, 2. Kačna Jama (Snake Cave), 3. Jama 1 v Kanjaducah, 4. Brezno v Stržinkni dolini, 5. Abisso di Trebiciano (Labodnica), 6. Grotta Meravigliosa di Lazzaro Jerko, GG. Grotta Gigante. Upper right: broader geographical position of the area. The thick blue transparent line shows the outflow region.

Figure 4.2 presents the simplified geological situation. The plateau is made up of a succession of Cretaceous to Lower Paleogene carbonates deposited on the Adriatic–Dinaric Carbonate Platform (Buser *et al.* 1968; Jurkovšek *et al.* 2016). The geological structure of the broader area is a result of the collision between the Apulian and Eurasian lithospheric plates. The Kras Plateau is an anticlinorium, which structurally belongs to the External Dinaric Imbracted Belt, a part of the thrust system of External Dinarides, which furthermore underthrusts below the Southern Alps. Underthrusting also resulted in an en-echelon formation of strike slip faults. Several fault systems

cross the area, typically along the so-called Dinaric SE–NW and cross-Dinaric direction. The most recent structural description of the area can be found in Placer (2008, 2015). Some faults have been identified that affect the ground water flow (Šebela 2009; Žvab Rožič *et al.* 2015). The carbonates are surrounded by flysch, which provides the input of allogenic water on the SE, while at the same time prevents outflow along the SW boundary. This way, the main flow is forced to follow the Dinaric (SE–NW) direction. Along the NW coast of the Trieste Bay, the topographical elevation of the limestone flysch contact is low enough to permit outflow through numerous karst springs. Among these, the Timavo Springs, with an average discharge of almost 30 m³/s are the most important.

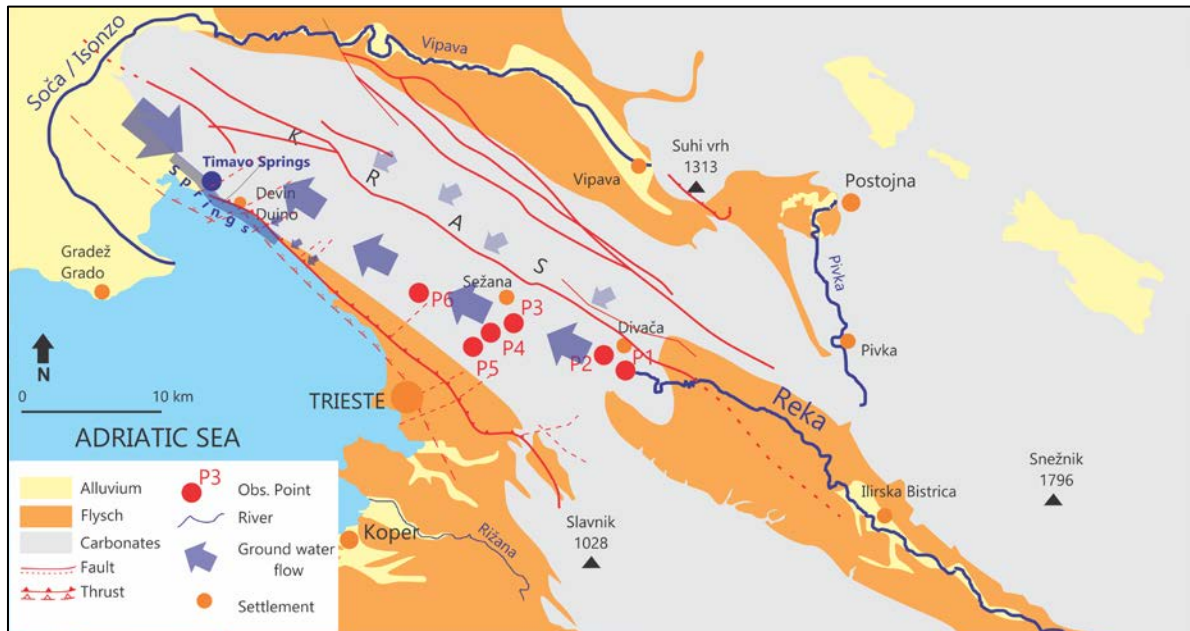


Figure 4.2: Simplified geology of the area with the main lithological units and structural elements. P1–P6 mark the position of the caves with groundwater flow. Blue arrows indicate the general ground water flow direction towards the springs.

The Reka River is the main allogenic input to the system; ~41 % of its catchment is karstic and ~54 % is underlain by flysch. It flows ~50 km on the impermeable flysch rocks, continues for another 7 km as a surface flow on a limestone terrain, sinks at the Škocjan Caves and contributes to the springs in the Trieste Bay (Fig. 4.1). The straight-line distance between the Škocjan Caves and the Timavo Springs is ~33 km. The average discharge of the Reka River in the period 2007–2013 was 7.1 m³/s, while the long-term average (1952–2013) is about 8 m³/s. The ratio between the highest and the lowest flow rate is ~1700, with the maximum measured discharge 305 m³/s, and the minimum 0.18 m³/s. It should be noted, that the Reka River makes an important contribution to the Timavo Springs during high flow, however, during mean and base flow, most of the spring water originates from the Soča alluvium in the NW (Doctor 2008) and from diffuse infiltration from rainwater (Civita *et al.* 1995). In other words, the Soča River provides the base flow while the Reka River and diffuse infiltration from the surface contribute the variability of the Timavo and other springs.

The climate of the area is transitional from Mediterranean to continental, with precipitation ranging from 1400 mm/y close to the Adriatic Sea to < 1800 mm/y in the inland NE part of the Kras Plateau. Yearly precipitation in the mountainous catchment of the Reka River can reach > 2000 mm. These areas form an important orographic barrier where extreme precipitation events (e.g., 250 mm in 12 hours) have been recorded.

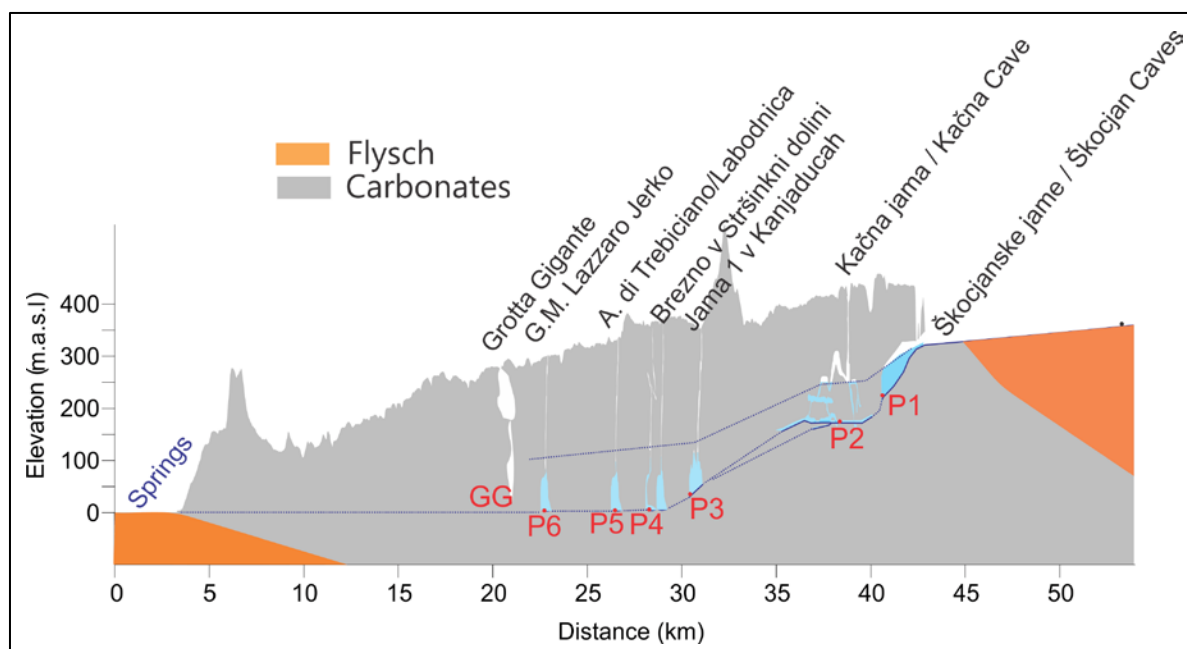


Figure 4.3: Simplified cross-section of the Kras/Carso Plateau between the Škocjan Caves and the springs along the NW coast of Trieste Bay. The dotted blue lines denotes the position of the base flow and extreme floods. P1 to P6 indicate the positions of the observation points used in this work. Vadose parts are filled white, while phreatic and epiphreatic parts are filled by light blue. Higher base flow line between P2 and P3 denotes flow along the partially known overflow channels in this segment.

The epiphreatic flow of the Reka–Timavo system

The Kras/Carso Plateau is a complex speleological environment with many relict caves distributed through the entire thickness of the vadose zone. The sediments in the oldest, topographically highest caves, were dated to > 5 Ma (Gabrovšek *et al.* 2018). The Reka River reaches the flysch–limestone boundary ~7 km upstream from the Škocjan Caves. Before sinking underground, it flows along a limestone canyon where it already loses some flow. The Reka starts its underground flow at Škocjanske Caves (P1 in Figs. 4.1, 4.2 & 4.3), where flow is more or less uninterrupted and follows the channels of extreme dimensions until the available cross-section drops by three orders of magnitude at Martel's chamber. Škocjan Caves end with a sump, not yet explored. About 800 m NW Reka reappears in Kačna Jama (P2 in Figs. 4.1, 4.2 & 4.3). The cave is >13 km long and 280 m deep. The lower epiphreatic level is dominated by the flow of the Reka River, which mostly flows in an open channel during low to medium hydrological conditions, when water leaves the cave through the terminal sump at 156 m a.s.l. The base level sump has limited flow capacity, as soon as the recharge surpasses 15 m³/s, it is diverted to the sequence of large overflow galleries. More than 2 km of the overflow channels, interrupted by perched sumps, have been explored. Currently sump No. 4 is waiting for eventual new explorers. The underground flow can be reached again ~5 km to the SW in the Jama 1 v Kanjaducah (P3 in Figs. 4.1, 4.2 & 4.3). The cave is 330 m deep and ~1.5 km long. Its geometry is rather simple, dominated by the large inclined gallery, which sinks practically uninterruptedly from 20 m below the surface to the Reka River channel. The main channel of the Reka River is > 60 m high, < 50 m wide and 600 m long. It narrows and lowers only near the inflow and outflow sumps. Both sumps have been explored; behind the outflow sump over 300 m of vadose passages were found that again end in sumps. About 2.6 km SW from P3 is the next observation point in Brezno v Stržinkni dolini (P4 in Figs. 4.1, 4.2 & 4.3). The entrance is at 344 m

a.s.l., the cave follows a system of vadose shafts that lead to a large chamber where the underground flow is reached at an altitude of about 10 m a.s.l. Along the floodwater maze, the cave connects to another, more recently explored cave. These caves share a typical geometry with other caves in the lower part of the Reka–Timavo system: a system of vadose shafts that generally increase in size with depth and end with a large chamber (often > 100 m high and > 1000 m² in cross-section). The system of vadose shafts is connected via small channels that often required a lot of digging to pass. The upstream sump from Brezno v Stršinkni dolini was explored by divers to a maximum depth of 60 m, which is 38 m below sea level. The most well-known among the caves in the lower part of the Reka–Timavo system is Abisso di Trebiciano (Labodnica Cave) (**P5** in Figs. 4.1, 4.2 & 4.3), about 1 km west from the Brezno v Stršinkni dolini, just across the border in Italy. When explored in the 19th century, it was the deepest cave at the time. Its depth is 329 m and reaches the Reka–Timavo flow at about 12 m a.s.l. The last observed cave was Grotta Miravigliosa Lazzaro Jerko, a further 3.4 km NW from the town of Trebiciano (Italy). The low ground water stand in the cave is about 4 m a.s.l. (**P5** in Figs. 4.1, 4.2 & 4.3). Few kilometres from the P2 is the Grotta Gigante (**GG** in Figs. 4.1, 4.2 & 4.3), which deepest point is also reached by the high waters. Between Grotta Gigante and the springs of Timavo, Abisso Massimo and Grotta Lindner reach the groundwater level. Recent explorations will surely open new paths to the level of the Reka–Timavo flow. These caves could become the future observation sites. Little is known about the structure of the deeper phreatic zone. However, the base level in the geological past was often well below the present, favouring conduit development in what is now a deep phreatic zone. A well-karstified phreatic zone is also indicated by the observation that during very dry periods, when the discharge of the allogenic Reka River falls below 500 l/s, the stream loses all its water before reaching the Škocjan Caves.

Characteristics of flood propagation through the Reka–Timavo system

During last two decades epiphreatic flow was monitored with autonomous loggers in most caves reaching the flow. Figure 4.4 shows the response of the system (P1–P5, see Fig. 4.1, 4.2 & 4.3) to a large flood in December 2008.

Details on monitoring, interpretation and modelling can be found in Gabrovšek *et al.* (2018). Here we outline just some conclusion of their work:

- Floods in Škocjan Caves (P1) and Kačna Jama (P2) are controlled by local restrictions. During large events, back-flooding of Škocjan Caves and Kačna Jama are caused by the same restriction.
- The base outflow sump in Kačna Jama drains water effectively until the discharge is below 15 m³/s. When this is surpassed, the flow is diverted along higher positioned overflow galleries. This can drain efficiently flow rates up to 130–150 m³/s. At higher discharge the levels in Kačna Jama and Škocjan Caves rise very fast with increasing flow. The rate of the level rise can reach 10 m/h.
- Analysis of temperature hydrographs showed that a large amount of perched water is stored in the galleries between P2 and P3 between successive floods.
- The level in the lower part of the system P3–P6 reacts very simultaneously, indicating uniform variations of water level in this part of the system.

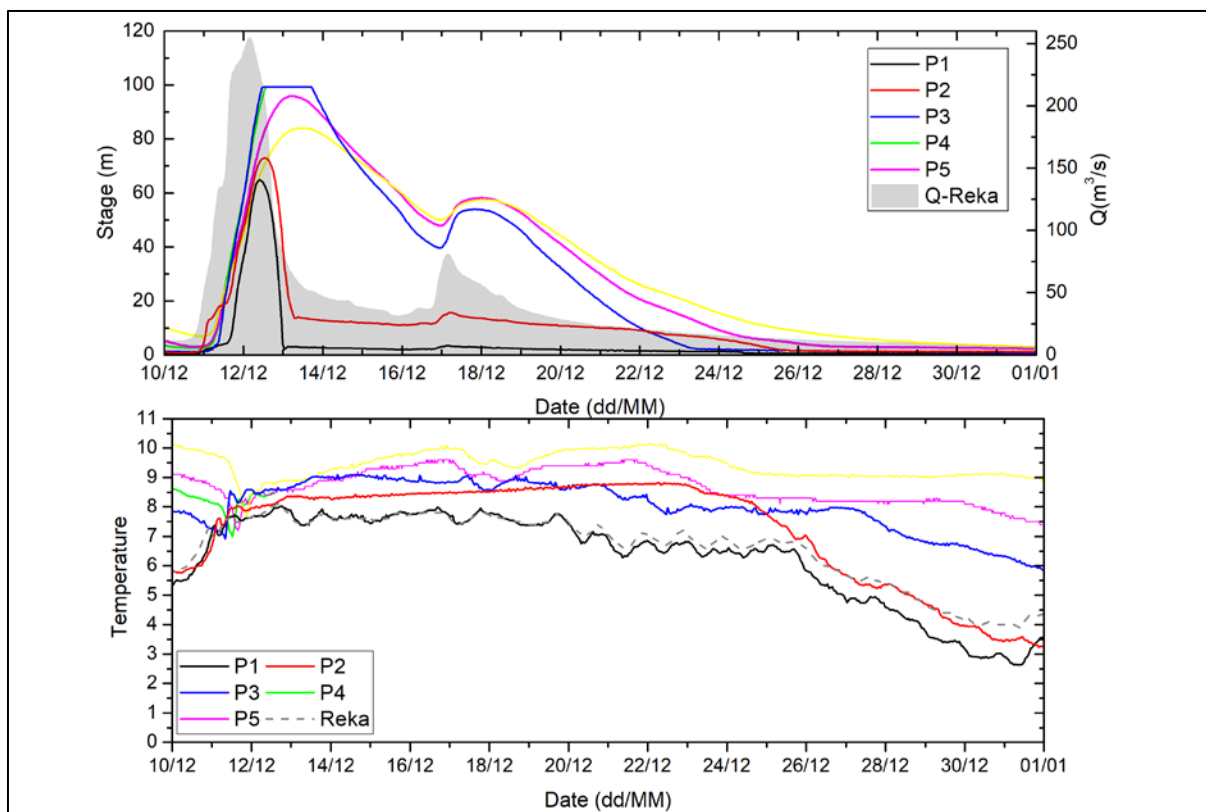


Figure 4.4: Level and temperature hydrographs recorded in caves of the Reka-Timavo system during major flood in December 2008.

Flood event in February 2019

Between January 27th and February 4th 2019 over 300 mm (almost 200 mm in the most intensive 30 h period) of rain fell in the mountainous region of Mt. Snežnik and about 150 mm in the area of Škocjan. The discharge of Reka at the gaging station Cerkvenikov Mlin peaked at 300 m³/s. During the event the water in Škocjan Caves rose with rates up to 10 m/h and reached the level of 305 m a.s.l. in Martel's chamber and about 307.5 m a.s.l. in Šumeča Jama. The flood was largest in the last 50 years. High water caused severe damage to infrastructure and deposited a considerable amount of mud; at some places the thickness of fresh deposits was above 50 cm.

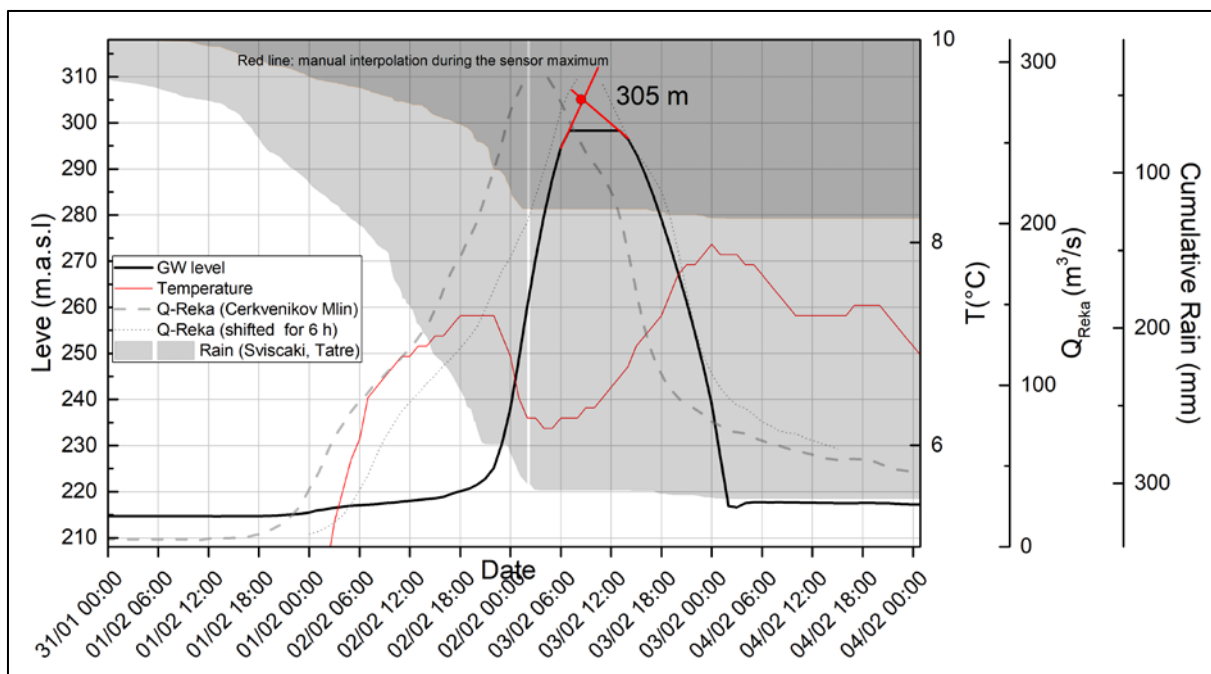


Figure 4.5: The flood event of 2019: Cumulative rain at two stations, discharge of Reka and level and temperature in Martel's chamber. Dotted grey line shows discharge shifted for six hours, an estimated travel time from gaging station to Martel's chamber.



Figure 4.6: The water rose for over 90 m during floods in February 2019. The flood caused severe damage in infrastructure and deposited a thick layer of mud. Lower right: a satellite picture of Timavo springs region on February 5th (Photos: Borut Lozej, Škocjan Caves Regional Park). Below: rough cross-sectional schematic view of water level during the 2019 flood.

Geophysical and geodetic response to floods

Continuous recording gravity stations were installed above the Škocjan Caves and inside Grotta Gigante in 2018 (Pivetta *et al.* 2019). The Škocjan Caves serve as a test site because the cave geometry and the hydraulic system here are well known. Gravitational response of 2019 flood was clearly recorded and the records are currently being analysed. Furthermore, high overpressure (up to 10^6 Pa) may form in conduits during flood propagation. This could result in measurable terrain uplift as discussed in recent paper by Braitenberg *et al.* (2019).

ŠKOCJANSKE JAME (ŠKOCJAN CAVES)

A brief speleological review

Škocjanske Jame (Škocjan Caves) are 5.8 km long cave (Fig. 4.7) formed by the river Reka that enters the cave at an altitude of 314 m a.s.l., flows towards Martelova Dvorana (Martel's Chamber) at 214 m a.s.l. and to terminal sump at 190 m a.s.l. (i.e. 124 m lower). At low water levels the Reka sinks before it enters the cave. Floods usually reach up to 30 m. The largest known flood in the 19th century raised the water table level by 132 m. The largest chambers are Martelova Dvorana, with a volume of 2.6×10^6 m³, and Šumeča Jama with 0.87×10^6 m³ (Mihevc 2001). Some of the big chambers have been transformed into collapse dolines like Velika and Mala dolina. Škocjanske Jame are developed on a contact area of Cretaceous thick-bedded rudist limestone and Paleocene thin-bedded dark limestone (Šebela 2009).

The first paths in the cave area were made in 1823, but construction of paths for exploration and for the visitors started in 1884. Cave exploration was done by cavers of DÖAV (Littoral section of Austrian Alpine Club) from Trieste. The most important explorers were Anton Hanke and Joseph Marinitsch. In 1891 they had already reached the final sump in the cave.

In 2019 a new connecting surface and Martel's chamber was explored. In the cave two large passages were found that offer promising leads along the high flood pathways. In 2018 and 2019 a complete lidar scan of the caves was made.

Because of the caves' extraordinary significance for the world's natural heritage, the Škocjanske Jame were included in UNESCO's World Heritage List in 1986. The Republic of Slovenia pledged to ensure the protection of the Škocjanske Jame area and therefore adopted the Škocjanske Jame Regional Park Act.

the water table in the cave was 340–300 m above sea level and the gradient was towards the SW. The Reka formed new passages or adopted old passages by bypassing or paragenesis, respectively. The large galleries with paragenetic ceilings were formed in the entrance part of Škocjanske Jame (Mahorčičeva and Mariničeva Jama, Tomičeva Jama, Schmidlova Dvorana and Tiha Jama).

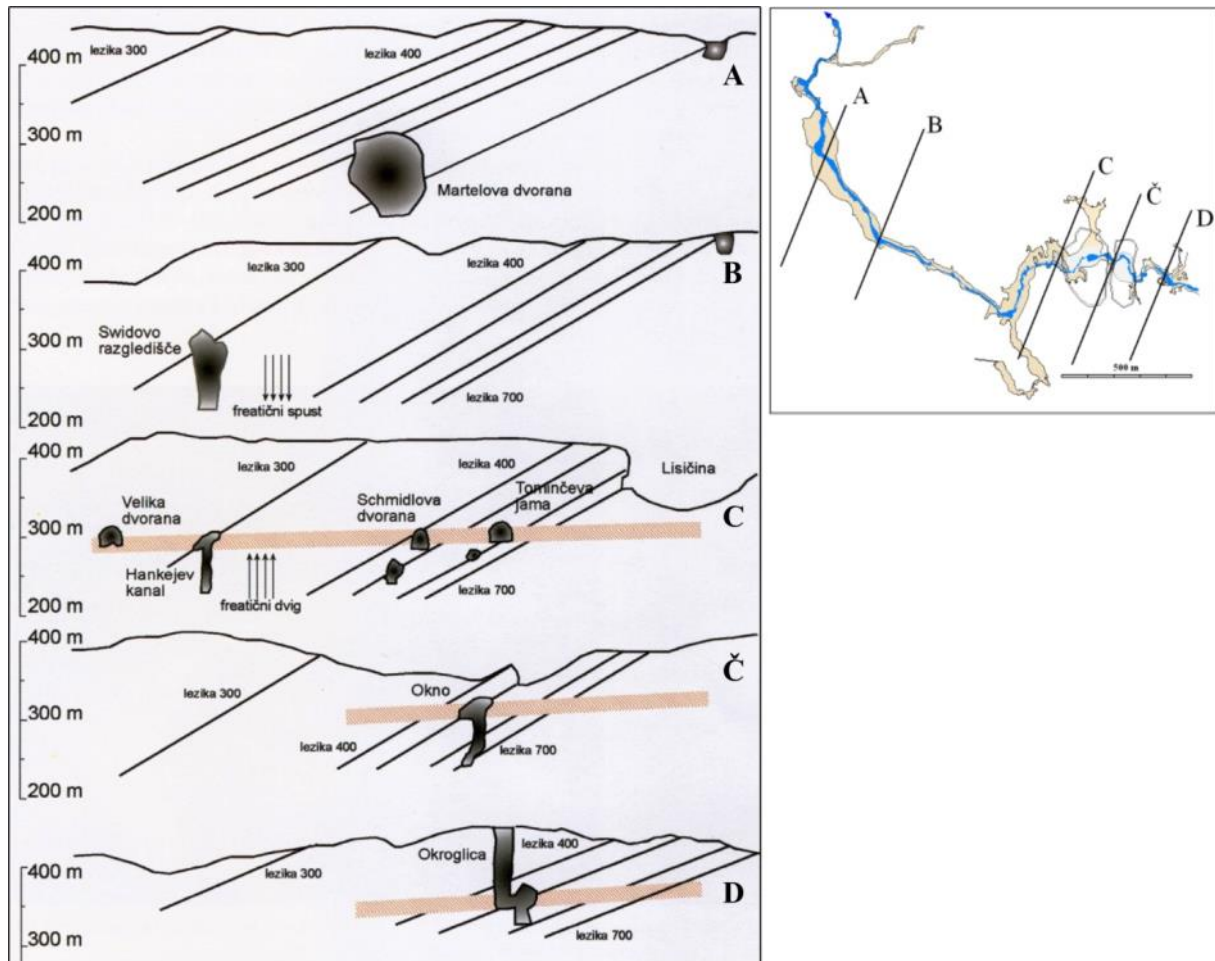


Figure 4.8: Schematic cross sections of characteristic parts of the cave and relation to main bedding plains of Škocjanske Jame. Important tectonized bedding planes, sections of the main parts of the cave and level of paragenesis are presented (after Mihevc 2001).

The next phase of the cave evolution included important changes. Gradient increased and turned towards NW. This resulted in the entrenchment of the main stream passage. In the inner parts of the cave, in Hankejev Kanal, cutting resulted in an 80 m gorge, while in the entrance part of the cave, down cutting did not exceed 10 m. These changes can be connected with regional tectonic activity, i.e. uplift and tilting of the whole Kras delayed by the time needed for adaptation of all caves in the Reka system.

SPRINGS OF THE TIMAVO

The recharge of Kras/Carso massif is mainly threefold: the autogenic recharge from the surface of the massif; the allogenic input of the Reka River and the input coming from the Soča/Isonzo alluvial aquifer. The autogenic input is estimated to be $20 \text{ m}^3/\text{s}$, the average flow rate of Reka River is about $8.5 \text{ m}^3/\text{s}$, and about $10 \text{ m}^3/\text{s}$ is estimated as the contribution of Soča alluvial.

The water from the aquifer is drained by several springs located between Aurisina and Monfalcone, along the NW coast of the Trieste Bay (Fig. 4.1). The main spring is the Timavo, with an average discharge of $29.3 \text{ m}^3/\text{s}$, the second by size is Sardos ($1.9 \text{ m}^3/\text{s}$), followed all the other smaller springs: Aurisina ($0.3 \text{ m}^3/\text{s}$), Moschenizze ($0.5 \text{ m}^3/\text{s}$), Pietrarossa and Sablici lakes ($1.2 \text{ m}^3/\text{s}$), Monfalcone ($0.2 \text{ m}^3/\text{s}$), Lisert ($1.0 \text{ m}^3/\text{s}$). There are known submarine springs located between Aurisina and Timavo with an estimated discharge of $0.5\text{--}1 \text{ m}^3/\text{s}$ (Zini et al. 2014; Doctor 2008).

The springs between Aurisina and Timavo are mostly recharged from the Kras massif (Reka-Timavo system), i.e. by the autogenic water from Kras/Carso and allogenic input of Reka River. Water from Isonzo alluvial dominates the western springs Moschenizze, Lisert and Sablici. Sardos and Timavo receive water from both systems, depending on the hydrological conditions: during low water regime water from the Soča alluvium is prevailing in both springs. During high water Sardos receives water from the Reka-Timavo system and from the Soča alluvium, while Timavo drains only Reka-Timavo system. During average flow, Timavo spring discharges only Reka-Timavo system and Sardos spring receives all its water from the Isonzo alluvial.

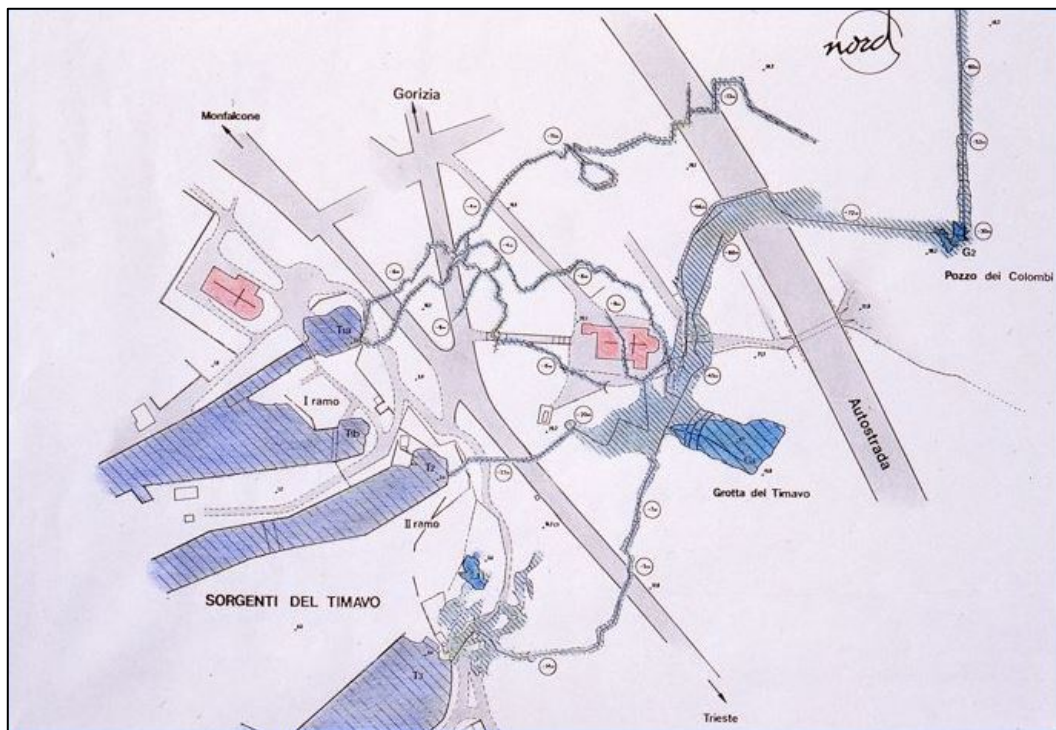


Figure 4.9: Map of the Timavo Springs and Timavo Cave System at San Giovanni di Duino (Figure provided by Prof. F. Cucchi).

The springs constitute Timavo River, which flows for about two kilometres to the Adriatic Sea. Three main branches of Timavo River present outflow from the Timavo Cave System (Pozzo dei Colombi di Duino, Risorgiva ramo 3° del Timavo and Grotta del Timavo) (Fig. 4.9). The total system is over 2100 m long with altitude difference of 106 m; the highest entrance is at 24 m a.s.l. and the

deepest point is at -82 m b.s.l). The system is mostly submerged and explored by diving (Calligaris *et al.* 2017).

The Reka was in the past heavily industrially polluted; therefore the Timavo Spring was despite the abundance, not a good source for the water supply of Trieste (Cucchi *et al.* 2015). Several pollution events forced the water providers to search and use other sources. Springs less influenced by the Reka (Sardos) were the exploited and can nowadays provide about 20 % of the regional demands; however, the main water source of Trieste is now a series of pumping wells drilled into the alluvial aquifer of the Soča River Plain.

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ABSTRACTS

IZVLEČKI

*sorted according to family names of the first authors

**the corresponding author is responsible for any grammatical errors

*razporejeno glede na priimke navedenih prvih avtorjev

**za slovnične napake je odgovoren glavni avtor prispevka

Seasonality in cave air and drip water properties – implications for speleothem palaeoclimate studies, Nova Grgosova cave (Croatia)

Sezonska spremenljivost jamskega zraka in prenikle vode – implikacije za paleoklimatske študije kapnikov, jama Nova Grgosova (Hrvaška)

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Speleothems, cave carbonate deposits that decorate many karst caves around the world, are also valuable continental natural archives of past climate changes. The vast majority of paleoclimate studies dealing with speleothems use their geochemical properties (also called proxies) to explore the causes and timing of past climate variations from seasonal to orbital time scales. However, the link between proxies and climate is not easy to interpret, as this relationship can be influenced not only by climate but also by site-specific processes. To better understand how the climate signal is converted into speleothems at a particular cave site, monitoring campaigns are nowadays often carried out in caves. These monitoring studies, especially when conducted over longer periods of time, are often of utmost importance for a reliable paleoclimatic interpretation of the speleothem proxies studied. Here we present the first results of an ongoing cave monitoring campaign in Nova Grgosova Cave in central Croatia. Our results show the evidence of seasonal variations in elemental ratios in the drip water (Sr/Ca and Mg/Ca) at this site. In this presentation, we discuss the possible causes for the observed patterns using cave air microclimatic properties (i.e. cave air CO₂ concentration) and drip water recharge data. This study aims to corroborate the accompanying paleoclimate research of speleothems, which so far indicates that vadose conditions and speleothem formation were intermittently possible at this site for at least the last 220,000 years.

Keywords: cave monitoring, drip water Mg/Ca and Sr/Ca, air pCO₂, recharge, ICP-MS

Ključne besede: jamski monitoring, prenikla voda, Mg/Ca in Sr/Ca, zrak pCO₂, napajanje, ICP-MS

Necessity of establishing geoinformation for speleological heritage objects in Kosovo

Potreba po vzpostavitvi geoinformacij za objekte s speleološko dediščino v Kosovu

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This study aims to address a large lack of information related to speleological heritage objects in Kosovo, emphasizing the importance of establishing a structured geoinformation system. With a significant number of caves (over 200 recorded and it is assumed that there is a very large number of them), it is noticed a substantial lack of data and information about them. In recent years, the

number of tourists who want to visit these caves has increased, but the available information is limited, only for a small number of them. This means that local and central institutions do not have a clear geodatabase on their values, including natural (hydrological, geomorphological, biological), archaeological and touristic aspects. To cope with this lack of information, it is required the establishment of a common geoinformation system that will include the location of caves, their special features and the potential they offer. This platform will serve as an important resource for academic, local and central institutions to explore, manage and utilize these objects for research and tourism purposes. This study aims at the necessity of establishing a complete geodatabase and the use of geoinformation methods in the preservation and promotion of the speleological heritage in Kosovo, emphasizing their natural, educational and touristic potential.

Keywords: Kosovo, geoinformation, speleological heritage, identification, management, tourism, geodatabase

Ključne besede: Kosovo, geoinformacija, speleološka dediščina, prepoznavanje, upravljanje, turizem, geopodatkovna zbirka

Morphostructural and geomorphometric properties of the Rovte karst (Central Slovenia)

Morfostrukturne in geometrične lastnosti krasa Rovt (osrednja Slovenija)

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Karst is a landform type where structural and lithological control is likely to be especially important. The study area around Rovte is located within the Trnovo nappe, i.e., the highest unit of the External Dinarides. This area is built by a few hundred-meter-thick sequences of Middle Permian to Upper Triassic carbonate and non-carbonate rocks. The main goal of the research was to identify the relief's lithological and structural conditions, karst relief especially. For that, we performed the morphostructural and geomorphometric analyses based on the digital elevation model (DEM), supported by geological and geomorphological field mapping. A dense network of dolines developed both in limestones and dolomites characterises the relief of the study area. Geomorphometric indices for closed depressions were used to analyse the spatial diversity of dolines and to link their shape with lithostratigraphic units. High lithological variability results in numerous contacts of marly or siliciclastic rocks with limestones and dolomites. Small-scale contact karst (sinking streams and blind valleys) developed in these zones. Landscape analysis shows the relationship between the developed karst landforms and N-trending tectonic structures perpendicular to bedding planes, which in this area regularly dip at ~30° towards S. The research was funded by the National Science Center (Poland), grant No. 2020/39/I/ST10/02357 and the Slovenian Research Agency (Slovenia), grant No. N1-0226.

Keywords: morphostructural analysis, geomorphometric indices, karst relief, Rovte, Central Slovenia

Ključne besede: morfostrukturalna analiza, geometrični indici, kraški relief, Rovte, osrednja Slovenija

GIS in 3D: A tool for karst reservoir studies - Example of Larzac Causse, southern France

GIS v 3D: pripomoček za študije kraških rezervarjev – primer Larzac Causse, južna Francija

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GIS is widely used by geoscientists to collect, display, map, and analyse spatial data, such as DEMs, geological maps, well data,... Meanwhile, karstologists use different softwares to construct 3D geological models or cave surveys, thereby multiplying the digital work environment. However, a key technical challenge in studying the geometry of the karst reservoir lies in understanding the 3D geometric relationships among geology, cave networks, and surface morphology. Hence the interest in utilising tools that integrate virtual navigation within the rock volume and, visualisation of data within their geological 3D context, while respecting angle, size and scale in depth. Using the recent 3D functionalities of QGIS, we propose a workflow as follows: i) identification and mapping of karstic features (such as alteration corridors) at surface level, ii) integration of the 3D geological model and cave digital survey into the GIS, iii) 3D-mapping of the karstic features within the geological volume, iv) quantitative and statistical analyses of geometrical parameters. We illustrate this workflow using the example of the Larzac Causse in southern France, where the karstic reservoir is mainly composed of a network of alteration corridors (Baral et al., 2024). These vertically elongated karstic features extend across the whole Jurassic interval. They were mapped, using DEM data covering a 20 x 20 km area on the plateau's surface. Underground morphological criteria were first described during speleological investigations. Then corridor morphology was recognised into other 3D digital cave surveys. The geological model, constructed on the VisualKarsys platform, was integrated into the GIS project. This allowed to assign a maximum vertical extension to alteration corridors. In this integrative digital environment, the geometrical parameters of alteration corridors can be statistically analysed in order to interpret the factors controlling their organisation. This approach constitutes a first step towards estimating the volume of karstic reservoirs.

Keywords: GIS in 3D, karst reservoir, 3D cave survey, geological model, water resources

Ključne besede: GIS v 3D, kraški rezervar, 3D jamsko kartiranje, geološki model, vodne zaloge

Paleoclimatic implications of The Tatra Mountains in Central Europe during MIS 11-6 based on multi-proxy speleothem records

Paleoklimatski kazatelji v Tatrah v srednji Evropi za MIS 11-6 na podlagi multi-proksi kapniških zapisov

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The SC-5 twin stalagmites from Szczelina Chochołowska cave, located in the Tatra Mountains, were studied in detail. U-series dating and age-depth modelling allowed us to constrain the period of speleothems growth to between approximately 315 and 170 ka, i.e., during marine isotope stages

(MIS) 9 - 7. The complementary use of stable isotope analyses, petrographic studies, and trace element analyses allowed the identification of warm and wet climatic conditions that were favourable for speleothem growth during MIS 9c and MIS 9b. Unfavourable climate periods included the cold glacial conditions of MIS 8 and MIS 6. The hiatus in the growth of the SC-5 stalagmite were most likely connected with extreme hydrologic events during MIS 8 and rapid climate changes during the MIS 8/MIS 7 transition. Comparisons with other European records suggest that the climatic variability recorded in the speleothems from the Tatra Mountains is not only a record of local environmental conditions but can also be linked to European climatic patterns during both interglacial and glacial intervals. Gathered results provides also new insights into important issue concerning the potential role of Tatra massif in shaping of the climate in the area of the Tatra Mountains and geographically close the Low Tatras area.

Keywords: *speleothem, paleoclimate, MIS 9-7, stable isotopes, Tatra Mountains*

Ključne besede: *kapniki, paleoklima, MIS 9-7, stabilni izotopi, gorovje Tatre*

Making a geomorphological map in karst area based on high resolution DEM - experiences from the Plitvice Lakes National Park (Croatia)

Izdelava geomorfološke karte kraškega območja na podlagi visoko ločljivostnega DMV - izkušnje iz Nacionalnega parka Plitvičkih jezer (Hrvaška)

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Plitvice Lakes National Park (Croatia) is a world-famous site located in the area of the Dinaric Karst. It is on the UNESCO World Heritage List since 1979. The most famous phenomenon are tufa barriers that made series of barrage lakes with waterfalls. The aim of this research was to determine the geomorphological features and the conditions and processes of relief formation. The goal was also to create a detailed geomorphological map on a scale of 1:25000. The main data source was a high resolution DEM (0.5 x 0.5 m and 1 x 1 m) prepared from Lidar data. In addition, places of special interest were additionally surveyed geodetically and scanned with a terrestrial lidar and also for some places orthophoto maps was made using a UAV. In the first phase, a geomorphometric analysis of the terrain was made. The methods of general geomorphometry were applied, such as the analysis of heights, slopes and relative relief, as well as the methods of specific geomorphometry (drainage network and basins, dolines). For the geomorphological mapping several derivatives were created from the high resolution DEM that were used in the interpretation of relief forms (contours on 1 and 2 m; hillshade; RRIM, various profiles, etc.). Some landforms were mapped by semi-automatic methods (dolines), while most are mapped by visual interpretation of DEM and its derivatives. Specific parts of the terrain are mapped directly by fieldwork in order to further enhance the cartographer's ability to visually interpret remote data. In the framework of this lecture, some interesting case studies from this area will be shown, and in conclusion, the advantages and disadvantages of this approach will be presented.

Keywords: karst geomorphology, LiDAR, geomorphological map, Plitvice Lakes

Ključne besede: kraška geomorfologija, LiDAR, geomorfološka karta, Plitvička jezera

Sulfuric Acid Speleogenesis in the Plavecký Karst, Slovakia (model developed during data acquisition)

Speleogeneza z žveplovo kislino v krasu Plavecký, Slovaška (model razvit med zajemom podatkov)

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Plavecký kras is situated at the western fault edge of the Malé Karpaty Mountains at the contact with Vienna Basin. Active faults controlled cave development. Plavecká jaskyňa Cave (PL), Plavecká priepasť Shaft (PP) and Pec Cave (PE) were studied in detail. The caves consist of three (PE) to five (PL, PP) subhorizontal passages and halls with water table notches, flat corrosion bedrock floor surfaces (corrosion tables), fissure discharge feeders, wall niches, upward wall channels, replacement pockets, rounded hollows delimited by cusps, convection niches, and cupolas. The subhorizontal segments are interconnected by steep to vertical oval chimneys (feeders). We studied caves from 2018 to 2023 improving step-by-step the methodology, knowledge and interpretations. In 2019, the hypogene origin of caves was indicated only by morphological features, identical with the morphology of sulfuric acid caves (SAS); other direct evidence (e. g., diagnostic minerals) was missing. Co-action of CO₂ and H₂S was expected during speleogenesis by slightly heated waters ascending along faults. Later in 2019, after XRD and stable isotopic analysis, we identified gypsum and alunite (SAS diagnostic minerals) in rare sediments. The isotope alteration (O and C) in the uppermost thin layer of limestone bedrock on the cave wall resulted from its interaction with hypogene water. We interpreted multi-phased hypogene speleogenesis with several epiphreatic phases related to an intensified sulfuric acid dissolution. Slightly warmer upwelling water ascending during compressional tectonic phases along deep faults. We interpreted source of H₂S involved in the sulfuric acid speleogenesis as derived from hydrocarbon reservoirs of adjacent Vienna Basin. In 2022, additional XRD (PL) confirmed jarosite and gypsum. U/Th dated speleothems (from ca 13 ka up to >0.6 and <1.2 Myr) framed time relations. Paleomagnetic analysis detected normal polarization of samples in PL (clays) and PE (flowstones, <773 ka) and reverse polarization in PE (flowstones, >773 ka). Dating resulted in conceptual evolution model. Three (PE) and five cave levels (PL) corresponded to phases of stable local erosional base levels during periods of strongly decelerated and/or interrupted subsidence. The subhorizontal parts of the PE are of late Early Pleistocene age (>0.99 Ma). The two PL highest levels developed during the early Middle Pleistocene (>0.6 Ma). The PL middle level was formed in the mid-Middle Pleistocene, while the lower and lowermost levels formed in the late Middle Pleistocene (>270 ka). In 2024, we presented results from PP, where XRD detected jarosite, alunite, gypsum and anhydrite as well as exotic secondary sulfate minerals (melanterite, szolnokite, indicators of earlier occurrence of Fe sulfides in host-rock), and abundant

Fe-, Ti- and Al-rich minerals (gibbsite, diaspore). We correlated cave levels in PP with PL. We compared calculated $\delta^{34}\text{S}$ derived from the anhydrites ($\delta^{34}\text{S} \sim 17\text{--}19\text{‰}$) and $\delta^{34}\text{S}$ from nearby H_2S -bearing mineral waters and proposed the conceptual model of SAS. The source of H_2S we reinterpreted as derived mainly from Upper Triassic anhydrites in the basement of the Vienna Basin. We suggested that the processes of H_2S formation were both abiotic and biotic sulfate reduction, which subsequently allowed pyrite precipitation. The main mineral phenomenon of the speleogenesis is sulfate minerals (gypsum/anhydrite, minerals of alunite group) that probably formed from residual aqueous sulfate ions. The multidisciplinary research of the three most significant caves in the Plavecký hradný vrch proved their hypogene origin and explained their development phases with sulfuric acid dissolution from idea of (1) hypogene speleogenesis with expected role of CO_2 and H_2S , through (2) multi-phased hypogene speleogenesis with several epiphreatic phases and source of H_2S in hydrocarbon reservoirs of the Vienna Basin up to (3) sulfuric acid speleogenesis with H_2S source in Upper Triassic anhydrites of the basement of the Vienna Basin. RVO67985831; VEGA 1/0146/19 and 1/0323/24.

Keywords: ascending water, cave level, hypogene sulfuric acid speleogenesis, multi-proxy approach

Ključne besede: spuščajoča voda, jamski nivo, hipogena speleogeneza z žveplovno kislino, multi-proksi pristop

Imaging the submerged karst landscapes in the eastern Adriatic Sea using acoustic methods

Slikovna rekonstrukcija potopljenih kraških pokrajin v vzhodnem delu Jadranskega morja z uporabo akustičnih metod

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Marine transgression after the Last Glacial Maximum (LGM) led to the formation of numerous present-day shelf seas. The evolution of these areas is closely associated with multiple transitions from terrestrial to marine environments and vice versa during the Quaternary glacial-interglacial cycles. The Adriatic Sea is a shallow, semi-enclosed shelf sea. Thus, numerous karst features previously exposed along the eastern coast of the Adriatic Sea have been submerged by the post-LGM sea level rise. In our research, we used acoustic methods to obtain insights into the karst geomorphology and landscapes that were formed before the most recent marine flooding. Acoustic methods, such as sub-bottom profiler, enabled penetration of sound waves into the subsurface and produced a high-resolution seismic image of the submerged karst landforms. Detailed analysis of sediment cores provided additional chronological and palaeoenvironmental information. Using these methods, we investigated several locations along the eastern coast of the Adriatic Sea and recorded submerged dolines, karst canyons, karst lakes and karst poljes that existed during the periods of Quaternary glacial sea-level lowstands. Our findings enabled a reconstruction of different submerged karst landscapes that remain hidden deep below the present sea surface and contributed to a better understanding of regional palaeoenvironmental changes that occurred due to late Pleistocene and Holocene climate and sea-level variability. This work was supported by the Croatian Science Foundation projects LoLADRIA (HRZZ-IP-2013-11-9419) and QMAD (HRZZ IP-04-2019-8505) and the internal research project RIM funded by the National Recovery and Resilience Plan 2021–2026 of the

European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia.

Keywords: *submerged karst, Adriatic Sea, high-resolution seismic methods, paleoenvironments, Quaternary*
Ključne besede: *potopljen kras, Jadransko morje, visoko-ločljivostne seizmične metode, paleookolja, kvartar*

The Ebbou cave in Ardèche, France, an archaeological site confronted with karst evolution

Jama Ebbou v Ardèche, Francija: arheološko najdišče v soočenju s kraškim razvojem

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The Ebbou cave, in the Ardèche Gorge is famous for its late Pleistocene engravings. Together with the Oddouy cave, it forms a speleological system installed in one of the first meander loops of the Ardèche Gorges. The karstic system is a capture of the Pas du Mousse meander. It is tiered, reflecting the river's entrenchment during the Pliocene and Pleistocene periods. Archaeological studies on the art, the making of the engravings and their context in the cave provide limited answers. It is difficult to establish a reliable chronology for the development of sedimentary deposits, wall morphologies, patterns and the context of the cave at the time the engravings were made. To answer these questions, over the past 4 years we have carried out extensive work on gallery topography, archaeological evidence inventories, geochemical and isotopic analyses and 3d modeling of the archaeological section. The data were integrated into databases and processed in a geographic information system. The cross-analysis of these data provides new elements for understanding the archaeological context at the end of the Pleistocene, and in particular the location of the Rock Art and the context of the cave at the time of their creation.

Keywords: *LiDAR and photogrammetry, geochemistry and isotopic analyses, geographic information system*
Ključne besede: *LiDAR in fotogrametrija, geokemija in izotopske analize, geografski informacijski sistem*

POS-based MIS 5e Relative Sea Level for Mallorca and Sardinia

Relativna morska gladina v MIS 5e na Majorki in Sardiniji na osnovi epifreatičnih sigovih prerastkov (POS)

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Sea level highstands during past interglacials are a key determinant in gaining insights into ice sheets' stability and sea level rise in the context of anthropogenic warming. Marine isotope stage (MIS) 5e has been thoroughly investigated in this regard, as it features an extensive database of significant sea

level records and is considered an appropriate analogue for future warming trends. Nonetheless, the peak global mean sea level (GMSL) during this interglacial is still a source of debate, with estimates ranging from ~1 to 8 m above present sea level (mapsl). To improve MIS 5e GMSL estimates, accurately dated and spatially precise sea level records and better-constrained models of the glacial isostatic adjustment (GIA) process are required. Here we present new MIS 5e relative sea level (RSL) curves corrected for GIA and dynamic topography. These are based on previously reported and new uranium-series dates of phreatic overgrowths on speleothems (POS) from the Island of Mallorca (>50 dates) and the Island of Sardinia (5 dates), in the Mediterranean Sea. The POS record extends from 127 to 116 ka. The MIS 5e POS from Mallorca report an average RSL highstand of 2.15 mapsl, while POS from Sardinia show a 4.3 mapsl RSL highstand. Using a large suite of 1-D and 3-D Earth models, we test the hypothesis that the two-meter discrepancy in the RSL highstand values arises from differential GIA and dynamic topography responses. This research was supported by NSF Awards AGS 2202683 (B.P.O.), 0326902 and 2202712 (V.J.P. and Y.A.).

Keywords: *GIA, dynamic topography, highstand, Last Interglacial, Mediterranean*

Ključne besede: *GIA, dinamična topografija, visok nivo morske gladine, zadnji interglacial, Mediteran*

Achieving full Scale high resolution 3D cave mapping using action cameras and photogrammetry

3D fotogrametrično snemanje jam v visoki ločljivosti z uporabo športne kamere

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While advancements in underground topography have progressed in recent decades, creating comprehensive 3D cave models remains challenging. Speleologists typically rely on laser pointer measurements to generate topographic skeletons, enabling surveying of extensive cave systems but suffering from limited resolution. Conversely, Lidar technologies offer sub-millimeter scans but require costly equipment and delicate electronics, often unsuitable for harsh cave environments. This study proposes testing low-cost action cameras for complete cave 3D modeling through photogrammetry, comparing results with Lidar surveys using precisely measured topographic markers. Our findings suggest photogrammetry is a faster and more adaptable approach, reducing artifacts and shadows compared to static Lidar. Although photogrammetry's post-processing is computationally intensive, strategies are explored to reduce calculation times. Ultimately, we demonstrate similar centimetric positioning errors between photogrammetry and Lidar, indicating photogrammetry's potential as a promising alternative for extensive cave mapping. Advances in computing capabilities further support the feasibility of using photogrammetry in underground environments.

Keywords: *photogrammetry, structure from motion, cave survey, 3D modelling*

Ključne besede: *fotogrametrija, struktura iz premikanja, jamsko kartiranje, 3D modeliranje*

Occurrence of Organochlorine Pesticides (OCPs) in Multimedia Environment from Zigui Karst Area, China

Pojavnost organokloridnih pesticidov (OCPs) v multimedijem okolju v krasu Zigui, Kitajska

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Karst areas exhibit distinct hydrogeological characteristics that differentiate the transport processes of organochlorine pesticides (OCPs) from those in non-karst areas. The distribution and transport processes of 24 OCPs in different environmental media (water, soil and sediment) and across various river basins in a typical karst area, the Zigui karst area were illustrated in this study. OCPs were detected in all samples although banned for decades in China. Compositions of OCPs in different basins were different, which indicated the hydrologic properties of conduit systems varied in different basins. Our results also showed that OCPs in the study area were primarily derived from fresh input of Lindane, Endrin, and historical residues of technical DDT and Endosulfan, as well as secondary weathering of Chlordane. High similarity between the composition of OCPs in different media indicated the main transport pathways of OCPs were from soil to water and from water to sediment. In the karst environment, degradation of OCPs was negligible during transport.

Keywords: organochlorine pesticides (OCPs), multimedia environment, level and distribution, composition and sources, karst, Zigui

Ključne besede: organokloridni pesticidi (OCPs), multimedijско okolje, nivo in distribucija, sestava in izvor, kras, Zigui

Convective Mixing of CO₂ in Fractures: Small Scale Investigation and Large Scale Implications?

Konvektivno mešanje CO₂ v razpokah: raziskave manjših in posledice velikih razsežnosti?

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We investigate the convective mixing of CO₂ in water-filled open fractures under karstic-cave conditions to determine its potential effects on large-scale karst environments and potentially speleogenesis. High-resolution numerical simulations were conducted to analyze the convective mixing processes within idealized fractures. The aperture sizes of these fractures were varied to

study three-dimensional effects. Different conditions were simulated to understand the impact of cave conditions on convective mixing. Non-dimensionalization and theoretical work were utilized to derive effective CO₂ fluxes into the water-filled fractures. Simulations indicated that convective mixing in fractures with centimeter-scale apertures enhances CO₂ dissolution, achieving dissolution rates of several tens of grams per square meter per month. Although initial non-dimensionalization provided effective laws, unresolved jump-like behavior in fluxes poses key questions. However, the order of magnitude for CO₂ fluxes confirmed previous studies. This study highlights the potential critical role of convective mixing in understanding the geochemical dynamics within karst environments, especially during periods of stagnant water. The findings prompt further investigation into how these small-scale processes could impact larger geological structures. Collaboration between modellers and field experts is essential to refine models and extend the implications of our findings to broader karst research.

Keywords: *convective-mixing, fractures, boundary-layer, CO₂, simulation*

Ključne besede: *konvektivno mešanje, razpoke, mejna plast, CO₂, simulacija*

Leveraging open data and open source software to study karst processes

Izkoriščanje odprtih podatkov in odprtokodne programske opreme za preučevanje kraških procesov

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As the world becomes awash in data, we, as scientists, have increasing opportunities to advance our understanding through the use of publicly available datasets. Here, I will provide two examples that illustrate how we have used public datasets to provide a large-scale picture of karst processes. In the first example, I will describe a Python package that I developed, called Olm. This package contains functions for common carbonate chemistry and calcite dissolution rate calculations. It can read in data from many common datalogger formats and use these data in chemical calculations. However, it also has the capability to automatically retrieve water quality data from an online database that houses data from the United States Geological Survey, the Environmental Protection Agency, and many state and local agencies across the US. We mined data from these databases to examine controls of calcite dissolution rates within streams across a wide range of climate and geological settings. In the second example, we utilize recently created public databases of karst depressions to examine the controls on the intensity of karstification. Here we explore the controls on the extent to which a landscape drains into karst depressions versus into a fluvial network. Using the available depression databases, an open source python package called HyRiver, which enables automatic queries to high resolution topographical data across the US, and Whitebox, an open source terrain analysis tool, we developed scripts to conduct flow routing into karst depressions across the entire US. This enabled us to partition the landscape into the percentage that drains into karst depressions and the percentage that drains into surface fluvial networks. We use this karst drainage percentage as an index of karstification and examine how it relates to potential climate and geological controls.

Keywords: *dissolution, geochemistry, dolines, terrain analysis*
Ključne besede: *raztapljanje, geokemija, vrtače, terenske analize*

Library of the Karst Research Institute ZRC SAZU

Knjižnica Inštituta za raziskovanje krasa ZRC SAZU

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The first ideas for the establishment of a speleological library in Postojna date back to the beginning of the 20th century. When Ivan Andrej Perko, the world-famous speleologist and long-time director of the cave Postojnska jama, came to Postojna in 1909, his plan was to turn Postojna into an internationally recognised speleological and scientific centre with an institute, an underground biospeleological laboratory, a cave museum and a speleological library. At the same time, Perko began collecting newspaper clippings from Postojnska jama and soon after, he also started collecting speleological literature from all over Europe. The realisation of Perko's plan was interrupted by the First World War. Later, in 1929, during the Italian occupation, the Italian Speleological Institute (Istituto speleologico italiano) was founded in Postojna, which built on the existing knowledge and infrastructure and began to systematically collect speleological material. In 1947, the modern Karst Research Institute was founded by the Slovenian Academy of Sciences and Arts, whose tasks included the collection and preservation of national and international speleological and karstological literature. The institute acquired Perko's private library from his son Leopold in 1961. The literature in his collection is mainly in German and Italian, with a few works in Slovenian. The second chronological part of the library dates from the time of the Italian institute in Postojna (1929–1943). This part consists of various speleological and karst-related literature, including magazines and newspapers from this period. The third large part of the older literature comes from donations from Trevor R. Shaw, who also provided the oldest book from 1556. Nowadays, most of the material is regularly purchased or donated in exchange for the Institute's scientific journal *Acta Carsologica*. An important newer part of the library's holdings are various publications regularly issued by the Institute. In addition, the library also houses the estates of Franci Bar (1901–1988), a photographer who specialised in cave photography and is best known for his impressive stereoscopic slides, as well as several other renowned Slovenian and foreign karstologists. The library collection comprises around 50,000 individual items of various bibliographical materials. The library of the Karst Research Institute in Postojna houses world and regionally important karstological literature and is particularly important because it contains some rare and old works. The Institute's library is technically and infrastructurally part of the Library of the Slovenian Academy of Sciences and Arts (SASA) in Ljubljana, a large national specialised library in the field of science in Slovenia.

Keywords: *karstological library, karstological literature, SASA library*
Ključne besede: *krasoslovna knjižnica, krasoslovna literatura, Biblioteka SAZU*

Modelling the relationship between micro-relief characteristics and the occurrence of cave entrances: the example of the Slovenian Dinaric Karst

Modeliranje povezanosti mikroreliefnih značilnosti in pojavljanja jamskih vhodov: primer Slovenskega Dinarskega krasa

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Karst surface, covering 49.7% of Slovenia, is dissected by numerous surface and sub-surface landforms, such as conical hills, dolines, uvalas, poljes, and caves. Karst is also known as one of the most rugged geomorphological systems on Earth. Surface ruggedness, fragmentation and rockiness often signify tectonic activity and bedrock fractures, which are essential for the cave formation. In karst environments, caves typically form along tectonic joints that create discontinuities in the rock. Various automatic methods for assessing surface characteristics and identifying landforms prove invaluable in the delineating morphological features of extensive, remote, and inaccessible areas, such as the Slovenian Dinaric Karst. Here we investigated the influence of micro-relief characteristics on the cave entrance occurrence along with potential differences in cave distribution based on the lithology (all rocks, limestones, dolomites and other rocks, respectively). First, we assessed the micro-relief characteristics of the vicinity of the cave entrances by calculating topographic attributes and automatically detecting karst landforms using a high-resolution LiDAR digital terrain model (DTM). Next, we employed an ecological modelling approach known as “use-availability” to determine which micro-relief characteristics were significantly correlated to cave occurrence. Our findings reveal a significant impact of micro-relief characteristics on cave occurrence. In general, caves are more likely to occur near rocky outcrops and dolines, as well as in rockier terrain and in areas with lower Topographic Position Index values. We observed significant variations in the influence of predictors on cave occurrence across different lithological units compared to the occurrence of all caves. This study demonstrates the potential of integrating remote sensing techniques and ecological modelling methods into geomorphological research. Such integration facilitates the efficient detection and analysis of spatial patterns and surface morphology, thereby aiding in the preservation and conservation of these unique landforms.

Keywords: *GIS, LiDAR, geomorphology, caves, ecological modelling, Dinaric mountains*

Ključne besede: *GIS, LiDAR, geomorfologija, jame, ekološko modeliranje, Dinarsko gorovje*

Occurrence of antimicrobial resistant and pathogenic *Escherichia coli* from the water of two karst springs in Slovenia

Pojav odpornih proti antimikrobnim učinkovinam in patogenih sevov *Escherichia coli* v vodah dveh kraških izvirov v Sloveniji

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Karst aquifers are an important source of drinking water and are also habitats to many endangered species. Therefore, regular monitoring of the occurrence of pathogenic and/or antimicrobial resistant (AMR) bacteria can help to develop strategies to protect these important water resources. The aim of our study was to investigate the diversity, AMR and potential pathogenicity of *Escherichia coli* strains isolated from two important karst springs, Rižana and Malni, during the dry season and after heavy rainfall in June and August 2023. Using the ERIC-PCR method, non-clonal isolates were identified, assigned to phylogenetic groups and analysed for the presence of 20 virulence factor genes (VAGs), resistance genes blaCTX, blaTEM, blaSHV, blaOXA and qnr alleles. In addition, all isolates were tested for phenotypic resistance to 9 antimicrobial agents. Our results revealed that the strains isolated in June and August mainly belonged to phylogenetic groups A or B1, although the proportion of these groups varied. The occurrence of isolates from group A decreased at both sampling sites after heavy rainfall. The proportion of isolates from groups B2 and D was relatively low and constant in the Rižana spring, while it increased in the Malni spring after heavy rainfall. A high proportion of isolates from groups F (20 % in the dry season) and E (24 % after rainfall) was isolated from the water of the Malni spring. The latter group is rarely described in human isolates. All isolates were highly susceptible to all antimicrobials tested, with the most frequent resistance to tetracycline and ampicillin. The presence of bla genes was confirmed, but qnr alleles were not detected. The isolates had an average number of VAGs between 1 and 5. Up to 11 VAGs were detected in isolates from the Malni spring after rainfall. Although, the two springs were not heavily contaminated with resistant *E. coli* isolates during the sampling period, potentially pathogenic strains were found, especially after heavy rainfall. A new species *Escherichia marmotae* was detected for the first time in both karst springs during periods of low and high water; its role in these aquatic ecosystems remains unclear. The results of this study are important as they can be used to develop strategies to control and protect these important water resources, which are critical to human, animal and environmental health.

Keywords: environmental health, virulence genes, antimicrobial resistance, *Escherichia marmotae*

Ključne besede: zdravje okolja, virulenčni geni, odpornost proti antimikrobnim učinkovinam, *Escherichia marmotae*

Qualitative and quantitative approach for understanding karst hydrodynamics in artificial and natural conditions

Kvalitativni in kvantitativni pristop k razumevanju kraške hidrokinamike pod umetnimi in naravnimi pogoji

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Understanding the hydrodynamics of karst aquifers is challenging due to their significant heterogeneity and anisotropy. Quantitative and qualitative approaches, along with multivariate statistical analysis, can contribute to a better understanding of the karst aquifer behaviour. This methodology was implemented to study flood events on binary karst in Slovenia and the influence of hydrotechnical structures on the karst aquifers in Serbia. In each of these examples, certain innovations were introduced in the monitoring system or data processing methods. The qualitative approach involved analyzing chemical and microbiological tracers at various points in the karst system, including ponors, karst channels, and springs. The overall data analysis included multivariate statistical analysis which led to the construction of new multivariate chemographs forming the final spatio-temporal conceptual model of the research area. This significantly contributed to an improved understanding of the complex hydrodynamics relationships within the system. Well-designed monitoring on the numerous observation wells in the vicinity of the reservoir (grout curtain and dam), along with the combined use of hydraulic (hysteresis) and hydrochemical approach, have played an important role in understanding the mechanism of groundwater circulation under artificial conditions. This approach has been particularly useful for estimating hydrogeochemical processes, the hydraulic barrier's functioning, and flow dynamics at different water levels within the surface-water reservoir. Through the integrated research of hydrochemical and hydraulic methods in the pressure tunnel, significant insights were gained into the spatial heterogeneity and complexity of the hydrogeological environment. Hydrochemical research played a crucial role in the initial examination of the aquifer surrounding the hydrotechnical tunnel. On focal points are installed internal piezometers into the tunnel with probes, providing valuable insights into the internal structure of the karst. This new approach achieved a deeper understanding of groundwater dynamics, pressure transient phenomena, and hydrogeochemical characterizations of the karst-fissured aquifer system.

Keywords: karst hydrodynamics, hydrochemistry, multivariate statistical methods, Serbia, Slovenia

Ključne besede: kraška hidrokinamika, hidrokemija, multivariantne statistične metode, Srbija, Slovenija

Spatial Data Acquisition and Analysis in Karst by GIS: Examples from Florida and Turkey

Pridobivanje in analiza prostorskih podatkov v krasu z GIS: primeri iz Floride in Turčije

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This presentation summarizes the use of GIS in karst studies with examples from Florida and Turkish karst regions in subtropical and temperate climates respectively. The following aspects are discussed: (A) morphometric parameters and spatial analysis of karstic depressions, (B) orientation of surficial and subsurface karst features, (C) structural and topographic control on karst development, (D) land use and environmental problems around cave/spring systems.

Keywords: karst geomorphology, dolines, caves, GIS, land use, groundwater contamination

Ključne besede: kraška geomorfologija, vrtače, jame, GIS, raba zemljišča, onesnaženje podzemne vode

Characterization of the hydrogeological role of weathered rock in karst aquifer using a multidisciplinary and multiscale approach

Karakterizacija hidrogeološke vloge preperelih kamnin v kraškem vodonosniku z multidisciplinarnim in večstopenjskim pristopom

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The objective of this work is to combine hydrogeological, geophysical and geochemical approaches to revisit the role of weathered rocks (ghost rocks), on water transfer and storage in the unsaturated zones of karst aquifers. To build a conceptual model of the unsaturated zone we acquired, first of all, spatial data. Geophysical methods (electrical resistivity tomography and seismic refraction tomography) were used to characterize the geometry of weathered rocks. Geochemical analysis on rocks is performed to investigate their porosities and mineralogical compositions (XRD, XRF and SEM). Secondly, to characterize the evolution of the water body over time in the unsaturated zone, we used geophysical monitoring in surface (gravity), piezometry in 3 boreholes and discharge in 4 cavities and in the spring, as well as hydrochemical data. Thirdly, in order to establish a link between all water bodies characterized by the different time series (piezometric, discharge, and gravity time series), we computed a transfer model (black-box approach using Tempo software ©BRGM) simulating spring discharge from different geophysical, hydrogeological and hydrochemical informations. The studied area is the karst aquifer of the Durzon spring, located in the South of

France, under a Mediterranean climate. The recharge area is about 100 km² and is mainly composed of dolomitic rocks characterized by large weathered areas. The recharge occurs by diffuse infiltration, resulting in an inertial spring response. Regarding spatial characterization, our results show that dolomite weathering creates corridors of several ten meters deep in the unsaturated zone. In those weathered rocks, samples have porosities up to 50% compared to ~10% in unweathered rocks. Results show that piezometry (local scale) and gravity (integrative scale) signal in the unsaturated zone have the same pattern, linked to the seasonal recharge. Concerning temporal analysis of rainfall and discharge signals, correlation analysis evidence contrasted contributions of fast (piston effect) and slow flow according to location sites in the unsaturated zone. These multidisciplinary and multiscale approaches provide more information about the role of the unsaturated zone in karst and show that weathered rocks (ghost rocks) can play a key role in their overall hydrogeological functioning.

Keywords: *weathered rocks (ghost rocks), multidisciplinary, hydrogeological functioning*

Ključne besede: *preperele kamnine (»ghost rocks«), multidisciplinarno, hidrogeološko delovanje*

Cave diving researches of karst springs in the Una river cathment (Bosnia and Herzegovina)

Jamarske potapljaške raziskave kraških izvirov v porečju reke Une (Bosna in Hercegovina)

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In the Una river cathment, in the northwest of Bosnia and Herzegovina and the border area with Croatia, there are several karst springs. Over the past few years, speleodiving research has been carried out, mainly by foreign speleologists and researchers. Some of the research results have been published in foreign magazines and internal publications of speleology societies and associations, as well as published in various social media. For this reason, they are mostly unavailable to the domestic professional and scientific community and the public, for whom they may be of importance. The primary goal of this paper is to provide a systematic review of the so far known and available results of some speleology research on the morphological characteristics of karst springs in the Una river cathment. Also, the goal is to give a brief description and comment on some geological, hydrogeological, hydrographic and geomorphological characteristics of the area where the springs are located, which can be useful for understanding their origin and recent morphological and hydrological characteristics, as well as some conclusions about the geomorphological development of the wider area. Therefore, the work is based on the compilation of data from different sources that have been critically reviewed and analyzed. The paper presents data for the Una spring, Bastašica spring, Klokot spring, Crna Ruka spring and Krušnica spring in the immediate Una river cathment, and for the Mračaj spring, Sanica springs, Dabar spring, Zdena spring and Bobijaško Oko spring in the Sana river cathment. The location and appearance of the springs and the way the water flows out indicate that most of the springs are connected to siphons and that the water moves under hydrostatic pressure.

Keywords: speleodiving, karst spring, karst, Una river, Sana river, Dinaric karst

Ključne besede: jamarsko potapljanje, kraški izvir, kras, reka Una, reka Sana, dinarski kras

Phreatic overgrowths on speleothems (POS) from coastal caves: classification and characterization

Freatični sigovi prerastki (POS) iz obalnih jam: klasifikacija in karakterizacija

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Phreatic Overgrowth on Speleothems (POS) are a particular type of speleothem that grow on previous substrate (mainly previous speleothems) at the air-water interface of hypogean lakes in littoral caves. These lakes contain brackish waters and have the special characteristic of being directly or indirectly related to the sea level. Therefore, POS precipitates at the height of the sea in the moment of their growth. This condition makes POS an excellent marker of past sea level. These speleothems are very rare globally, with most deposits located and studied on the island of Mallorca (western Mediterranean), home to the largest collection of POS. This study presents a comprehensive classification of POS at two different scales: hand-size and thin section. The first classification is based on the internal and external morphology and the shape acquired depending on the substrate on which these precipitates grow. The second classification, based on the thin section study, allows for the recognition of various crystalline fabrics. Some of the analyzed characteristics are related to classical speleothems, while others are new. The main concepts extracted are: 1) POS precipitate preferentially around previous stalactite-type formations; 2) aragonite POS have globular and fan shaped external and internal morphologies, with a needle-like crystal fabric; 3) calcite POS exhibit branched internal and external morphologies and commonly present a mosaic crystal fabric. The data obtained have been used to identify relationships between the precipitation conditions of POS and the features of these precipitates. This study provides new insights into the process and conditions of POS precipitation and highlights the importance of these deposits as a proxy. The data presented can be applied to and reviewed in POS deposits from other parts of the world.

Keywords: phreatic overgrowth on speleothems (POS), morphology, crystal fabric, calcite, aragonite

Ključne besede: freatični sigovi prerastki (POS), morfologija, kristalna tekstura, kalcit, aragonit

Sulfur and oxygen isotopes in waters and cave gypsum of the Rovte karst area (central Slovenia)

Žveplov in kisikovi izotopi v vodah in jamski sadri v krasu Rovt (osrednja Slovenija)

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Dedolomites were found in the Middle Triassic dolostones, and inside the Mravljeto brezn v Gošarjevih rupah (MBGR) cave, in the Rovte region, Slovenia. Multi-proxy studies were undertaken to understand the potential role of dedolomitization in the MBGR cave formation. The study included isotopic analysis of sulfates of water samples (artesian wells and springs) and gypsum collected from the MBGR cave walls. A dual isotopic approach of S and O in sulfate has been applied to obtain information about the source and reaction pathways of sulfur and oxygen in the studied sulfate. Isotope values on sulfates dissolved in the well waters ($\delta^{34}\text{SSO}_4 = 19.2\text{‰} - 23.3\text{‰}$; $\delta^{18}\text{OSO}_4 = 13.7\text{‰} - 18.1\text{‰}$) indicate the origin of the SO_4^{2-} ions from evaporite minerals, corresponding to the presence of the Permian and Lower Triassic gypsum strata in the region. In the case of springs ($\delta^{34}\text{SSO}_4 = 5.2\text{‰} - 7.1\text{‰}$; $\delta^{18}\text{OSO}_4 = 0.6\text{‰} - 1.5\text{‰}$), the situation is different. The natural source of the SO_4^{2-} ions in the springs is groundwater. When carbonate rocks dissolve, sulfides that were dispersed in the rock are released and subsequently oxidized to sulfate, characterized by light $\delta^{34}\text{SSO}_4$ values and light $\delta^{18}\text{OSO}_4$ values. Isotopic analyzes on MBGR cave gypsum ($\delta^{34}\text{SSO}_4 = 10.3\text{‰} - 14.0\text{‰}$; $\delta^{18}\text{OSO}_4 = 0.3\text{‰} - 2.2\text{‰}$) indicate that these sulfates were formed by sulfide oxidation processes. This supports the hypothesis that the sulfate in MBGR cave originated from the Permian–Triassic sulfate rocks that were dissolved deep under the surface in the reductive conditions where the hydrogen sulfide was formed. Then the rising water with dissolved H_2S mixed with oxygenated meteoric water, and nowadays the observed calcium sulfate crystals deposited on the cave walls are a product of this process. Our research continues with deeper investigations into the cave minerals and their relation to dedolomitization.

Keywords: sulfate, gypsum, stable isotopes, speleogenesis

Ključne besede: sulfat, sadra, stabilni izotopi, speleogeneza

First approach on the multiparametric study for the development and evolution of a karstic environment: The case of Petroto karstic system (Northern Greece)

First approach on the multiparametric study for the development and evolution of a karstic environment: The case of Petroto karstic system (Northern Greece)

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This case study concerns a multimethodological, innovative approach to reveal the characteristics and evolution of Petroto karstic geosystem (Serres, Northern Greece). This system could be characterized as a complex 3-level system, including many caves (Alistrati, Orfeas, etc.), multiple smaller caverns and surface geomorphs. The multiparametric study includes: (i) karst-geomorphological survey, using state-of-the-art techniques; (ii) combined geophysical survey to assess the extent of the unknown part of cave systems; (iii) continuous monitoring of climate conditions of the karst environment and (iv) site-response measurements for the evaluation of the karstic system earthquake vulnerability. The first results of the detailed surface karst-geomorphological survey highlighted the characteristics of surface karstic geomorphs, through remote sensing products and on-field observations. The next step concerns the detailed mapping of Petroto system through UAS LiDAR and photogrammetry techniques with a remarkable resolution (point-cloud density >1000 points/m²). The preliminary results of the combined geophysical survey in a selected area highlighted the possible extension of Alistrati karstic conduit and the presence of an upper karst level between Alistrati cave and the surface. The geophysical survey will be extended using 2D/3D data acquisition techniques, at areas whose location will be chosen based on the geomorphological investigations. The continuous monitoring of climatic conditions inside and outside the main caves will be implemented using state-of-the-art, Arduino-based systems, manufactured by NKUA laboratory. The monitoring will provide additional information on the extent of the karstic system and its evolution. Ultimately, the combination of 3D-models of the existing/explored karst voids (LiDAR inside the caves), the 3D-topographical model (UAS-LiDAR), the geophysical survey results (unexplored karstic voids), the climate monitoring and the site-response measurements, aims to reveal the characteristics and the possible evolution of Petroto system. Through this study, the development of an innovative methodology (tool) that could be applied to other karstic systems will be achieved.

Keywords: karst geomorphology, geophysics, LiDAR, climate monitoring, site-response measurements

Ključne besede: kraška geomorfologija, geofizika, LiDAR, klimatski monitoring, meritve lokalnega odziva

On Sustainable Cave Mapping

O trajnostnem kartiranju jam

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Arguably the most important foundational piece of cave documentation is the map of the underground space. It is a human-interpreted, significantly simplified schema of the underground space, carrying information about its layout, position, cave shape, sediments, waters, findings, observations, equipment of the spaces with various aids, and so on. The justification of its use in the current expanding possibilities of 3D tools and visualization is left for discussion, but it seems that the simplicity and rapid readability of quality interpreted 2D maps may condemn them to permanent use even in the future. The goal of sustainable cave mapping, as it is proposed here, is to acquire high-quality, reliable data with the fewest possible visits to the given spaces; minimizing the energy required for their acquisition, ensuring the verifiability of their quality over time, and leaving a permanent system of orientation in underground spaces that does not require significant irreversible interventions into the environment. This method combines existing, more or less used ways of documenting underground spaces into one workflow. It serves for the rapid acquisition of high-quality data about caves and human-made underground spaces, and it is universal for documenting small cavities to large systems. It combines the traditional method of mapping using modern instruments (Paperless Cave Surveying; Heeb, 2020) with highly efficient work with SLAM-based scanners (Zlot and Bosse, 2014). The result is a system of permanent reference points in the cave, accurate speleological maps (in UISv2 6-4-EF quality and higher; see Häuselmann, 2012), and 3D models with minimal occluded areas.

Keywords: *cave map, paperless surveying, SLAM-based LiDAR, speleocartography*

Ključne besede: *jamski načrt, brezpapirno kartiranje, LiDAR na osnovi »SLAM«, speleokartografija*

3D analysis and geomorphology of Upper Palaeolithic decorated caves (Grotte Chauvet, Grotte aux Points, Grotte des Deux Ouvertures, Ardèche, France)

3D analiza in geomorfologija jam s pozno paleolitskimi najdbami (Chauvet, aux Points, des Deux Ouvertures, Ardèche, Francija)

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Over the last twenty years, terrestrial lasergrammetry has made it possible to produce 3D models of caves with very high (sub-centimetre) resolution. This technique has been used in a number of decorated caves to study cave art or to guide the construction of tourist replicas. Combined with a good geomorphological analysis, it can be used to reconstruct paleo-landscapes, calculate volumes

and simulate light. Here we present three examples of Upper Palaeolithic decorated caves in the Gorges de l'Ardèche (France). In each case, we propose geomorphological research based on 3D lasergrammetric acquisition. At the Chauvet cave, a 3D analysis of the escarpment and the deposit closing the cave was carried out. This made it possible to refine the chronology of events by identifying several key surfaces and then to simulate the entry of light into the palaeo-entrance. The grotte aux Points has been modified by historical excavations. It was possible to reconstruct the cave in 3D, contemporary with past human and animal occupation. Finally, at the Deux Ouvertures cave, volumetric calculations of cupola submerged during past floods have made it possible to explain the relative positions of Palaeolithic artefacts and detrital sediments. For each of these examples, it was the combination of a detailed geomorphological study and an analysis of high-resolution 3D models that enabled us to arrive at a solution that answered the question.

Keywords: 3D LiDAR, lasergrammetry, Chauvet cave, Ardèche

Ključne besede: 3D LiDAR, lasergrametrija, jama Chauvet, Ardèche

Modelling and Interpretation of Interaction between Circulation of Surface Water and Groundwater

Modeliranje in interpretacija interakcije med kroženjem površinske in podzemne vode

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The interaction between surface water and groundwater constitutes a critical process to understand the quantitative and qualitative regime of dependent hydrosystems. The simulation process constitutes the most effective tool for such analysis. The results of the simulation process contribute to the raising of awareness for water protection and the application of better management strategies. Knowledge of models' parameters has great importance to ensure reliable results in the modeling process. The main finding of the analysis highlights uncertainties and gaps in the modeling process due to the lack of high frequency and depth dependent field measurements.

Keywords: modelling, surface water, groundwater, water protection, India

Ključne besede: modeliranje, površinske vode, podzemne vode, zaščita voda, Indija

Basic hydrogeochemical methods in karst research

Osnovne hidrogeokemične metode pri raziskovanju krasa

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Geochemical studies on waters from karst areas can provide a wealth of information allowing, for example, the assessment of water quality for consumption, identification of the water source and an understanding of water–rock interactions. In the absence of contaminating agents, the geochemical composition of karst waters is very simple, predominantly comprised of calcium, magnesium and hydrogen carbonate ions. A key concept in karst hydrogeochemistry is the saturation index with respect to certain minerals, such as calcite and dolomite, which quantitatively assesses the potential of the water to dissolve or precipitate the particular mineral, and thus, indicates water–rock interactions. Moreover, due to the intricate balance between these ions (Ca^{2+} , Mg^{2+} and HCO_3^-) in solution, carbonate rocks and carbon dioxide, understanding the total budget and fluxes between these states can have implications on a global scale. As such, it is important to correctly sample, chemically analyse, process data and interpret the results from karst water research. Based on my personal experiences, I will show various methods and tips that can be useful for field sampling of karst water. Subsequently, I will discuss how certain graphical representations typically used to assess water–rock interactions are not particularly suitable to describe variability in these highly carbonate-rich waters. Data from a number of samples taken in Slovenia will be used to show the best ways to interpret karst hydrogeochemical data and show what information can be gained from such simple chemical analyses. This work is funded by the Slovenian and Polish research agencies (ARRS and NCN) through the bilateral Polish-Slovenian research project CEUS (project code in Slovenia: N1-0226; project code in Poland: 2020/39/I/ST10/02357) and by the Slovenian Research Agency and the Croatian Science Foundation within the project Dynamics and distribution of CO_2 in karst vadose and epiphreatic zone (CARDIKARST) IPS -2022-02-2260.

Keywords: *hydrogeochemistry, karst water, Rovte region, Postojna Cave, Slovenia*

Ključne besede: *hidrogeokemija, kraške vode, Rovte, Postojnska jama, Slovenija*

Monitoring of water infiltration into an Alpine karst system during snowmelt events

Monitoring of water infiltration into an Alpine karst system during snowmelt events

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In alpine Aquifers, snowmelt is an important contributor to groundwater recharge. Yet, the pathways and mechanisms controlling water flow into the epikarst are not well understood. Since the Hochschwab karst massif (Styria, Austria) is one of the most important aquifers for Vienna's water supply, we aim understanding snowmelt water infiltration into the uppermost vadose zone using the

combination of geophysical (electrical resistivity tomography, ERT) and hydrological methods (drip water in a cave, soil moisture). In particular, we present here results from monitoring activities at the Hirschgruben cave (3 weeks in March/April 2024). The cave opens at 1896 m a.s.l. in limestone of the Dachstein Formation below a paleo surface with up to 40 cm soil cover. The cave passages near the entrance run horizontally into the mountain, while the surface topography increases with it, resulting in a rock overburden of up to 25 m. Drip water from a chimney is measured for discharge, fluid electrical conductivity, and temperature (interval: 10 minutes). Soil moisture is measured at three locations between 5 and 30 cm depth. In addition, ERT monitoring is conducted with 96 electrodes (1 m spacing) along a profile extending from the surface through the cave entrance and ceiling to the drip water chimney. Comparing results from different sensors, i.e. hydrogeological and geophysical, showed good agreement for all occurred hydrologic events. In total, 12 events could be observed at the weir, two as a mixture of snowmelt and rain and 10 from snowmelt. A total of 70 ERT-images are conducted and provide spatial images of different saturation conditions, with temporal variations in resistivity. The combination of several methods provides detailed information on the flow rates, saturation of the rock, and resident times in relation to the infiltration rate.

Keywords: epikarst, hydrology, geophysics, snow melt, soil moisture

Ključne besede: epikras, hidrologija, geofizika, taljenje snega, vlažnost prsti

The Pleistocene remains horses (genus *Equus*) from Slovenian Karst - the preliminary results

Ostanki pleistocenskih konjev (rod *Equus*) iz Slovenskega krasa – preliminarni rezultati

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The genus *Equus* was common in the Pleistocene of Europe, but data so far show that fossil remains of horses from Pleistocene sediments in Slovenia are rare. The only evidence comes from Middle Pleistocene sites: Postojnska jama, Črni kal and Parska golobina nar Pivka. Revision and international research of the paleontological collections of the biological department of the Notranjska museum in Postojna, allowed us to expand our paleontological knowledge about Pleistocene horses from Slovenia. The collection consisted of long bones and teeth in various stages of preservation. Material comes from: Zasuta jama and Lokev III, these are horse remains discovered during the construction of highway and railway infrastructure. Two further sites: Črni kal quarry and Uršnja Luknja come from recent paleontological excavations conducted by the authors. The last of them is the Kanegra quarry, from which the materials preserved in the Postojna collection were excavated in 1933–1935 by Franco Anelli. Fossil material was measured and resulting data were analyzed using statistical programs. The results are as follows: the teeth from Zasuta Jama are from a small to medium-sized horse which may have been adapted to cool or cold environments; the evidence from horse bones from Črni kal quarry suggest the site is similar in age to Achenheim layers 20e-b (MIS11-9) and

Schöningen 13II-4 (MIS9); The horses from Uršnja Luknja may date from the Eemian. Horses bones from Kanegra quarry are similar to Achenheim layer 20a (MIS9) or Weimar-Ehringsdorf (MIS7). According to morphology and morphometric features, all the examined material belonged to the species - *Equus ferus* Boddaert, 1785. In the collection, we did not recognize any horses from the stenonid group.

Keywords: *Pleistocene, Slovenia, fossil remains, Equus ferus*

Ključne besede: *pleistocen, Slovenija, fosilni ostanki, Equus ferus*

Karst evolution in Borneo, Malaysia

Razvoj krasa v Borneu, Malezija

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The northern Borneo mountains host some of the largest caverns on earth: the caves at Mulu, Niah, and Gomantong. Their Eocene-Miocene host limestone was deposited in shallow seas, forming carbonate platforms up to 2 km thick. There are similar, active platforms today in the South China Sea: the Luconia Shoals. Here, carbonate sediments are being deposited, free from clastic input, since the Miocene, similarly to the older limestone units on land. Due to crustal subsidence, carbonate production stopped, and the platforms drowned. Eventually, deep marine fine grained clastic sediments were deposited represented by impermeable silt and clay. In the Mulu region, the limestones are overlain by 3.5-5.5 km thick pelagic Temburong shales. The burial depth was sufficient to induce the loss of primary porosity and partial recrystallization of the limestone. Subsidence down to high temperature and high-pressure conditions reached the depth of the oil kitchen, where organic matter in the shales was transformed into hydrocarbons. The ensuing hydrogeological cycle drove distributed downwelling, concentrated horizontal flow, and concentrated upwelling. Aggressive fluids, gaining H₂S and CO₂ from buried organic matter, assisted the development of conduits and caverns. Due to ongoing orogeny (subduction of Mulu horst), altogether 8 km uplift and erosion occurred since the Pliocene. Caves, formed initially at great depths in the phreatic zone, breached the surface; further enlarged under vadose conditions, sedimentary fill entered the caves, and speleothems were precipitated. Sediments within the conduits at higher altitudes are older than those on lower levels, indicating gradual uplift at least during the last 700 ky. Thermal water springs, rich in CO₂ and H₂S, methane-producing, active mud volcanoes, and oil residues preserved in the limestone testify to these processes. Since exhumation, several major cavities have hosted human habitation. The succession in time of phreatic, epiphreatic, and vadose morphology observed on cavern and conduit walls at various scales, revealed by overprinting relationships, records details of what happened at depth and on the surface.

Keywords: *hypogenic cave, Cenozoic, tectonics, SE Asia*

Ključne besede: *hipogena jama, kenozoik, tektonika, JV Azija*

Integrative analysis of long-term CO₂ measurements and weather patterns in the Swabian Jura: Insights into karst processes and potential speleogenesis

**Integracijske analize dolgoročnih meritev CO₂ in vremenskih vzorcev v Swabian Jura gorovju:
vpogled v kraške procese in potencialno speleogenezo**

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This study explores the dynamic interplay between atmospheric conditions and internal CO₂ levels within the Laichinger Tiefenhöhle, a karstic cave in the Swabian Jura (green karst). The focus is on how these external factors impact the cave's internal environment and its potential stagnant water bodies. CO₂ data from a long-term measurement campaign inside the cave were correlated with weather data from the German Meteorological Service (DWD). A conceptual model was developed to assess the influence of these conditions on internal cave dynamics. We furthermore subjected a stagnant water column to cave conditions to analyze how deep convective mixing reaches into water bodies how it affects CO₂ distribution. Our analysis shows a significant correlation between external weather patterns, soil moisture, and seasonal trends with CO₂ levels inside the cave. Experiments demonstrated that convective mixing could transport peak air CO₂ concentrations into a depth of 6 meters within weeks to months. During periods with lower ambient CO₂ levels, unresolved processes allowed for CO₂ release from shallow depths (within 1 meter), but not from deeper sections (6 meters). The correlation of CO₂ levels with atmospheric conditions shows complex dynamics within karst environments. Convective mixing under certain conditions can transport significant amounts of CO₂ deep into stagnant water bodies. Collaborations with field experts are crucial to further investigate these mechanisms, determine their frequency, and assess their relevance across other karst regions.

Keywords: CO₂, long-term measurements, convective mixing, stagnant water, weather patterns

Ključne besede: CO₂, dolgoročne meritve, konvekcijsko mešanje, stoječa voda, vremenski vzorci

Karren of Gréolières

Škraplje Gréolières

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At the top of the karren on the upper surfaces of an inclined rock strata along which a slope formed a unique rock relief developed that reveals the manner of karren formation and its development. Relatively large surfaces of unfissured, mostly evenly composed, and largely subsoil rounded and smooth and later denuded rock mostly exposed to rain resulted in special hydraulic circumstances that fostered the formation of rock forms and the development of the rock relief. On the parts of

rock directly exposed to rain there are rain flutes, and where the layer of water trickling down the inclined surface is thicker, there is a system of large and small steps that dissect the surface in an undulating fashion. The trickling water collects in channels that in parallel dissect the surface and together with the channels that conduct the water from subsoil rock forms gradually assume the role of the main conductors and increasingly distinctly dissect the tops of the karren. Relatively flat surfaces with dominant traces of sheet flow of large amounts of water therefore represent one of the initial stages in the development of the denudation of this type of rock base. New factors gradually transform the subsoil rock relief that is revealed when the rock is denuded. Only in individual places does the composition of the rock dictate the development of protrusions on flat surfaces. The long-term parallel position of channels also appears to be dictated by the hydraulic conditions of this type of formation of larger inclined surfaces, which has been confirmed by laboratory tests with plaster of Paris. On the latter, the most conductive channels gradually assume the leading role. A number of forms have been newly identified and described in detail for the first time with the development of this type of the relief.

Keywords: karren, rock relief, Greolieres, France

Ključne besede: škraplje, skalne oblike, Greolieres, Francija

Remains of Canidae (Fischer de Waldheim) from the Niedźwiedzia Cave

Ostanki Canidae (Fischer de Waldheim) iz jame Niedźwiedzia

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The Niedźwiedzia Cave in Kletno, located in the Śnieżnik Massif, is currently the largest cave in the Sudetes in Poland. Discovered on 1966, it is renowned for its rich Upper Pleistocene fauna, with the dominant component being the remains of the cave bear *Ursus spelaeus ingressus*, constituting over 98.5% of all discovered bones. In addition to bears, remains of other predators, such as the steppe brown bear *Ursus arctos priscus* and the cave lion *Panthera spelaea spelaea* (Goldfuss, 1810), have also been found, forming an important part of the fossil collection. Alongside these large species, remains of the canids were also found in the cave. In the sediments of this site, remains of three species have been identified: the cave wolf *Canis lupus spelaeus* (Goldfuss, 1823), the red fox *Vulpes vulpes* (Linnaeus, 1758), and the Arctic fox *Vulpes lagopus* (Linnaeus, 1758). The most abundant remains belong to the massive, large wolves characterized by massive molars and strong jaws. Although the wolf did not match the steppe brown bear or the cave lion in size, large packs could effectively compete with these predators. Wolves were attracted to the interior of the Niedźwiedzia Cave by the scent of sleeping or dead bears, on which they scavenged. Occasionally, they could hunt young individuals. A similar scent may have attracted both fox species to this site. Their fossil material, mainly consisting of cranial skeleton remains, provided radiocarbon and uranium-thorium dates confirming their presence in the cave during the MIS 3-1 period.

Keywords: Upper Pleistocene, Niedźwiedzia Cave, carnivore remains

Ključne besede: zgornji pleistocen, jama Niedźwiedzia, ostanki mesojedcev

Morphogenesis of the Čepovan dry canyon

Morfogeneza suhega kanjona Čepovanski dol

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The study area comprises of Čepovan Dol, a hydrologically inactive canyon, entrenched into high karst plateaus in western Slovenia. The aim of this paper is geomorphological analysis of Čepovan Dol and its morphogenetic and morphodynamic interpretation. The sediment analysis included X-ray fluorescence analysis and X-ray diffraction analysis. We concluded that the development of the Čepovan Dol occurred in at least three phases. Initially, the southern part functioned as a corrosion plain in shallow karst, while the northern part was characterized by cone karst. From the north, a watercourse flowed into the area. Later, due to the tectonic uplift of the area, the watercourse antecedently carved and formed the canyon. A karst basin was formed in the Grgar area where the canyon cut through flysch rocks. After the activation of the Idrija Fault in the final phase the watercourse was beheaded, causing Čepovan Dol to become hydrologically inactive.

Keywords: *geomorphology, karst, Dinaric karst, dry canyon, XRF, XRD*

Ključne besede: geomorfologija, kras, dinarski kras, suha dolina, XRF, XRD

Building up a depositional model of clastic sediments in the enclosed cave system as a proxy for landscape evolution (Grgos Caves, Croatia)

Izdelava modela odlaganja klastičnih sedimentov v zaprtem jamskem sistemu kot proksi za razvoj pokrajine (jame Grgos, Hrvaška)

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When preserved in enclosed cave systems, clastic sediments prove to be a distinctive tool for paleoenvironmental reconstructions and indispensable archives of speleogenesis. Such a sedimentological dataset is recently discovered in the Grgos Caves (continental Croatia). The previously enclosed caverns are now used as a cave laboratory for advanced speleothem-based research for palaeoclimatic reconstructions. However, vadose carbonate features with recent high speleothem growth rate mask the undissolved fluvial phase of the cave channels. Recently, clastic deposits sealed with speleothems were observed at the various cave levels. As a base for sedimentological and petrological analyses sedimentological column is constructed followed by sampling according to stratigraphical principles. Preliminary data based on grain-size analysis, and

mineral assemblages determined using optical microscopy of heavy and light mineral fractions proves that the sediments are of allogenic origin. The light mineral fraction is quartz-dominated (> 95 %, subangular, allotriomorphic grains) followed by chert particles, micas, and alkali feldspar. Although the light mineral composition is homogeneous throughout the investigated section, a slight increase of lithic particles and the occurrence of plagioclase is observed upwards. The heavy mineral fraction is dominated by the opaque mineral grains. Among transparent heavy minerals, a high zircon-tourmaline-rutile index is observed. Pleochroic tourmaline is dominant followed by at least three morphotypes of zircon, rutile, staurolite, and epidote. The lack of diversity of transparent heavy minerals and the predominance of quartz among light mineral fractions implies a high weathering rate and structurally mature source rocks. According to grain-size characteristics (clayey silt - gravel range) and sedimentary structures, the clastic sequence within the cave is deposited in a fluvial system. However, today morphological features of the surface relief in the area are masking possible paleotransport routes and input zones within the cave. To reconstruct the drainage system and provenance of allogenic deposits, as well as the dynamics of cave-forming processes future data collection is planned within various cave levels. Combined with the LiDAR DEM analysis, speleothem-based chronology, and planned burial dating of clastic sediments it should be a valuable indicator for the understanding of the geomorphological evolution of the area.

Keywords: *allogenic cave sediments, lithofacies, grain size, provenance*

Ključne besede: *alogeni jamski sedimenti, litofacies, velikost zrn, izvor*

Analytic methods in structural speleology and deducing the “unit cell” of stripe karst caves

Analitične metode v strukturni speleologiji in izpeljava »enotne celice« progastih kraških jam

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Karst caves may take a variety of morphological shapes, spanning from linear, strongly fracture-controlled conduits in telogenetic or metamorphic carbonates to irregular, “blubby” shapes in eogenetic flank margin caves or ghost-morphologies in the porous variants. Modelling structural geology (stratigraphy, stress, fracturing) and hydrology (pressure gradients) may not work the same way all over this spectrum. Here, we will consider ways of analysing cave and geological data from the fracture- and bedding-plane controlled conduits in low-porosity lithology (marbles and telogenetic limestones). Direct observations in phreatic conduits suggest that speleogenesis often took place along a guiding fracture, inside a stratum or within a lithological structure of optimal solubility. Thus, the “ideal” phreatic conduit occur along the line of intersection between two or more planes, the guiding fracture and a geologic structural plane that may either be mechanical (another fracture) or chemical (bedding, stratigraphic). Therefore, from a set of observations of fractures, bedding planes and chemical stratigraphy, we may successfully predict or model the trends of phreatic conduits within limited blocks of karst rocks. The simplest approach is to calculate the axis of intersection between fractures and bedding planes, thus producing a synthetic set of potential passage central axes. The distribution of these axes can in turn be compared to real cave data, of which the survey “centerline” is readily available and attractive. However, the precision of a

“centerline” depends largely on the (individual) survey technique, it is rarely placed along the central axis of the passage. This can be remedied by using wall, roof and ceiling data, so a survey “centerline” may be transformed into a true passage axis. It is a long recognised challenge to try to predict a cave pattern from, say 30- 100 structural measurements at the entrance; this exercise has been done many times in the 2-dimensional regime, comparing and testing histograms (rose diagrams). Non-parametric tests are available, like the Kolmogorov-Smirnov (KS) test. Results are variable, but often quite good. Modelling 3D patterns (axes) are more challenging as we would have to compare azimuths and dips separately, although in recent years, 2D non-parametric tests are available (2D Kolmogorov-Smirnov). When comparing 3D axes in 2 dimensions, we may expect deviations caused by pitch, i.e. a passage may undulate (looping) within an inclined plane. The azimuth may then deviate from that of the guiding plane. Examples from marble stripe karst – a geometrically rather simple situation – will be presented and discussed. From these analyses, we may deduce a minimum unit of two intersected sets of fracture within a bedding unit. This forms a minimum “unit cell”, and the attitude (tilt and rotation) of this cell, combined with a superimposed hydraulic gradient, can produce known cave types (tiered, labyrinths and loops).

Keywords: cave, structural geology, documentation, mapping, statistics, structural speleology

Kľúčne besede: jama, strukturna geologija, dokumentiranje, kartiranje, statistika, strukturna speleologija

A comparison of the structural data acquired in the Okno Cave (Slovakia) from field research versus the laser scanner 3D models – a case study

Primerjava strukturnih podatkov pridobljenih v jami Okno (Slovaška); primerjava terenskih raziskav s 3D modeli iz laserskega skenerja – študija primera

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Recent advances have led to an increasing number of portable/handheld SLAM-based laser scanners that allow relatively quick production of 3D models of entire caves. Herein, we present the structural data from the Okno Cave obtained from the 3D lidar model of main passages and compare them to data obtained from several personal geological surveys realised prior to the cave's scanning. Almost one hundred measurements were collected in two dedicated and several supplemental geological surveys of the cave, while we obtained nearly three hundred measurements from the cave model. One of the chief limitations of the personal cave survey is the limited field of view caused by light conditions and the relatively constricted nature of most cave spaces, which rarely permit examination of the structures in a broader context. Also, the orientation in the cave is more challenging than at the surface outcrops, which might hinder the tracing of some of the geological structures. High-quality cave maps might somewhat mitigate this issue; however, these are not always available. In contrast, the 3D model enables the overview of the cave from a broader perspective and allows direct measurements of the structures at the cave's ceiling, high walls, and

other otherwise inaccessible parts. The model permits resolution of the macroscopic and even some mesoscopic structural features, provided the structures influence the morphology of cave space. Although the study of the cave model cannot fully replace personal surveys, it can significantly facilitate them, especially when realised before the geological survey. It presents a valuable tool for mapping the major geological features, especially in more extensive or remote caves, where repeated personal surveys would prove too costly, dangerous, or physically challenging. In this sense, 3D cave models can be compared to the LIDAR terrain models, which are also indispensable tools in geological mapping.

Keywords: structural mapping, fractures, bedding, SLAM-based laser scanner, 3D cave model

Ključne besede: strukturno kartiranje, razpoke, plastnatost, lasersko skeniranje na osnovi SLAM, 3D jamski model

Monitoring of water-level fluctuations in a coastal cave: methods and implications for POS based sea-level reconstructions

Opazovanje nihanja vodne gladine v obalni jami: metode in pomen za rekonstrukcijo paleo morske gladine na osnovi epifreatičnih sigovih prerastkov (POS)

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Coastal caves can interact with both freshwater and saltwater systems, resulting in distinct hydrological conditions. Tidal forces play a significant role in coastal cave hydrology, as the tidal fluctuations cause water level changes within caves, affecting the movement and exchange of fresh and saltwater. In some cases geochemical environment of coastal caves is favorable for the formation of specific carbonate phreatic encrustations known as phreatic overgrowths on speleothems (POS). POS forms around existing vadose speleothems in coastal caves, within the tidal range which can be used as a sea-level index point. Following the recent discovery of the first POS in the Adriatic, we conducted a year-long monitoring of tide fluctuations in the sea and the submerged part of Medvjeđa špilja coastal cave (Lošinj island, northern Adriatic). The goal was to explore the relationship between marine oscillations and those within Medvjeđa Cave, as well as to identify maximum and minimum water levels in both locations for a more precise POS-based reconstruction of relative paleo sea-level. Two HOBO U20-001-02 data loggers were used to measure water levels: one in Malo Jezero cave lake and another in the sea close to the cave. The 12-hour and 24-hour peaks at both locations align with daily and semi-daily tidal forces, underscoring the strong and direct influence of sea-level and tidal fluctuations on water level variations within Medvjeđa Cave. These results suggest that the connection between the cave and sea water is through the karstified fractures, enabling direct interaction between fresh groundwater and the sea, a phenomenon frequently observed along the eastern Adriatic coast. The research was conducted within the SEALevel project (HRZZ-IP-2019-04-9445) funded by Croatian Science Foundation.

Keywords: coastal karst, submerged cave, tidal fluctuations, sea-level, northern Adriatic, Croatia
Ključne besede: obalni kras, podvodna jama, plimovanje, morska gladina, severni Jadran, Hrvatska

Challenges and obstacles during cave monitoring programs in Modrič Cave (Croatia)

Izzivi in ovire pri programih monitoringa jame Modrič (Hrvatska)

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Long-term monitoring programs within the caves and on the surface have proven their value in palaeoenvironmental research primary in determining suitability of caves for such studies. Since the monitoring equipment is often left in caves unattended for long periods numerous factors, such as the protection of the sensitive instruments from cave atmosphere, their proper placement etc., have to be taken into consideration. However, unexpected events may hamper the length and the quality of the data series. Modrič Cave is a relatively small show cave located in the northern part of the eastern Adriatic coast and is one of the most studied caves in Croatia since its discovery in 1985. Over the last two decades scientists from the Department of Geography, University of Zadar (in collaboration with domestic and foreign colleagues), have conducted several research campaigns mostly aimed at speleothem-based palaeoenvironmental studies. During the monitoring scientists faced occasional challenges and obstacles including: (1) environmentally-induced equipment malfunctions, (2) biogenic risks, (3) impact of human activities. One of the typical problems was battery malfunction in different types of loggers (TH, CO₂ loggers) mostly due to the high humidity environment which shortens battery life. In the case of CO₂ loggers, that problem was solved by putting the instruments in to sealed casings. Collecting the composite rainwater samples also proved challenging as the plastic container needed to be replaced several times because of the exposure to the sun, which caused plastic to break. Strong winds and heavy rains also posed the threat to the container. On several occasions animals interfered with the data collection. Unknown animal(s) have displaced drip loggers and damaged the mount of radon loggers. Displacement of the drip loggers completely disrupted the data series. Human impact has been negligible, although a problem with illegal visitors in the cave have been noticed so additional warning signs and locks have been placed to address this issue.

Keywords: monitoring programs, paleoenvironmental studies, challenges and obstacles, Modrič Cave, Croatia
Ključne besede: program monitoringa, paleo-okoljske študije, izzivi in ovire, jama Modrič, Hrvatska

Late Miocene to Quaternary relief evolution, cave networks development, and tectonic/climatic forcing in the Western French Alps

Pozno miocenski do kvartarni razvoj reliefa, jamskih sistemov in tektonski/klimatski vpliv v Alpah v zahodni Franciji

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The evolution of karstic networks is intimately coupled with the topographic relief dynamics. Both are controlled by tectonic and climatic forcing on timescales ranging from thousands to millions of years. To decipher these interrelationships, we focus on the frontal limestone massifs in the Western French Alps, where extensive and historically renowned underground networks develop. Our goal is to reconstruct both the evolution of these karstic networks and the topographic relief since the Late Miocene. We target two distinct paleogeographic settings: (1) the Bourne River system, which drains both the underground and surface water fluxes of the Vercors Massif, and has been protected from Alpine glaciations. We aim to quantify there the long-term incision dynamics of the frontal western Alps; (2) the Isère River valley has been deeply carved and overdeepened by Alpine glaciations. The neighboring karstic networks have evolved following both the Isère valley incision and successive Alpine glaciations. The extensive topographic data acquired by generations of speleologists are integrated into underground 3D models of karstic networks in order to (1) extract the fossil (epi)phreatic tubes and (2) constrain the underground phreatic flow reorganizations in response to topographic changes. Phreatic phases are identified using sedimentology and dated using burial $^{26}\text{Al}/^{10}\text{Be}$ dating and paleomagnetism. The abandonment phases of the paleo-drains are dated using U/Th and U/Pb on speleothems. Our main results show: (1) a first late-Miocene downgrading phase of karstic conduits in response to tectonic shortening and topographic uplift; (2) a significant Pliocene karstification phase, during a period of stable base level (tectonic quiescence and relatively stable climate); (3) karstic evidence for Quaternary incision and first glacial incursions since ~2 Ma. Our spatio-temporal constraints on karstification phases provide quantification of the late-Miocene/Quaternary incision and uplift dynamics in the Western French Alps, demonstrating the relevance of combining quantitative geomorphology methods (3D modelling and geochronology) in karst research.

Keywords: karstic networks, quantitative geomorphology, $^{26}\text{Al}/^{10}\text{Be}$ burial dating, U/Th dating, U/Pb dating, cave sediments

Ključne besede: kraški sistemi/povezave, kvantitativna geomorfologija, $^{26}\text{Al}/^{10}\text{Be}$ datiranje pokopa, U/Th datiranje, U/Pb datiranje, jamski sedimenti

U-series dating of speleothems using ICP-MS – case studies

Datiranje sige z U-serijami z uporabo ICP-MS – študije primerov

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The U-Th dating method has been known since the 1960s. Among all its applications, it has been proven to be an excellent method for dating cave materials. In addition to all its advantages, such as overall theoretical simplicity and the elegance of results, the method suffers from sensitivity to several crucial factors, especially to the sample preparation and measurement techniques. This contribution demonstrates the long-term practice of our laboratory with U-Th dating. The presented laboratory is capable of dating a wide variety of cave materials, such as speleothems, stalactites, calcite corals, travertines, as well as bones and teeth. The dating itself is performed on calcite (geogenic cave materials), hydroxyapatite (teeth) or collagen (bones), which are first separated from the studied sample. The age range of cave materials dated up to now covers ages 600,000 to 1000 years. Knowledge of the geological environment and the formation process of the sample is important information prior to the dating procedure, as the key factor for successful analysis is the proper isolation of homogeneous calcite crystals (0.1 - 0.5 g). It is crucial to avoid contamination with other minerals (usually clay minerals containing detrital thorium or Fe-oxyhydroxides). The ideal sample for analysis is obtained by precise microdrilling. Proper sampling, sample processing and instrumental analysis on high resolution inductively coupled plasma mass spectrometer will provide age information with high accuracy. However, the samples may represent an open system, making the age determination impossible, which unfortunately cannot be verified in advance.

Keywords: U-Th dating, speleothem, calcite, travertine, ICP-MS

Ključne besede: U-Th datiranje, siga, kalcit, lehnjak, ICP-MS

Building a doline map with applied machine learning

Kartiranje kraških vrtač s strojnim učenjem

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Dolines are small to intermediate enclosed depressions and are the most numerous karst feature in Slovenia. They are circular in plan form and vary in diameter from a few metres to over a kilometer. They are developed in limestone, dolomite, carbonate breccia and conglomerate and occupy different geomorphic settings. They were formed by various processes like dissolution, collapse, suffosion and transformation of caves to surface features by denudation. Publicly accessible lidar data, provided by a nationwide laser scanning project of Slovenia (2014), was used for this study. To catalogue the dolines, we manually label a fraction of the digital elevation model (DEM) with a binary

mask indicating if the area is a doline or not. We then train a slightly modified u-net, a type of machine learning algorithm, on the labelled territory. Using the trained algorithm, we infer the binary mask on the entire DEM. We convert the resulting mask into an ESRI Shapefile and manually verify the results. We note that the training and inference are error prone on types of relief that were less common in the training set (e.g., cockpit karst). We believe manual verification mitigates most of these errors, so the resulting map is a good basis for study of Slovenian dolines. We have made our georeferenced catalogue of 471,192 Slovenian dolines available at <https://dolines.org/>. This basic data set for dolines enables further study and comparison of dolines with the geology and topography of the karst. Dolines in Slovenia are found in most of the karst areas, except mountains where they were eroded by glacial action or covered by glacial deposits. The average doline is 9 m deep, has a diameter of 42 m and a volume of 14,000 m³. The density of dolines on levelled surfaces can be as high as 500/ per km². They are absent from the floors of poljes and steeper slopes, and are less abundant on sloping surfaces. Further, we apply the machine learning model trained on Slovenian dolines to DEMs of US, Costa Rica and France. We discuss results, model's ability to generalize and challenges in doline segmentation.

Keywords: *dolines, Slovenia, DEM, number of dolines, size of dolines, machine learning, catalogue of dolines, US, Costa Rica, France*

Ključne besede: *vrtače, Slovenija, DMV, število vrtač, velikost vrtač, strojno učenje, katalog vrtač, ZDA, Kostarika, Francija*

Small, sparsely preserved outcrops of unroofed cave sediments: are they worth investigating?

Majhni, delno ohranjeni izdanki brezstropih jam: ali so vredni proučevanja?

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Karst landscapes are formed by dissolution processes and are highly dependent on climate, which represents the opportunity to study the water flow, rainfall and environmental conditions of the past. However, two major issues hinder the palaeoenvironmental interpretation in karst areas. Firstly, most karst landscapes are generally empty spaces in the rock where much of the ancient archive has been removed by dissolution or mechanical weathering. Secondly, surface denudation, a dominant karstification process, is constantly lowering karst surface by dissolution, thus removing most of the information about the past. However, the by-products of denudation are the sediment-filled unroofed caves, which may represent the only remaining archive of past environmental conditions. Although cave sediments are generally more resistant to dissolution than the host rock, their preservation on the surface is usually sparse, and the available outcrops may only provide an incomplete and spatially limited record, which usually cannot preserve the complexity of spatial patterns of ancient cave conduits. This poses a concern whether the sedimentological characteristics of a single outcrop can provide sufficiently meaningful information about the karst palaeoflow direction. To test this hypothesis, it is very important to select an appropriate karst area that is rich in

sedimentary outcrops of unroofed caves and has a very thoroughly studied current subsurface flow regime. One of the most significant areas for such research is the elevated karst plain of Laški Ravniki, where a small outcrop of the Merjasec unroofed cave has been thoroughly investigated. The cave deposits are represented by coarse-grained sediments with well-defined sedimentary structures. The sediment characteristics indicate a very complex organisation, which leads to sorting and thus to short transport distances of the coarse-grained sediments. Our research demonstrates that the combination of provenance analysis of the cave material and clast imbrication is a very reliable flow indicator, while cross-stratification should be treated with caution. This shows that small, sparsely preserved, surface-exposed succession of unroofed cave sediments archive important data for understanding the hydrological history of an area, and that they are most reliable when sedimentary structures and textures are combined with the provenance of the cave material.

Keywords: *unroofed cave, clastic cave sediments, sedimentary structures, provenance, paleoflow*

Ključne besede: *brezstropa jama, klastični jamski sedimenti, sedimentne teksture, provenienca, paleotok*

Contrasting occurrence of karrentisch in Alpine and tropical environments and challenges of their analysis

Razlike v pojavljanju kraških miz v alpskem in tropskem okolju ter izzivi njihove analize

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Karrentisch have been extensively studied and their pedestals used for denudation rates estimates in formerly glaciated environments, where the onset of karrentisch formation is strongly associated with the end of the last glaciation. Less studies have been conducted in tropical environments, where their formation is linked to cliff proximity or tsunamis. In this study we aimed to characterize karrentische in both environments and compare them. The study locations were in the Julian Alps (NW Slovenia), and the Mariana Islands (W Pacific). We measured pedestal heights using a water level scale and measuring tape. In addition, in the classic (glacial) environment we used unmanned aerial vehicle (drone) for photogrammetry to develop 3D scans for each karrentische individually as well as a digital terrain model for the wider area of their occurrence to obtain a degree and direction of general sloping. The measured karrentisch pedestal heights in the Julian Alps were from 8 to 23 cm, while in the Marianas ranged from 10 to 500 cm. The stunning difference in pedestal heights is a consequence of the difference in environment and formation type. The measured pedestal heights of the same karrentisch could differ up to 30 to 50% with respect to the surrounding surface. Averaging the sloping of a surrounding surface with 3D scans of karrentische can significantly help determining the most representative pedestal height. However, the interpretation of pedestal development on inclined surfaces is still challenging and needs further elucidation. Based on our analysis and measurements, tentative estimates for denudation rates are 1-2 mm/ka in Julian Alps, and 40-70 mm/ka in the Marianas.

Keywords: *karst, geomorphology, 3D-imaging, surface lowering*

Response of dripwaters to Mediterranean climate in Don Juan Cave (E Spain)

Odziv kapljajoče (prenikle) vode na Mediteransko klimo v jami Don Juan (V Španija)

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We present the results of the hydrogeochemical monitoring program initiated at the end of November 2019 in Don Juan Cave (E Spain), in order to determine the response of the cave's drip water to climatic variations. Don Juan is a tourist cave with a small bat colony, developed in a thick carbonate breccia unit corresponding to a Neogene alluvial fan. The clasts in the breccia are derived from Cretaceous marine carbonates. The region has a Mediterranean climate with dry summers with no effective infiltration. The hydrogeochemical study included: (1) collection and analysis of rainwater, cave water, and present-day calcite, and (2) recording of discharge pathways (e.g., drips from stalactites, fissures, or pooled water in gours), and discharge rates, including seasonality. Following these criteria, the sampling points are classified into 6 groups according to flow rate (greater or less than 1 drip/min), seasonality (seasonal or perennial), and pathway. Most of the analyzed cave waters have values of $\log p\text{CO}_2^{\text{atm}} < \log p\text{CO}_2^{\text{water}} < -2.0$, which is typical for ventilated caves. Waters with the highest discharge rates have low Mg/Ca ratios and tend to precipitate calcite in both seasonal and perennial drips. The waters with lower discharge have high Mg/Ca ratios, evidence of PCP, and are in equilibrium with calcite. Some waters are oversaturated in hydroxypatite and fluorapatite, which is a clear influence of the bat colony that lives inside the cave. This study provides with abundant information about the interactions between climate (precipitations, evapotranspiration, seasonality), the karst system (pathways, cave ventilation) and the biological imprint in dripwater (soil, bat colonies and tourists).

Keywords: mediterranean cave, hydrogeochemistry, monitoring, drip rate

Ključne besede: mediteranska jama, hidrogeokemija, monitoring, frekvenca kapljanja (prenikanja)

New approaches to identifying and classifying karst landforms in the Central Apennines (Abruzzi, Central Italy)

Novi pristopi za prepoznavanje in klasifikacijo kraških površinskih oblik v centralnih Apeninih (Abruzzi, osrednja Italija)

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The Central Apennines fall among the areas of greatest interest regarding the Italian karst landscape, yet the Abruzzi region remains understudied in modern karst geomorphology, particularly lacking GIS and remote sensing analysis. Existing data, mainly archives, databases, and maps, are limited and focused in specific areas, not allowing comprehensive understanding and landscape evolution reconstruction. Approximately 40 % of Abruzzi region is covered by carbonate karst terrain, consisting of N-S to NW-SE Jurassic and Cretaceous limestone ridges, with elevations spanning from 100 to over 2900 meters above sea level. These terrains, designated as carbonate karst morpho-units (CKMU), are separated by Miocene flysch valleys and tectonic or tectonic-karstic plains filled by Quaternary deposits, bounded by SW and NE dipping normal faults active since late Pliocene-early Pleistocene. Utilizing a 10-meter resolution DEM and geological maps (1:50,000 to 1:100,000 scale), morphometric parameters, surface hydrography, and carbonate lithofacies were characterized for each carbonate karst morpho-unit. Main karst areas were manually mapped within each unit, classified into six types based on visual recognition of key landforms. This mapping, albeit without delineating individual landforms, relied on 10-to-1-meter DEM, topographic maps (1:25,000 to 1:5,000 scale), on multitemporal and multiscale satellite imagery and aerial photographs, as well as on existing geomorphological maps and datasets. This comprehensive analysis produced an updated map of karst morpho-units and karst area types of the entire Abruzzi region. Furthermore, statistical analysis of morphometric parameters, surface hydrography, and carbonate lithofacies allowed the comparisons between the ones of the entire carbonate karst morpho-units and the ones of specific karst areas within them. The work presented here results from a PhD research project concerning the analysis of the relationships between karst and neotectonic in the context of the central Apennines.

Keywords: Central Italy, Abruzzi, karst morpho-units, epigean karst landforms, morphometric analysis, remote and field mapping

Ključne besede: osrednja Italija, Abruzzi, kraške morfološke enote, epigene kraške površinske oblike, morfometrična analiza, daljinsko in terensko kartiranje

Microbiological exploration of underground environments, ethical and legal dilemmas with implications for extraterrestrial research in role of education

Mikrobiološko raziskovanje podzemnih okolij, etične in pravne dileme, odnos do nezemeljskih raziskav ter vloga izobraževanja

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Exploration of subterranean environments, especially caves, is of great importance for microbiological research and provides analogues for situations that may arise in extraterrestrial missions, especially in the search for microbial life signatures. In astrobiology and space exploration, it is essential to ensure integrity of research and prevent the unintentional transfer of microorganisms, debris and wastes from Earth to extraterrestrial environments. Due to extreme individual or combined environmental conditions, microbial life is particularly challenged in deep caves, lava tubes, ice caves, sulphur, acidic and salt caves, and in cracks or voids within the biosphere below the Earth's surface. Sometimes caves are considered as natural laboratories for in situ investigations. Conducting experiments in caves should not introduce additional biological hazards in the form of exposure to dangerous biological agents or unsafe conditions for researchers or cave biota. Responsible science and research involves compliance with laws and safety measures at all levels, and this includes sampling of material containing microorganisms. It is important to limit the collection of material to the minimum amount that is relevant and necessary to ensure successful and productive conduct of the planned research. No specific international convention deals exclusively with the protection of microbial diversity. More specific in relation to microorganisms is the Nagoya Protocol, which entered into force in 2014 as a supplementary agreement to the Convention on Biological Diversity from 1992. The key to responsible science lies in appropriate education, which includes active participation of students in research activities. If they are active in cutting-edge research in particular, they are better recognised by their scientific peers and potential employers.

Keywords: cave microbiology, Nagoya Protocol, strategic sampling, underground experimentation, science education

Ključne besede: mikrobiologija jam, Nagojski protokol, strateško vzorčenje, podzemni poskusi, izobraževanje v znanosti

Quantification of near-surface cave drip-water by combining different measurement approaches

Oštevilčevanje kapljajoče vode v jami blizu površja s kombiniranjem različnih merilnih pristopov

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Drip water in caves can fluctuate by several orders of magnitude due to different precipitation conditions, which is often difficult to record using a single measuring method. On the Hochschwab karst plateau (1.400 - 2.277 m.a.s.l., Austria), several recent studies and still ongoing projects aim to gain a better understanding of the behaviour of water in the uppermost karst zone. Therefore, in a cave (Hirschgrubenhöhle, 1.896 m.a.s.l.) drip water is collected from a near-surface chimney (7 m overburden) by combining a weir for measuring discharges above 4 mL per second and a rain gauge for lower discharge rates. To collect the dripping water over an area of several square meters, some plastic sheets were installed and tilted towards a drainage point. An acrylic glass box was installed underneath, with one side designed as a v-notch weir with an acute angle of 8.5°. To reduce the issue of overflowing waves at high discharge the box is divided into two chambers – one input chamber collecting the drip water and one output chamber with the weir – which are siphon-like connected underwater. In the second chamber discharge, temperature and electrical conductivity are monitored in a 5-minute interval with a multiparameter pressure rod. Low discharge is below the resolution of the pressure probe and therefore cannot be differentiated. For this reason, a tipping bucket rain gauge was installed under the outlet of the weir in order to quantify low drip water with high resolution. A smaller chimney nearby with a greater overburden (13 m) and a significantly lower discharge (1/80) correlates with most, but not all, of the heavy rainfall events during summertime. This study shows that by applying different measurement methods, a wider range of drip water differences can be quantified.

Keywords: epikarst, hydrology, vadose zone, discharge monitoring, soil moisture

Ključne besede: epikras, hidrologija, vadozna cona, monitoring pretoka, vlažnost prsti

Dinaric Faults: do they creep

Ali dinarski prelomi lezejo?

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Hall effect creepmeters, serve as cost-effective extensometers, offer a practical solution for monitoring shallow slip or creep along active faults. These instruments are strategically positioned on

globally seismically active faults with fast deformation rates. In 2022, a project commenced to monitor creep activity along the western Dinaric Faults in Slovenia, focusing on the Idrija, Raša, and Predjama faults. Three creepmeters were installed on the Idrija and Raša faults to investigate whether these faults experience aseismic creep or remain locked during interseismic periods. Such investigations aim to enhance understanding of the mechanics of Dinaric Faults, potentially improving seismic hazard assessments in the Dinarides. Laboratory studies of rock friction behaviour suggest that faults typically exhibit velocity-strengthening behavior, indicating the potential for stable sliding or creep during interseismic periods. Field observations and numerical simulations support this hypothesis, highlighting the occurrence of shallow interseismic creep on various active faults worldwide. Creepmeter instrumentation, based on Hall effect principles, provide an effective mean of monitoring fault displacement. Deployed on the western Dinaric Faults, these instruments aim to capture subtle indications of fault creeping activity, offering crucial insights into seismic behavior and deformation patterns in the region. Preliminary findings from the project suggest anomalous displacements, emphasizing the importance of continuous monitoring. Despite the absence of definitive evidence of creeping behaviour, ongoing observations from Hall effect creepmeters contribute to enhanced seismic hazard assessments and the development of effective risk mitigation strategies in the seismically active western Dinarides. The deployment of creepmeters represents a significant step forward in understanding the dynamic geological processes shaping this region. The study is carried out within the Karst Research Programme (P6-0119) and Infrastructure Programme (I0-E017), all financially supported by ARIS and the project operation RI-SI-EPOS and EC Horizon 2020 project EPOS SP.

Keywords: *creep fault, displacements, active tectonics, Dinaric Fault System, Slovenia*

Ključne besede: *lezenje preloma, premiki, aktivna tektonika, dinarski prelomni sistem, Slovenija*

The Slovenian Near Fault Observatory: SLO KARST NFO

Slovenske opazovalnice ob prelomih: SLO KARST NFO

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The Slovenian Near Fault Observatory (SLO KARST NFO) was established in 2020 - 2021. It is located in SW Slovenia, in the NW Dinarides, a region still undergoing active tectonic deformations (<5mm/yr). The area consists mainly of highly karstified Mesozoic carbonate rocks and minor patches of Cenozoic siliciclastic flysch sequences. The main seismogenic sources of the NFO are sub-vertical dipping dextral strike-slip faults of the Dinaric fault system (NW–SE and NNW–SSE) with moderate to strong (historical) seismicity with occasional swarming events. The strongest historical earthquakes in NW Dinarides occurred close to the NFO, and ruptured the faults of the Dinaric fault system. Until 2020, the wider area of SLO KARST NFO was monitored only by four seismic stations. With the new SLO KARST NFO (<http://dx.doi.org/10.7914/7w0j-ge89>) covering an area of about 2600 km², the

seismic network in the area was densified by six new stations. A broadband seismic station (in cooperation with University of Trieste, Italy and ARSO, Slovenia) is installed in Postojna Cave 100 m below the surface and has been in operation since May 2010. In addition to micro-climatic [air T, air pressure, CO₂, CH₄, Rn, humidity, ventilation, etc.] and tectonic micro-displacement monitoring [TM extensometer monitoring], it creates an exceptional subsurface karstic laboratory. The SLO KARST NFO lies on voluminous karst aquifer, which represents critical water source for SW Slovenia. As a result of its importance permanent hydrological, surface and subsurface, monitoring operations are maintained. Offering potential insights on how seismic events influence the karst aquifer (water dynamics, physical and geochemical parameters) as well as hydrological induced seismicity. The main scope of the SLO KARST NFO is to detect seismic activity in the area and subsequently use the collected data for seismic and active tectonic studies. To improve understanding of the mechanics of the earthquake cycle and the structure of the shallow and deeper crust in NW Dinarides. Consequently, adding input to the earthquake hazard of the SW Slovenia and its neighbouring countries (Croatia and Italy) and potentially reducing earthquake risk in the future.

Keywords: *EPOS Slovenia, RI-SI EPOS, karst NFO, seismicity*

Ključne besede: *EPOS Slovenija, RI-SI EPOS, kras NFO, seizmičnost*

Quantification of hourly particle movements on sorted circles in a karst cave in Slovenia

Količinska opredelitev urnega gibanja delcev na sortiranih krogih v kraški jami v Sloveniji

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One of the most distinctive periglacial landscape landforms is patterned ground, which has also been reported from karst caves in temperate climates. Observation of surface movements on patterned ground during the freezing season is very challenging due to presence of snow, lack of stable points and difficult site accessibility. Karst caves, on the other hand, are unique environments for such observations due to absence of snow and vegetation and stable cave walls that allow multitemporal comparison of particle movements. Our observation site is in Barka Cave that lies close to Snežnik Mountain at an elevation of 1100 m. It is a 20 m deep and 50 long oval collapse doline with locally overhanging walls. Sorted patterned ground developed on vegetation free floor under these walls. Especially characteristic are sorted circles with diameters ranging between 40 to 70 cm. We installed four time-lapse cameras steered by microcomputer that are taking photos of the sorted circles from different angles at hourly resolution. We used Structure from Motion (SfM) to generate 3D models for each time-step. A wide grain size range of sediment (gravel and sand) present on sorted circles enables tracking of ground movements in both vertical and horizontal directions. Up to 20 freeze-thaw cycles per year that can last several days cause intense frost heaving. First results show that

needle ice growth and frost heave up to 10 cm were observed during freezing conditions. Lateral particle movements are in the range of 5 cm during one winter. These particle movements will later be related to temperature characteristics, sediment properties and soil moisture. Sorted patterned ground studies in karst caves can thus help to reveal cryoturbation mechanisms that are responsible for large organic carbon storage in soils underlain by permafrost.

Keywords: *cryoturbation, ice caves, ground sorting*

Ključne besede: *krioturbacija, ledene jame, sortiranje tal*

Building FAIR data for karst hydrology and applications to foster research advances

Zbiranje FAIR kraških hidroloških podatkov in aplikacij za pospeševanje napredka v raziskavah

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In a rapidly changing world, the observation of climate and hydrological variables is increasingly necessary. Access to these observational data is crucial as they provide historical and real-time snapshots, offering invaluable insights into the complex processes that govern our planet. Effective hydrological research and management thus require data that are Findable, Accessible, Interoperable, and Reusable (FAIR). Building databases that adhere to FAIR principles is essential for advancing research and addressing environmental challenges in karst terrains. Recently, the World Karst Spring hydrographs (WoKaS) database has been developed through community-wide support. Its development emphasized data integration, transparency, and reproducibility. The WoKaS database is facilitating several advancements in karst hydrology, including improved model predictions, comparative understanding of karst systems, and interdisciplinary collaborations. Additional initiatives to develop complementary databases (e.g., soil moisture, isotopes, water quality, catchment attributes) specifically for karst environments are also under discussion. This presentation details methodologies for structuring and sharing karst hydrological data in compliance with FAIR principles - key elements include standardizing data formats, enhancing metadata descriptions, and leveraging open-access platforms. Finally, it highlights ongoing research advances facilitated by access to open data and provides recommendations for further development of open data products in karst hydrology to foster more innovative research advancements.

Keywords: *FAIR data, data integration, open-access, observation data, WoKaS*

Ključne besede: *podatki FAIR, integracija podatkov, odprti dostop, podatki opazovanja, WoKaS*

Challenges of non-periodic behaviour in cave climate and other karst processes due to climate change

Izzivi neperiodičnega obnašanja v jamski klimi in drugih kraških procesih kot posledica podnebnih sprememb

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Microclimatic and other environmental measurements in caves in recent years are facing new challenges caused by the increasingly evident phenomena associated with climate change. Previously, research relied on relatively stable samples and periodicity in the behavior of key climatic parameters such as temperature and precipitation, which enabled predictions of future conditions. In recent years, climate change has led to more frequent and intense extreme weather events that are typically non-periodic and cause changes in local and global systems. Due to clear deviations from regular, periodic behaviors, it is necessary to develop new strategies for monitoring climatic and other conditions in caves. This includes well-planned continuous monitoring that detects anomalies in temperature behavior, water dynamics, CO₂ dynamics and ice conditions if present in the cave, over shorter and longer time scales. Systematic data collection can analyze whether and how external climatic conditions affect the microclimate of caves and improve models that describe processes in caves. In this context, collecting data and analyzing it pose new challenges that include discussions on instruments and methods, choosing representative research locations, connecting with external climate data, and other features through an interdisciplinary approach. This work is supported by the Slovenian Research Agency and the Croatian Science Foundation within the project Dynamics and distribution of CO₂ in karst vadose and epiphreatic zone (CARDIKARST) IPS -2022-02-2260.

Keywords: non-periodic behaviour, cave microclimate, research methods, climate change

Ključne besede: neperiodično obnašanje, jamska mikroklima, raziskovalne metode, klimatske spremembe

Chronology building using fluorescence in Late Holocene stalagmite from Nova Grgosova cave, NW Croatia

Nadgradnja kronologije z uporabo fluorescence na stalagmitu iz poznega holocena iz jame Nova Grgosova, SZ Hrvatska

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Radiometric dating techniques are a geochronological tool whose rapid refinement enabled speleothem dating with high precision and accuracy. However, there is a certain limit of precision that these techniques cannot exceed, particularly when dating young, low uranium speleothem samples. A number of studies reveal that some speleothems may be characterised by annual lamination in their geochemical or/and organic properties. These laminas can be used as an additional geochronology tool providing relative chronology data, capable of improving the overall speleothem chronology when coupled with radiometric dating methods. Here we present the first results of a study where we investigate the potential of using lamination in a stalagmite sample from Nova Grgosova cave (NW Croatia), in order to improve U-Th age-depth model. The stalagmite NG-2 was actively growing by the time of collection. The sample consists of well-developed, white and translucent macroscopic laminae couplets which are supposed to be of annual origin, as demonstrated by U-Th radiometric dating. A preliminary U-Th age-depth model indicates that the stalagmite grew continuously during the last ~1400 years with an average growth rate of ~0.1 mm/yr. The growth rate increased to about 0.25 mm/yr over the last 150 years. To improve the U-Th chronology we performed confocal laser scanning microscopy (CLSM) on thin sections of the NG-2 stalagmite. The results revealed distinctive fluorescent patterns indicating annual and subannual lamina occurrences. To optimize the U-Th age-depth model we applied several lamina counting techniques and here we present some preliminary results.

Keywords: stalagmite, lamination, fluorescence, Nova Grgosova cave, Croatia

Ključne besede: stalagmit, laminacija, fluorescenca, jama Nova Grgosova, Hrvatska

The sampling problem in the construction of a speleothems age distribution curves – introduction for the conception of growing phases

Problem vzorčenja pri izdelavi krivulj starostne porazdelitve kapnikov – uvod v koncept faz rasti

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Speleothem growth frequency is the most basic proxy, that can be estimated from the speleothems data. It is widely used in the reconstruct changes in rainfall and/or regional or global temperature during the Quaternary. However, the shape of reconstructed curve depend on list of factors some of then may biases the precision of distribution of speleothems growing curve. This factors may be

grouped in three cluster: the potential for preservation for the speleothems; the uncertainty of U-series dates and the sampling problems. In this work we focused on the specified sampling problem which can be described as the intentionally sampling. This problem was point out in earlier research as the tendency for sampling in the areas, where the important changes occur. Hercman point out that sampling in the areas were cessation of speleothems growing (hiatus) occurred can bring to the artificial bimodality in the distribution. All previous studies were based on the age of a single sample as the core data, we come up with different approaches to the construction of speleothem growth frequency curves, in this approach we consider the single growing phase as the core data for distribution of growing of speleothems curve. The growing phase can be define as the segment of continuous growing between the two hiatuses, growing phases" (PHAS) method. In fact, the main purpose of speleothem growth frequency curves is the reconstruction of growing phases. Therefore, this approach is philosophically compatible with the main idea of speleothem growth frequency curves. It basis on the additional information which include the internal structure of speleothem. It not cause any problems, if the samples was collected by the investigator, but if the large amount of data previously published is taken on, it must be carefully checked before the PHAS method can be applied for that data.

Keywords: *distribution curves, speleothems, SISAL, EPICA Dome C deuterium record*

Ključne besede: *porazdelitvene krivulje, siga/kapniki, SISAL, EPICA Dome C deuterium zapis*

Data acquisition for analysis through modelling

Pridobivanje podatkov za analize z modeliranjem

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Computational models can be a valuable tool for analysing time-series data on karst systems. One can use physics-based models, in which the differential equations that (are presumed to) describe the observed system are solved. The parameters of the equations can be adjusted to achieve a good fit between the model predictions and the measurements. The main result of such an endeavour are the adjusted parameter values, which represent the information about the system that is inferred from the measurements. Another possibility is data-based modelling or machine learning, where the algorithm seeks patterns in the data and relationships between the quantities, which can be revealing as well. In both cases, we take advantage of the available computer hardware, software, and large data sets, which all became more available in the recent decades. The modelling is often based on data that was not acquired specifically for the purpose but is nevertheless useful. However, some choices in data acquisition that may be inconsequential for more basic studies, such as basic statistics and inspection of graphs, can significantly affect modelling. General data hygiene, such as keeping track of time zones, may turn out to be especially important when modelling. The chosen sampling time, accuracy of the measurement device, and sensor location have to be suitable for the

phenomena one is studying, and this also applies when the data is interpreted with the help of modelling. Furthermore, there are some surprising sources of modelling issues: time-averaging may be standard in data collection for other purposes but is not optimal for modelling. Our general suggestion is to acquire time-series data as if it was going to be used in modelling, since other uses of the data are typically less demanding and not affected by this choice.

Keywords: *time-series data, meteorology, mathematical modelling, machine learning*

Ključne besede: *podatki časovnih vrst, meteorologija, matematično modeliranje, strojno učenje*

The impact of subsurface life on ghost-rock karstification processes

Vpliv podzemeljskega življenja na fantomsko zakrasevanje

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Karst systems represent an important carbon and freshwater reservoirs. Although karst systems have been studied for many years, a new paradigm has emerged that suggests some of them could be formed by ghost-rock processes (Dubois et al. 2014). Contrarily to the classical total karstification, ghost-rock karstification leaves in place a weathered rock, called the ghost-rock, that may contribute to epikarst water storage (Champollion et al. 2018) and that can constitute a microbial habitat (Spilde et al. 2005). The first results of a geomicrobiological study of the Sterkfontein's cave system in South Africa show that these ghost-rocks are mainly composed of iron and manganese oxides mixed with organic matter of putative microbial origin (Pisapia et al. in prep). Subsurface microbial communities may contribute to the formation of these ghost rocks through metal oxidation reactions and rock weathering. But they could also contribute to the dissolution of these oxides through metal reduction reactions. As the iron and manganese oxides in ghost-rocks can adsorb significant concentrations of elements and molecules (Tebo et al. 2004), the interaction between microbial communities and oxidized and/or reduced minerals of those ghost-rocks may have implications on elements (re)-mobilization to groundwater. To further understand the microbial community inhabiting these ghost-rocks, its specificity compared to groundwater, and its functional impact on the karst system of Sterkfontein, a metagenomic analysis from both ghost-rocks and groundwater samples was performed. The results highlight the differences in microbial community between these two environments, and suggest a high importance of microbe-minerals interactions in the ghost rocks, through metallophores production and extracellular electron transfer processes between bacteria and metallic ions, that may contribute to the Fe-Mn oxides reduction and dissolution.

Keywords: *microbiology, ghost-rock karstification, bioinformatics*

Ključne besede: *mikrobiologija, fantomsko zakrasevanje, bioinformatika*

20 years of LTER Slovenia: from challenging beginnings to successful national long-term research infrastructure

20 let LTER Slovenija: od zahtevnih začetkov do uspešne nacionalne dolgoročne raziskovalne infrastrukture

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Research infrastructures dedicated to long-term ecosystem research are important to support the assessment of the impacts of global change on landscapes, ecosystems and society. The European Long-Term Ecological Research Network (LTER Europe) is an initiative with the main objective of improving the understanding of the processes that shape ecosystems and socio-ecological systems under the influence of global change. In this paper we briefly present the twenty years of research since Slovenia joined this initiative and the main challenges and research activities carried out within the LTER Slovenia consortium.

The mission of LTER Slovenia is to establish a network of sites that will enable Slovenian scientists to address ecological questions on broad spatial and temporal scale in an interdisciplinary manner. In addition, the national network is aiming to create a legacy of well-designed and documented experiments and observations for future generations of society.

In 2023 we celebrated 20 years of successful partnership of Slovenian researchers and their institutions, who joined forces to form the LTER Slovenia consortium and their active contribution to eLTER RI. With their research results and collaboration, they have built a stronger community and scientific network in the European Research Area. We are grateful for these two decades of LTER Slovenia and look forward to new research challenges.

Keywords: eLTER, LTER Slovenia, research infrastructure, long-term ecosystem research, karst

Ključne besede: eLTER, LTER Slovenija, raziskovalna infrastruktura, dolgoročne ekosistemske raziskave, kras

Investigations volatile organic compound contamination in a Swiss karst system used drinking water supply

Raziskave onesnaženja s hlapnimi organskimi spojinami v švicarskem kraškem sistemu za oskrbo s pitno vodo

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The district of "Ajoie" is situated in the NW of Switzerland, along the French border, on a huge karstic area located to the NW of the Jura Mountains. The karstic area is constituted by a thick limestone layer (middle Jurassic) in sub-horizontal position with some intercalation of marl layers. This is a densely populated area where intensive human activities like agriculture and watch factories,

sometimes more than hundred years old, impact the quality of groundwater. Moreover, many dolines were filled with industrial waste. Because of these industrial activities, groundwater is polluted by persistent organic pollutants such as chlorinated solvents which have been used in very large quantities in the past. The drinking water of the largest town of this area and some other villages comes from polluted karst springs that require a strong and expensive treatment to make water potable. In response to the discovery of extensive pollution in karstic water resources, authorities have established a range of pollution monitoring systems, supported by local engineering companies and academic institutions. Concurrently with source monitoring, various measures have been implemented to enhance groundwater quality: (A) establishment of groundwater protection areas, (B) strong environmental regulations for the factories, (C) wastewater treatment, (D) identification and assessment of problematic polluted sites. As a result of the preventive actions groundwater quality improves, albeit slowly. However, preventive actions are ineffective when a contaminant, like a dense non-aqueous phase liquid (DNAPL) reaches the aquifer, because removing it from the aquifer is almost impossible. Recent data acquisition campaigns have been conducted to enhance the characterization of aquifer contamination. Integrative passive samplers have been deployed to detect contaminants at very low concentrations. Additionally, an analysis campaign has targeted all water types (spring, river, groundwater, wastewater) within a confined area. The objective is to discern the interactions among various environments and to investigate the contamination originating from primary pollution sources.

Keywords: *monitoring, groundwater protection, groundwater contamination, Switzerland, water supply, volatile organic compound*

Ključne besede: *monitoring, varovanje podzemnih voda, onesnaženje podzemnih voda, Švica, oskrba s pitno vodo, hlapne organske spojine*

Element of a pluri-disciplinary project on karstic reservoir characterization: first results of cave sediments paleomagnetic dating in Dévoluy Massif, France

Element pluridisciplinarnega projekta o karakterizaciji kraškega rezervoarja: prvi rezultati paleomagnetnega datiranja jamskih sedimentov v masivu Dévoluy, Francija

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Dévoluy is a mountain range located in the southern French Alps. It is the last foreland chain before the outer crystalline Pelvoux massif. The carbonate rocks that constitute it form a reservoir of several hundred meters thick, folded and fractured by Alpine orogeny during the Cenozoic. This reservoir, exposed to erosion, was then intensively karstified, creating a network of interconnected karstic conduits leading to a unique outlet: the Gillardes spring. Due to its position in the Southern Alps, a geographical area subject to increasing water stress in the context of climate change, the Dévoluy massif presents a major challenge in understanding and preserving the local groundwater reserves.

The aim of this study is to provide an overall analysis of the evolution of this geological entity by applying a reservoir approach: understanding its evolution from its formation to its current state by analyzing each of its components. This section of the study focuses on the karst evolution by analyzing karstic sediments observed in the Rama-Aiguille cave. These sediments are represented by three poles: debris flow, speleothems and pseudo-varves. They are preserved in few outcrops in the cave and can reach up to ten meters thick. Paleomagnetic dating has been carried out in pseudo-varves showing some reverse polarities indicating an age of more than 780ka for those sediments. This shows that karstic systems are settled at least since more than 780ka and that conduits have undergone phases of clogging and unclogging. The next phases of the study will have to identify the stratigraphy of these fillings more precisely by understanding their origin and determining whether they are specific to the Rama-Aiguille network or whether they are evidence of a global karst filling phase in Dévoluy. It will give important information about the karstic reservoir evolution.

Keywords: karstic reservoir, Dévoluy Massif, karstic sediments, paleomagnetism

Ključne besede: kraški rezervoar, masiv Dévoluy, kraški sedimenti, paleomagnetizem

Provenience of limestones used for Stečki Tombstones in the Dinaric Karst, Bosnia and Herzegovina

Izvor apnencev za izdelavo stečkov (nagrobnikov) na Dinarskem krasu, Bosna in Hercegovina

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One of the most characteristic features of the Dinaric karst in Bosnia and Herzegovina are large, often ornamented medieval tombstones known as Stečki. Their most numerous occurrence is in the poljes, but smaller groups are found also in the remote, mountain karst areas. Although they are widespread and numerous, little is known about them, particularly about the provenience of material used. We conducted a geological survey of selected necropolises in the wider area of Bileća. We focused on representative lithofacies characteristic of individual chronostratigraphic units (formations) identified on the Basic Geological Maps of Yugoslavia. Fourteen necropolises, the remains of a medieval church and one original quarry were examined. Preliminary results point the rocks used are largely limestones, some of them partially dolomitized. At one location we also noticed limestone with chert nodules and at another slightly marly limestone. In a few locations, limestone breccias and conglomerates with rare chert clasts and colourful (polyolithic) coarse-grained conglomerates occur. Observations show that the rocks used to make the Stečki are exclusively local. In most cases, the original formations of the identified characteristic lithofacies are located in the immediate vicinity of the necropolis, as a rule on the nearest slope above the necropolis or in the immediate vicinity along the valley. We also noticed that when extracting stone blocks, the makers followed the natural conditions, where they used the existing discontinuities (stratification and fractures) in the rock mass to separate them from the primary rock. Our preliminary results reveal that also in the past the Dinaric karst was hardly passable area. Namely, rather than transporting heavy stones across rough karstic terrain from the few large producing centres, medieval society of

Dinaric karst region preferred to move the Stečki makers, as local environments provided enough of suitable stone material.

Keywords: limestones, Stečki tombstones, Dinaric karst, Dabar polje, Bosnia and Herzegovina

Ključne besede: apnenci, stečki (nagrobniki), dinarski kras, Dabarsko polje, Bosna in Hercegovina

The diversity of karst geo-data and challenges for acquisition, management, analysis, and storage

Raznolikost kraških geopodatkov in izzivi za njihovo pridobivanje, upravljanje, analizo in shranjevanje

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Data serves as the basis of science, and the challenges for acquisition, management, analysis, and storage of geoscience data are many. In the subfield of karst studies, such tasks are even more problematic. These problems mainly fall in to 5 categories: A) difficulty acquiring data (Permits, physical rigor of traversing and working underground, conservation), B) diversity and complexity of data types (cave configurations, groundwater flow paths, water chemistry/quality, speleothem ages, clastic sediment data, C) lack of consistency in data structures (e.g. cave survey format/grades), D) difficulty processing/visualizing/analyzing data, and E) need for data security (e.g. cave entrance locations) for conservation. For many karst studies the use of land surface maps, increasingly derived from automated and high-resolution remote sensing (e.g. Lidar), is a powerful foundation. This can be applied to such things as landscape evolution analysis and groundwater flow from tracing experiments. However, remote sensing of subsurface karst is in its infancy, and may never be fully realized. For human-accessible voids this means highly labor-intensive mapping. Inaccessible voids cannot be delineated this way, but they are potentially significant in terms of water flow or land surface stability. Direct methods such as drilling/probing can be employed, or geophysical methods. But, the latter have limitations in interpretation, for example solid dense bedrock may give the same resistivity value as an air filled void. Perhaps the most significant challenge is that it is impossible to fully “see” a cave without mapping. When navigating the interior, one only sees a portion of the network, and many openings are too small to be delineated. We rely, gratefully, on the work on countless cave explorers. Training of scientists in the vagaries of karst data acquisition and management is mostly haphazard. Some university programs may offer specific content or methods courses (e.g., the Nova Gorica karstology program), but mostly young researchers gain such knowledge in a piecemeal fashion from mentors.

Keywords: data management, karst, education

Ključne besede: upravljanje s podatki, kras, izobraževanje

“Dirty calcite” and the search for suitable correction coefficient – an experimental approach

“Umazani kalcit” in iskanje ustreznega korekcijskega koeficienta – eksperimentalni pristop

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Uranium and thorium isotopes are commonly incorporated by adsorption, or present as a constituent of the crystal lattice of many materials (clay minerals, ferro-hydroxides, etc). Such materials are likely to be incorporated in Quaternary second carbonates. These carbonates are called dirty carbonates. Unlike clean carbonates, dirty carbonates contain ^{230}Th which is not related to the in situ decay of ^{234}U . Uranium-series dating of such carbonates involves the application of a correction method to deal with these non-authigenic isotopes. For many years now, correction methods with their respective assumptions have been employed without a profound understanding of some basic chemical information (e.g. U and Th behavior during acid treatment). Yet, some investigations have been held previously but mainly focused on a method involving the total dissolution of the sample (TSD method). The experiment is running right now and the first results will be presented on the 31st International Karst School.

Keywords: dirty calcite, experimental approach, U-series dating

Ključne besede: umazani kalcit, eksperimentalni pristop, datiranje z U-serijami

Microbial load and community composition on cave surfaces, and the impact of organic pollution from cattle slurry: A case study of Postojnska jama, Slovenia

Mikrobna obremenjenost jamskih površin in sestava tamkajšnjih mikrobnih združb ter vpliv organskega onesnaženja z gnojevko: Primer Postojnske jame, Slovenija

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The presence and abundance of cave biota on surfaces in Postojnska jama (Slovenia) are subjected to different natural and human factors, such as intensive air streaming, touching by visitors, active seepages and river floods. In February 2024, organic pollution originating from cattle slurry reached the Pivka River and the cave. The impacted flooding zone of the underground channel of the Pivka River was swabbed before and after the pollution event and compared with the swabs collected from the same surface during the late recession of a regular flood that occurred in December 2023. To quantify the microbial load, qPCR analysis targeting the bacterial 16S rRNA gene was performed and the microbial communities were compared by 16S rRNA amplicon sequencing. A qPCR analysis showed high microbial biomass in terms of abundance of 16S rRNA gene copy numbers before ($16.7 \pm 2.92 \times 10^9/100 \text{ cm}^2$) and after ($16.1 \pm 2.60 \times 10^9/100 \text{ cm}^2$) the pollution reached the cave, as well as after the regular flooding ($11.8 \pm 8.19 \times 10^9/100 \text{ cm}^2$). The most abundant phyla before and after the

pollution were Pseudomonadota (43.4% and 46.9%, respectively), Actinomycetota (26.2% and 22.5%, respectively) and Bacteroidota (14.7% and 15.0%, respectively). *Flavobacterium degerlachei* was the most frequently identified species (48.5% and 32.1%, respectively). An increase in representatives from the phylum Campylobacterota (10x) and genus *Acinetobacter* (100x), as well as species *Shewanella morhuae* (30x) was observed in comparison to their abundance before the diluted slurry reached the cave. *Bifidobacterium pseudolongum*, a species commonly found in cattle and swine faeces was identified only in the samples collected after the pollution. Results from the regular flood showed different community structure with the prevalence of representatives from the phyla Actinomycetota (62.6%) and Pseudomonadota (30.2%), and the most abundant species was *Pseudomonas xanthomarina* (23.4%). Our results show that the slurry altered the composition of the microbial community of the same sampled surfaces and that the surface microbiome of flooding zones changes according to individual flooding events. However, it remains open if the pre-flooding community re-establish again and to which extent.

Keywords: Postojna cave, microbiome, organic pollution, qPCR, 16S rRNA amplicon sequencing

Ključne besede: Postojnska jama, mikrobiom, organsko onesnaženje, qPCR, 16S rRNA amplikonsko sekvenciranje

Cave and Karst Data Management at the USDA Forest Service, USA

Upravljanje z jamskimi in kraškimi podatki v USDA gozdarski službi, ZDA

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The United States Department of Agriculture's Forest Service (FS) manages diverse cave and karst resources on more than 780,000 km² of public land. The FS has a responsibility under the Federal Cave Resources Protection Act of 1988 to designate significant caves and provide for their protection and preservation. More than 7,000 caves are estimated to exist on FS lands, but only 2,700 have been designated as significant. Designating new caves and recording their data in a protected database, that safeguards significant cave locations from public access under the U.S. Freedom of Information Act, is fundamental to their management and protection. Adopting a comprehensive approach is crucial in a multi-use agency, such as the FS, and this includes identifying karst features to create vulnerability maps. Using Lidar data, surface karst features can be derived and investigated for hazard prediction, hydrogeologic drainage assessments, and land management. Buffer zones, with a range of up to 0.8 km, are designated around karst features such as sinkholes, caves, sinking streams, and springs. These buffers aim to minimize the impacts of human activities in karst regions. Karst vulnerability maps play a vital role in safeguarding cave ecosystems and water resources, and help establish protective areas around karst features in active zones where timber harvest, grazing, oil and gas development, mining, fire retardant and herbicide applications, infrastructure development, and recreation occur.

Keywords: USDA Forest Service, cave and karst management, LiDAR, significant caves, vulnerability maps

Ključne besede: USDA gozdarska služba, upravljanje z jamami in krasom, LiDAR, pomembne jame, karte ranljivosti

Patterns of precipitation $\delta^{18}\text{O}$ through the Iberian Peninsula: Machine Learning dynamic modeling for climate proxy calibration

Vzorci padavin $\delta^{18}\text{O}$ na Iberskem polotoku: dinamično modeliranje s strojnim učenjem z namenom kalibracije klimatskega proksija

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Extensive paleoclimate research based in continental records such as speleothems and lake sediments has derived in the availability of huge data sets of geochemical variables of paleoenvironmental or paleoclimatic significance. Despite the high quality and the large amount of data, it is often difficult to reach accurate paleoclimate interpretations and, particularly, to quantitatively calibrate them as climate proxies. A paradigmatic example is given by the oxygen isotope ratios measured in carbonates ($\delta^{18}\text{O}_\text{c}$) in records of mid latitudes such as the Iberian Peninsula. These, assuming initial conditions of isotopic equilibrium, depend on both the local temperature for carbonate formation, and of the isotopic composition of water ($\delta^{18}\text{O}_\text{w}$). The later, in turn, is controlled by a wide range of hydrological and atmospheric variables, including changes in source areas for water vapor, storm trajectories, and temperature. We present an innovative Machine Learning-based model that integrates diverse datasets, including precipitation isotope data from the IAEA Global Network of Isotopes in Precipitation (GNIP) and local series derived from monitoring data. Our approach considers not only the dependence of the rainfall $\delta^{18}\text{O}$ on latitude and altitude, but also the main factors influencing the synoptic scenarios for winter precipitation variability over the Iberian Peninsula, such as the pressure balance between the North Atlantic Oscillation and the Western Mediterranean Oscillation. By considering these mesoscale atmospheric dynamics, we aim to refine our understanding of the spatial and temporal distribution of the precipitation isotopic composition, crucial for deciphering past climatic conditions. Our model emerges as an alternative to current static approaches by refining the accuracy of $\delta^{18}\text{O}$ estimates and incorporating monthly weather variability into the final output. This improvement enhances the calibration of carbonate-based proxies for paleoclimatic reconstructions based in records such as speleothems or lake sediments. Furthermore, our tool extends beyond paleoclimatic applications: it provides a valuable resource for ongoing cave monitoring efforts in areas where precipitation isotopic data are sparse or nonexistent. By addressing the challenges of acquiring and interpreting isotopic data within complex karst environments, our work contributes to the broader field of data acquisition, processing, and interpretation in karst research. Contribution to PID2021-122854OB-I00 and research group 910198 of the UCM.

Keywords: paleoclimate, stable isotope, artificial intelligence, lake speleothem, North Atlantic Oscillation

Ključne besede: paleoklima, stabilni izotop, umetna inteligenca, jezerska siga, severno-atlantska oscilacija

The influence of geotectonics on the hydrogeological conditions and regime of the karst aquifer in the Ravanica zone – Eastern Serbia

Vpliv geotektonike na hidrogeološke razmere in režim kraškega vodonosnika na območju Ravanica – vzhodna Srbija

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The study focused on the western belt of the Carpatho-Balkan arc, assess the specific geological and hydrogeological features of the Ravanica zone as well as the groundwater balance for sustainable uses. All the karst springs of the Ravanica zone are positioned at the contact of two regionally important geotectonic units, the Carpatho-Balkanides, and the Serbian-Macedonian Massif. Additionally, this belt is cross-cut by the incised streams, which represent the hydraulically connected zones with karst groundwater. The Ravanica zone represents an inclined structure, generally from the South to the North, which conditioned the development of the allogenic karst aquifer system in the northern part and the autogenic system in the South. Specific geotectonic conditions, e.g., Permian sandstone overthrust with Ravanica limestone to the East, intensified karst process development in the East-West direction. Analysis of the cave conduits' distribution proved this while the analysis of the doline elongations showed a dominant longitudinal direction, the same as structures. On the western part, in the karst spring zones, the development of Miocene lacustrine basins influenced the development of siphonal conduits, slowing down the karst process in the outlet zone. This led to slower depletion of the karst aquifer and, thus, a more stable discharge regime than the "classical" karst systems. The application of quantitative methods, including Time series analysis, provided information about the hydrogeological characterization of karst system. Furthermore, the analysis gave essential proof of the impact of the geotectonic condition on the regime and structural characteristics of the karst aquifer. The analysis conducted suggests that the geological conditions affect karst aquifers' hydrogeological features and hydraulic behavior of different springs in the research area. Consequently, these conditions affect not only the aquifer regime but also vulnerability, creating conditions that slowly reach potential contaminants in the aquifer zone, but with prolonged contamination.

Keywords: *Ravanica zone, karst aquifer system, karst conduits and doline elongation analysis, time series analysis, aquifer regime*

Ključne besede: *zona Ravanica, sistem kraškega vodonosnika, kraški kanali in analiza podaljševanja vrtač, analiza časovnih vrst, režim vodonosnika*

Dripstone formation from Gigant Cave – one of the oldest caves in Prokletije Mountains (Montenegro)

Nastanek kapnika iz jame Gigant – ena najstarejših jam v gorovju Prokletije (Črna gora)

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The Prokletije Mountains are the highest part of the Dinaric Alps, where intensive and systematic speleological exploration has been conducted since 2006. However, scientific research in this region has only recently been carried out. This study focuses on the Kolata massif, where the oldest cave systems in this area are located. During this study we collected speleothems from Gigant cave which entrance is located at the highest altitude in this area (2116 m.). Gigant Cave (depth -296 m, length 1635 m) is one of the deepest caves in the Kolata massif although only top level of the cave is rich in speleothems. From the entrance, a narrow passage leads to three chambers two of which, the bigger ones, contains speleothems. We collected several speleothems and used uranium-thorium dating to determine of their ages. The crystallization of the first generations of speleothems took place during the period ~600 ka. (Marine Isotope Stage 15), and later, during periods ca. 366-225 ka (from MIS 10 to MIS 7), 320-160 ka (from MIS 9 to MIS 6) and 366-127 ka (from MIS 10 to MIS 5e). The study also reveals a generation of younger speleothem dated for age 10.8-2.8 ka (Holocene). In our samples we can also observe zones of hiatuses which correspond to periods of colder climate. That observation shows that growth of most of the studied samples took place only in periods of interglacials, which is in contrast to speleothem studied previously in Carpathians. This study represents the first investigation of the application of uranium-thorium dating to speleothems in the Montenegrin part of the Prokletije Mountains.

Keywords: caves, speleothems, U-Th dating, MIS

Ključne besede: jame, kapniki, datiranje z U-Th, MIS

Analysis of karst springs data to aid in the understanding karst aquifer processes, disturbances in the karst catchment and longer-term climate change effects

Analiza podatkov iz kraških izvorov kot pomoč pri razumevanju procesov v kraških vodonosnikih, motenj v kraškem porečju in dolgoročnih učinkov podnebnih sprememb

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Considerable data has been collected over the last ten years from two karst springs one on Vancouver Island near Port Alberni and the other on nearby Quadra Island. Both karst springs are used for domestic water resources and have catchments that occur in areas of active forestry. The data collected at these springs include continuous measurements of spring flow rate (water level), conductivity, water temperature, turbidity and surface temperature and rainfall, along with some

geochemical analyses. A primary issue has been dealing with the vast amount data collected over time, its organization and analysis. Analysis using Hoboware software has been useful for rapid evaluation of small-time intervals of data (e.g., 3 months to a year) and can provide information on short term events like intense rainfall or summer droughts. However, examination of data over multiple years and longer time periods assessing forestry disturbances and/or climate changes is more challenging. A framework for the analysis of these data has been developed using R (a free software environment for statistical computing and graphics) and allows for a more structured approach. At the outset seven years of data from 2016-2022 at the Port Alberni spring were used as a test data set to develop an R software routine. A set of systematic data analysis steps were created allowing for the comparison of: i) annual surface temperature and precipitation records at the field site, and to a reference weather station nearby; ii) annual spring water temperature data to surface temperature data; iii) annual water level (flow) data to precipitation events; and finally, iv) annual water conductivity and turbidity data to precipitation and water level (flow) data. Results and graphical outputs from this work are in progress. Short-term changes are typically well defined such as the rapid response times of high spring water flows due to heavy rainfall events (with some correlation to turbidity) and distinct variations in conductivity and water temperature due to seasonal changes in surface temperature and precipitation. Longer term changes due to climate change (e.g., extreme events or otherwise) and land disturbances (e.g., logging of new forested cutblocks) are harder to define in the data. However, visual observations of the data have suggested a slight warming in spring water temperature over time and field observations have identified increased erosion and sediment movement around sink points potentially due to higher peak flows.

Keywords: karst springs, Vancouver Island, data analytical framework, R software, land disturbance, extreme weather events

Ključne besede: kraški izviri, Vancouverov otok, podatkovno analitično ogrodje, R program, motnja na kopnem/zemljišču, ekstremni vremenski dogodki

In situ, sequential $\delta^{13}\text{C}$ measurements in speleothem calcite via Laser Ablation Cavity Ring Down Spectroscopy – a novel method

In situ, sekvenčno merjenje $\delta^{13}\text{C}$ v kalcitu iz sige z metodo laserske ablacije “Cavity Ring Down” spektroskopije – nova metoda

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Carbon stable isotope records in speleothem calcite (together with oxygen stable isotope and elemental analyses) have long been accepted as a valuable tool for tracing past climate change. However, preparing the samples for stable isotope analyses is labor intensive and time consuming: individually micromilling samples at the highest spatial resolution allowed by a drill bit, weighing each powder sample, adding acid to release the gas to be measured, phase equilibration etc. Elemental concentration analysis on the other hand is quite straightforward: laser ablation is used as

the peripheral of choice for sample introduction into the mass spectrometer. The question follows naturally: why not use laser ablation as sample introduction for stable isotope analysis as well? We successfully tested an innovative method of measuring $\delta^{13}\text{C}$ in carbonates by hyphenating two instruments that are not usually found in the same lab. We coupled a laser ablation system (Teledyne Photon Machines Fusions CO₂) to a Cavity Ring Down Spectroscope (Picarro G2201-i) via a specially designed ablation chamber (the isoScellΔ100, Terra Analytic) to perform spatially resolved, highly accurate and precise in situ measurements of stalagmite calcite. This novel system (LA CRDS) requires minimal sample preparation (i.e., cutting and polishing the speleothem), allows for in-situ sequential and repeat sampling, all while eliminating the need to individually prepare samples. It is cost-efficient both instrument-, and labor-wise. The carrier gas used is N₂, with an average time per analysis of ca. 10 minutes. The novel method was tested on a stalagmite from the V11 Cave whose carbon stable isotope record was already published. Accuracy and precision shown by LA CRDS are on par with results from the traditional mass spectrometric approach, as seen by comparing results on the same area of the speleothem from both instrumental setups (LA CRDS vs. IRMS).

Keywords: $\delta^{13}\text{C}$ measurements, speleothem, Laser ablation - Cavity Ring Down Spectroscopy

Ključne besede: merjenje $\delta^{13}\text{C}$, siga/kapnik, laserska ablacija – “Cavity Ring Down” spektroskopija

Evolution of twenty-year monitoring in Modrič Cave (Croatia)

Razvoj 20 letnega monitoringa v jami Modrič (Hrvaška)

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Characterization of the karst environments plays vital role in speleothem-based palaeoenvironmental studies. Since the Croatian Littoral is recognized as important bordering belt between Atlantic- and Mediterranean-dominated regions, centrally positioned Modrič Cave has hosted various scientific research over the last two decades. Along with evolution of research idea, sample collecting, measurement techniques and data acquisition developed. Accuracy, precision and resolution has been improved with every new generation of temperature and relative humidity loggers which has directly led to the better understanding of the cave gasses content and behavior. In that segment, cumulative monthly and/or discreet measurements were perfect base for the upgrade to the continuous measurements. From the hydrogeological point of view, heterogeneity of the karst aquifer does not allow averaging; indeed, it requires systematic characterization of each site-specific dripwater. As an added value, modern data set utilized for the palaeoenvironmental studies that covers already substantial time period, (tentatively) indicate the concurrent climate changes.

Keywords: cave monitoring, data acquisition, speleothem-based studies, Modrič Cave, Croatia

Ključne besede: jamski monitoring, pridobivanje podatkov, študije sige, jama Modrič, Hrvaška

Anthropogenic effects in the thermal springs of the Transdanubian Mountains

Antropogeni vplivi v termalnih izviri Transdanubijskih gora

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The thermal springs located on the edge of the Transdanubian Mountains are among the highest discharge karst springs of Hungary. The springs located at Hévíz, Tapolca, Tata and Buda are located in very different environments, from the bottom of shallow lakes to a deep network of submerged cave tunnels, but all characterized by water temperatures significantly higher than the annual average temperature. These springs display only small seasonal variations. The water infiltrating the open karst areas of the mountain range reaches the springs following a deep path. Although thermal waters arriving from deeper aquifers are thought to be protected from short-term anthropogenic effects, all of the springs showed a significant decrease in discharge in the 70's due to extensive mine dewatering operations. Although after the collapse of mining industry in the 90's the springs gradually regenerated, the discharges today are still significantly smaller than the original values. In some cases pumped wells operated by hotels are suspected of the misbalance. High frequency monitoring of the springs might help in separating the natural effects from the anthropogenic ones. A direct measurement of the discharge is difficult or even impossible in cases. Physical or chemical parameters of the springs however might be in close correspondence with the discharge. The position of the mixing zone between hot and colder springs or the movement of the thermocline carries information about the relative discharge. Indeed these parameters show diurnal or even higher frequency variations on the investigated sites. A time series of a submarine thermal spring near Izola is also discussed.

Keywords: thermal springs, cave diving, anthropogenic effects, mixing zones

Ključne besede: termalni izviri, jamsko potaljanje, antropogeni vplivi, cone mešanja

An Arduino based tracer detector and flow rate logger for community science and large scale applications

“Arduino” sledilni detektor in merilec pretoka za znanost skupnosti in aplikacije večjega merila

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The aquifer under the Transdanubian Mountain Range stretches more than 150 km long. The numerous springs fed by this aquifer between Hévíz on the south-west and the Buda Thermal Karst on the northeast end require a large number of data loggers if we aim to monitor the effects of climate change on Hungary's largest aquifer. Currently there is no state-funded monitoring system

deployed, not even in the largest springs of the area. Without external funding no single educational or research institution can afford the cost of the commercial instruments needed for the task. The aim of the project presented here is to provide plans, part lists or even pre-assembled devices for volunteer teams that “adopt” some of the monitoring sites and provide the data for evaluation. The use of cheap, off-the-shelf materials and simple assembling techniques enable even middle-school classes or DIY -ers to participate in the monitoring efforts. In this presentation we introduce two such devices. One of the devices is a flow logger made of a floating body containing a 3 axis tilt sensor, fixed to the stream bed through a flexible stem. The sensitivity of the device can be adjusted with the size, shape, weight and surface of the float, and the length and flexibility of the stem. The versatility of the device is tested in very different environments: from the slow flows of the Molnár János Cave to the fast stream connecting the spring lakes at Tata. The second device is an underwater fluorescence logger designed for cave divers that is able to log the appearance of a fluorescent dye, providing help for the tracing experiments even in multilevel maze-like passage system of the MJC. The combination of a high power UV led and a sensitive 4 channel color detector allows the detection of very small tracer concentrations.

Keywords: *DIY, community service, karst monitoring, fluorescent tracer, flow measurement*

Ključne besede: *“naredi si sam”, znanost skupnosti, monitoring krasa, fluorescentni sledilnik, merjenje pretoka*

Dedolomitization in the cave environment – link to speleogenesis and geomorphological development of the carbonate-siliciclastic area in Central Slovenia

Dedolomitizacija v jamskem okolju – povezava s speleogenezo in geomorfološkim razvojem karbonatno–siliciklastičnega območja v osrednji Sloveniji

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This study investigates the occurrence of dedolomitization products and geomorphological features of the cave Mravljetovo brezno v Gošarjevih rupah, developed in the Middle Triassic dolostones in central Slovenia. The study area consists of Permian–Triassic succession with a mixed lithological composition, represented by carbonate and various non-carbonate rocks. Heterogeneous lithological composition, combined with tectonics, resulted in complex geomorphological features, both on the surface and underground. The cave contains dedolomitization products and various cave sediments that are indicating the diagenetic evolution, erosional–depositional dynamics, changes in hydrological environment and the geomorphological development of the area. To elucidate the spatio–temporal relationships between main features and processes in the cave, and to link them to the geomorphological development of the area, a multi-proxy approach was used. It integrated field-based geological and geomorphological mapping with extensive laboratory analyses. Rock and sediment samples from the field and cave were prepared and analyzed using petrography of stained carbonate samples, CL, SEM/EDS, microprobe, μ XRF, whole-rock geochemical analyses, oxygen and carbon stable isotopes ratio determination. The petrographic and geochemical results indicate that

the process of dedolomitization, potentially one of the initial phases of speleogenesis, occurred under phreatic conditions. This process was likely mediated by a solution-precipitation process facilitated by Ca-rich meteoric water, with additional calcium potentially sourced from the dissolution of evaporites in the Permian–Triassic succession by deep seated waters or from dissolution of secondary gypsum associated with pyrite oxidation in the adjacent marly limestone unit. Following this, the hydrological conditions within the cave system changed, likely as a result of tectonic uplift. Erosion of pre-existing structures occurred in epiphreatic and vadose conditions, and subsequently the deposition of siliciclastic material. In the final phases of cave evolution, vadose shafts developed and sparse speleothem deposition began. All the present features have been reworked mainly by strong condensation corrosion, which is still ongoing in the cave system, with secondary mineralization occurring in the form of crusts on the cave walls. Our results provide new insights into the processes of dedolomitization in the cave environment and some clues to the geomorphological development of the area. This work is funded by the Slovenian and Polish research agencies (ARIS and NCN) through the bilateral Polish-Slovenian research project CEUS (project code in Slovenia: N1-0226; project code in Poland: 2020/39/I/ST10/02357).

Keywords: *dedolomitization, speleogenesis, geomorphology, multi-proxy, Central Slovenia*

Ključne besede: *dedolomitizacija, speleogeneza, geomorfologija, multi-proksi, osrednja Slovenija*

Introduction of regular monitoring of critical environmental stressors for *Proteus anguinus* in Škocjan Caves, Slovenia

Uvedba rednega monitoringa ključnih okoljskih stresorjev za *Proteus anguinus* v Škocjanskih jamah, Slovenija

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The cave olm or proteus, *Proteus anguinus* (Amphibia: Urodela), is an endangered and protected animal. It is protected at EU level as part of the Natura 2000 network, where it is listed as a priority species in Annex II of the Habitats Directive. The protection measures for this organism also extend to the ecology of the habitat, and monitoring of critical environmental parameters with potentially harmful effects on the organism should be introduced. The karst aquifer, which is partly fed by the Reka River and sinks in Škocjan Caves, represents in the cave the species' habitat. Despite its robustness, *P. anguinus* is very sensitive to environmental stressors, especially those related to anthropogenic activities. Since 2012, physico-chemical and microbiological parameters have been measured as part of the occasional monitoring of the Reka River. Occasionally, high concentration of *Escherichia coli* (up to 33 CFU/ml) and a decrease in dissolved oxygen (~60 % oxygen saturation) were detected. Nitrate levels rarely exceeded 5 mg/l. In order to set up monitoring with higher resolution and faster response time, a continuous online measurement system (AquaTroll 600, InSitu, USA) with a recording interval of 15 minutes was installed in the cave in the Reka River in 2019. After initial technical adaptation of the system to the specific cave environment, measurements from 2023 onwards showed no nitrate levels above 10 mg/l, which is considered too high for the habitat or proteus. Dissolved oxygen levels were normally between 8 and 12 mg/l during

this period, with occasional brief drops to 4 mg/l (60 % oxygen saturation) observed during the low water period. These low levels of oxygen could indicate upstream pollution, but they quickly returned to normal levels. None of the most common pesticides routinely screened in drinking water were detected in the Reka River. On the other hand, there were few *E. coli* isolates in the river with phenotypic antibiotic resistance to cefotaxime and tetracycline. Such monitoring, which includes real-time measurements of temperature, oxygen and nitrates in conjunction with microbiological and chemical analyses during critical periods of the year, is important not only to characterise the habitat of proteus, but also to assess its resilience to natural and human-induced fluctuations in environmental parameters.

Keywords: *Proteus anguinus*, habitats directive, dissolved oxygen, nitrate, *E. coli*

Ključne besede: *Proteus anguinus*, habitatna direktiva, raztopljeni kisik, nitrat, *E. coli*

Post-Miocene tectonically induced hydrological changes revealed by cave sediments (Loza Cave System, W Slovenia)

Po-miocenske hidrološke spremembe kot posledica tektonske aktivnosti prepoznane v jamskih sedimentih (jamski sistem Loza, Z Slovenija)

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The evolution of karst in SW Slovenia is closely connected to past hydrological changes induced by tectonic activity. Cave sediments stored in contact karst represent important study sites to assess these changes chronologically. This study focuses on the hydrological evolution of the Loza Cave System located in the Slavina Plain. It employs an interdisciplinary approach, using geomorphological, speleological, and sedimentological analyses with paleomagnetism and rock magnetism, U-Th and paleontological dating. The Slavina Plain exhibits a complex history influenced by tectonic compression and successive uplift phases, as evidenced in the multi-proxy records of the Loza Cave System. This cave system has developed over three subhorizontal cave levels. Allogenic sediments reveal phases of epiphreatic cave development, followed by speleothem deposition, which corresponds to successive tectonic uplift phases and vadose speleogenesis after the groundwater level has dropped. The chronology of cave sediment deposition thus indicates distinct phases of tectonic stability and uplift, driving shifts in hydrological patterns and sediment deposition. Our findings provide a comprehensive insight into the hydrological development of the Postojna Basin and the functioning of the contact karst area over the last ~7 Ma. Overall, this research enhances our understanding of karst evolution in the Postojna Basin and similar areas within compression tectonic regimes, highlighting the importance of multi-level, multi-stage cave systems as archives of past hydrological changes. These discoveries have broadened our knowledge of tectonic activities of the

post-Miocene period and have introduced a new complementary methodology for studying these karst environments.

Keywords: karst hydrological zones, cave levels, contact karst, geochronology, tectonic uplift phases

Ključne besede: kraške hidrološke cone, jamski nivoji, kontaktni kras, geokronologija, faze tektonskega dviga

Neogene-Quaternary karst and landscape evolution in Crna Reka basin constrained by geochronological data from caves based on U-Th and cosmogenic nuclide burial age dating

Neogensko-kvartarni razvoj krasa na območju Crne Reke omejen z geokronološkimi podatki iz jam, na podlagi datacij U-Th in pokopne starosti s kozmogenimi nuklidi

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Research on cave morphology and sediments in the lower part of Crna Reka river basin (N. Macedonia) identified two major cave development phases: one related to Pliocene-Early Pleistocene basin infilling and establishment of lacustrine environments, and a subsequent phase related to valley incision due to draining of the lacustrine systems and tectonic uplift. New geochronological data were obtained from epigene caves in Crna Reka basin by U-Th dating of speleothems and ²⁶Al/¹⁰Be cosmogenic nuclide burial age dating of clastic cave sediments. The burial age (2.1 ± 0.5 Ma) of the clastic cave sediments from Temna Peštera – Dragožel indicates that cave passage development commenced in the Early Pleistocene, and supports previous results on placing the onset of the draining of the Pliocene lakes in Macedonia in the Early Pleistocene. U-Th dating of speleothems from four caves confirmed Middle to Late Pleistocene age, in agreement with the latest karst development phase related to Pleistocene valley incision. Calculated valley incision rates show increase towards the present, with values of <0.1 m/ka in Early Pleistocene, increasing to ~ 0.2 – 0.5 m/ka in Middle Pleistocene, and up to 1 m/ka in Late Pleistocene. Additionally, cosmogenic nuclide burial age dating was also applied at Melnička Peštera, a fossil hydrothermal cave, to quartz fragments in the cave-hosting carbonate breccia, that deposited as an alluvial fan filling up a paleovalley cut into Upper Miocene sediments. The burial dating confirms Early Pliocene age (4.7 ± 0.9 Ma to 3.8 ± 0.6 Ma) for the deposition of the breccia, and constrains the paleovalley incision to Late Miocene, likely related to base level lowering caused by the Messinian Salinity Crisis. The burial age of the breccia gives also a maximum age for the onset of the hypogene karst development at Melnica area, supporting previous data that relates the hydrothermal activity to the youngest phase of volcanic activity of the Kožuf-Voras system (3.0–1.8 Ma). This research was supported by the NKFIH FK 124807, GINOP-2.3.2-15-2016-00009 and RADIATE (Grant Agreement 824096) projects.

Keywords: U-Th dating, burial age dating, speleothems, cave sediments

Ključne besede: datiranje z U-Th, datiranje spokopno starostjo, kapniki/siga, jamski sedimenti

LiDAR Scanning's 3D mapping of Abu Sariye Alabaster Cave, Assiut Governorate, the Eastern Desert of Egypt

LiDAR 3D kartiranje jame Abu Sariye Alabaster, Assiut Governorate, vzhodna puščava, Egipt

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Abu Sariye alabaster cave is located in the NE portion of Assiut Governorate, Eastern Desert, Upper Egypt. The cave was formed on the side of one of the dry valley streams in the Al-Umrani Basin, which flows into the Nile River southeast of Dayrut City. The Minia Formation, a shallow marine limestone plateau of the Lower Eocene, forms its foundation. In March 2024, the authors, assisted by local quarry workers in Al-Houta Al-Sharqiya town, discovered the cave. They then surveyed and 3D mapped it using a SLAM100 handheld LiDAR scanner. For portable mapping, take fieldwork precautions. The cave being studied contains alabaster rocks. They formed when anhydrite near the surface quickly lost its water and turned into mostly plaster-grade gypsum deeper down during the Quaternary. We are utilizing the 3D mapping of the cave and the measurements of its parameters to enhance ecotourism in the area and to direct future studies that aim to understand the richness of the Karst habitat. The study found physical evidence indicating the presence of this highly endangered species in the cave.

Keywords: Alabaster cave, handheld LiDAR scanner, paleokarst, Quaternary, Assiut Governorate, Eastern Desert of Egypt, Upper Egypt

Ključne besede: jama Alabaster, ročni LiDAR skener, paleokras, kvartar, Assiut Governorate, vzhodna Egiptovska puščava, zgornji Egipt

Microclimatic characterization of turist caves in Cavernas do Peruaçu National Park, Minas Gerais, Brazil

Mikroklimatska karakterizacija turističnih jam v nacionalnem parku Cavernas do Peruaçu, Minas Gerais, Brazilija

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The cave environment possesses unique atmospheric conditions that significantly impact the existence and maintenance of biotic and abiotic components and socioeconomic and historical-cultural elements associated with caves. In caves frequented by tourists, human presence can disrupt its delicate balance. This study aimed to characterize the microclimate of seven caves included in the Cavernas do Peruaçu National Park tourist itinerary in northern Minas Gerais, Southeast Brazil. Data on temperature and relative humidity were collected using 41 data loggers, each recording more

than 110,300 readings. This research is notable for being one of the few long-term studies (2017 to 2019) conducted in the country and is still ongoing. The data analysis not only characterized the cave microclimate but also revealed the relationship between these attributes and the caves' internal morphology and positions within the karst landscape. This study should support the Cave Environmental Conditions Surveillance Programme, which the National Park administration will implement. Identifying more sensitive areas within the caves will allow better management and reordering of visitor access to these attractions. Results identified three distinct groups of caves based on temperature and humidity data. Lapa Bonita and Lapa do Índio showed the lowest average temperatures and standard deviations, consistent with their position at the Fazenda Terra Brava depression. They maintained higher relative humidity levels due to limited external influence. Despite their varied climates, Lapa do Carlúcio and Gruta do Janelão formed a group with intermediate humidity values. The third group, which includes Lapa dos Desenhos, Lapa do Rezar, and Lapa do Caboclo, had the lowest humidity levels, influenced by their proximity to drier regions and simple morphologies facilitating energy exchange with the external environment. Thus, it is expected that this study and its continuation provide essential data for the sustainable management of the tourist caves, aiding the development of a monitoring program by the National Park administration.

Keywords: cave microclimate, cave monitoring, Minas Gerais, Brazil

Ključne besede: jamska mikroklima, jamski monitoring, Minas Gerais, Brazilija

From pilot samples to high-resolution approach (to methodology of paleomagnetic sampling of karst sediments)

Od pilotnih vzorcev do visokoločljivostnega pristopa (do metodologije paleomagnetnega vzorčenja kraških sedimentov)

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Paleomagnetism is the study of the intensity and orientation of the magnetic field of the Earth as preserved in the magnetic orientation of certain minerals found in rocks that have formed throughout geologic time. The paleomagnetic method studies the past magnetic field by measuring the orientation of magnetic minerals in rocks and sediments. The study of paleomagnetism is possible because iron-bearing minerals (such as magnetite) may record past directions of magnetic field of the Earth. Cave deposits are generally a significant source of information on paleomagnetic polarities and on rock-magnetic data. The aim of such studies is to determine the principal magnetic polarity directions both in clastic and chemogenic deposits, to compare them with the Geomagnetic Polarity Time Scales (GPTS), and to prepare data for the stratigraphic correlation of studied sections. The GPTS boundaries have recently been well-calibrated (various numerical dating methods,

astrochronology). It is very useful to combine paleomagnetic results with other, especially numerical, dating methods. The samples are always in situ oriented. Initially, unconsolidated sediments were sampled by non-magnetic bronze trough; the sample column was cut into cubes ($20 \times 20 \times 20$ mm) with a knife. Since 1999, non-magnetic plastic boxes (Natsuhara Giken Co., Ltd., Japan) with an internal size of $20 \times 20 \times 20$ mm and a volume of about 6.7 cm^3 have been used. Speleothems are sampled, according to possibilities, as hand specimen (hammer and chisel) and/or as parallel cuts by engine-powered circular saw (since 2001). Field solid specimen are cut into cubes $20 \times 20 \times 20$ mm in the laboratory. When cutting, temperatures above 70°C must be avoided (sample remagnetization). Sampling in the first stages consisted of two steps: (1) collection of so-called „pilot“ samples at intervals of 10 cm and more, followed by (2) detailed sampling (at much denser spacing) along and across the boundaries of magnetozone with different polarization detected during laboratory processing and assessment of the paleomagnetic properties of the samples taken in the first step. Later sampling (ca since 2000) was based only on one step high-resolution sampling during the first visit, i.e. very dense sampling in soft sediments and continuous sampling in speleothems by cutting narrow trenches with usual sample spacing of 2 to 4 cm. The aim of high-resolution sampling is: (1) to avoid loss of narrow magnetozone / excursions during „pilot“ sampling (e. g., as in Ochtiná, Divaška, Trhlova), (2) to detect magnetozone boundaries with maximum precision, (3) to avoid the need to return to sections in caves / surficial outcrops; (4) sites that are not easily accessible (Tajna, Jama pod Babjim Zobom, Spodnji Tartarus), and/or (5) to avoid danger of (i) sections disappearing (Križna I) and (ii) slumps, collapses (Snežna), and/or (iii) construction works progressing too quickly (Divača, Kozina, Risnik). The samples must be protected from artificial remagnetization after collection, i. e. they must avoid transport in any kind of electrically-powered vehicles (trains, metro, trams, trolleybuses, cars, boats) and the samples must be protected against X-ray procedures during airport screening. RVO67985831; MOBILITY PLUS SAZU-24-04 Slovenian Research Agency research core funding no. P6-0119.

Keywords: karst sediments, paleomagnetism, sampling methodology

Ključne besede: kraški sedimenti, paleomagnetizem, metodologija vzorčenja