KARST RESEARCH INSTITUTE at ZRC SAZU

Slovenian National Commission for UNESCO

Speleological Association of Slovenia

Karst Commission IGU

14th INTERNATIONAL KARSTOLOGICAL SCHOOL
"CLASSICAL KARST"

Sustainable management of natural and environmental resources on karst

Postojna, 2006

Editorial board
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Cover photo
Highway construction in SE Slovenia – intersection Hrastje-Lešnica, 2005. Courtesy of Mitja Prelovšek.

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Contents

Dear Participant,

Karst Research Institute ZRC SAZU is organizing this year already the 14th International Karstological School “Classical Karst”. As in the past schools we thoroughly recognized some aspects and peculiarities of karst and karst features, in this year we will look for the answer to question how to preserve a brittle balance between natural resources on karst and human interventions. The core of this year school will be four keynote lectures given by the renowned experts; besides invited and thematic lectures a poster session will also be held. Discussions will continue during two half-day and one whole-day field trips. The school is included into EU Marie Curie Conferences and Training Courses *(MSCF-CT-2005-029674)*.

This printed Guide Booklet contains useful information on the programme of the conference held in Postojna, Slovenia, 26 June – 2 July 2006, and one whole-day and two half-day excursions. On the back you will find a CD accompanying the conference. This CD holds poster abstracts, short scientific papers and some other useful information about the conference.

We hope you will enjoy at the International Karstological School “Classical Karst” and we look forward to see you also next year when we will discuss management of transboundary karst aquifers!

10 June 2006,

Janez Mulec, Organizing Committee

General information

Lectures and poster presentations

Lectures will be held in the lecture room at the Cultural centre of Postojna (Kulturni dom Postojna, Prešernova ulica 1, Postojna). Presentation of posters will be held in the hall of the Karst Research Institute ZRC SAZU (Titov trg 2, Postojna). See schedule for details.

Excursions

Do not forget **register your participation at excursions at the registration desk!** Seats on buses are limited. Suitable clothes and shoes for the fieldwork are required.

Departures for the excursions

Meeting point for excursions is at parking place in front of PTC Primorka (Business Centre Primorka, see map). **PLEASE BE ON TIME!**

Beverages and food on the excursions

Organizer will supply some beverages for the field-trips, take some additional if you need more. For the whole day excursion on 30 June 2006 we will stop at Rakov Škocjan for the lunch break. Lunch is paid by your own (in Slovene Tolars), except Marie Curie grant-holders. Do not forget to notify at the registration desk whether you will take the lunch or not.

Important notice for the excursions

Ticks are excellent vectors for disease transmission. More than 800 species of these obligate blood-sucking creatures inhabit the planet. The areas of field trips are heavily populated by ticks. Before going to the field trip **USE INSECT REPELLENT!** Deer plays a key role in the mating of ticks; the increase in the deer population is an important factor in the epidemic of some tick-borne diseases, such as Lyme disease or meningitis. Do not forget to check yourself carefully for the presence of ticks after the excursions. Ticks are often found in tall grass!

Map of Postojna

1 – Karst Research Institute ZRC SAZU, Titov trg 2
2 – Cultural Centre of Postojna (Kulturni dom Postojna), Prešernova ulica 1
3 – Parking place for excursions (PTC Primorka, Novi trg 6)

See also http://www.postojna.si/

Programme

Monday, 26 June 2006

17.30 – 19.00 Registration of participants (Karst Research Institute ZRC SAZU)

Tuesday, 27 June 2006

8.00 – 12.00 Registration of participants (Cultural Centre of Postojna)

Opening Session

8.45 – 9.00 Opening
Janez Mulec, Organizing Committee
Tadej Slabe, Karst Research Institute ZRC SAZU
Andrej Kranjc, Karst Comission IGU

Session 1 - SPATIAL PLANNING

9.00 – 10.00 Keynote lecture: Spatial planning and protection measures for karst areas
Elery Hamilton Smith

10.00 – 10.15 Visualisations of human influences to the Earth's surface
Tomaž Podobnikar

10.15 – 10.45 Break

10.45 – 11.00 Heritage and patrimonial resources in a karstic mountain: the protection of the caves of Choranche (Vercors, France)
Christophe Gauchon

11.00 – 11.15 Sustainable mapping of caves
Philipp Haeuselmann

11.15 – 11.30 The Jeita cave (Lebanon): an example of sustainable development of a typical karstic resource
Sandrine El Nawwar

11.30 – 11.45 Sustainable management of natural and environmental resources in the karst of Aspromonte (Calabria, Southern Italy)
Mario Parise

11.45 – 12.00 Exploitation of natural resources and their environmental impacts in India
Vinod Kumar Jena

12.00 – 12.15 Classical karst
Igor Jovanović

12.15 – 12.30 Karstological monitoring of objects as a means of sustainable development of karst terrains
Mikhael Leonenko

12.30 – 15.00 Lunch break

Session 2 - SUSTAINABLE TOURISM

15.00 – 16.00 Keynote lecture: Caves as specific natural geosystems: structural and functional features, geoecological stability and anthropogenic impacts
Pavel Bella

16.00 – 16.15 Tourism and preservation policies in karst areas: Comparison between the Škocjan Caves (Slovenija) and the Ardeche Gorge (France)
Melanie Duval

16.15 – 16.30 Peştera Urşilor de la Chişcău" Cave – the impact of touristic activities upon the cave climate
Ioana Feier

16.30 – 16.45 Dynamics of air temperature in a show cave from Apuseni Mts., Romania
Aurel Perşoiu

16.45 – 17.00 Pseudo-state and sustainable management of karst regions - The case of Bosnia and Hercegovina
Jasmina Osmanković, Jasminko Mulaomerović

17.00 – 17.15 Ecoturism development of the white desert "a karst tower landscape" in the western desert of Egypt
Tamer Nassar, M. I. El Anbaawy

Wednesday, 28 June 2006

Session 3 - VULNERABILITY MAPPING

9.00 – 10.00 Keynote lecture: A pan-European approach to mapping groundwater vulnerability and contamination risk for the protection of karst aquifers
Nico Goldscheider

10.00 – 10.15 Gypsum karst as groundwater resource in Northern Cyprus
Mehmet Necdet

10.15 – 10.30 Modern tools for assessing, monitoring and predicting natural attenuation of contaminants in karst
Traian Brad

10.30 – 10.45 The discovery and protection of one of the most important ancient metropolitan cave sites of the Middle East: Hoq cave on Soqotra Island, Yemen
Pierre De Geest

10.45 – 11.15 Break

11.15 – 11.30 Changes in the natural resources use and human impact in the karst environments of the Venetian Prealps
Ugo Sauro

11.30 – 11.45 Hydrogeology of the coastal karst in Montenegro
Tijana Danilović

11.45 – 12.00 When is a karst resource feature damaged or rendered ineffective? A conceptual approach
Paul Griffiths, Carol Ramsey

12.00 – 14.00 Lunch break
14.15 – 17.00 Poster session (Karst Research Institute ZRC SAZU)
18.00 – 19.30 Visit to Postojnska jama cave
20.00 – 22.00 Slides and video projections (Karst Research Institute ZRC SAZU)

Thursday, 29 June 2006

Session 4 - BIODIVERSITY OF KARST ECOSYSTEMS
9.00 – 10.00 Keynote lecture: Biodiversity and ecosystems of selected karst areas
Alenka Gaberščik

10.00 – 10.15 Estimating total species richness of epikarst copepods (Crustacea, Copepoda) in a »hotspot« in Slovenia
Tanja Pipan

10.15 – 10.30 Turloughts: a mosaic of biodiversity and management systems unique to Ireland
Micheline Sheehy Skeffington

10.30 – 10.45 The European project "3 KCL - Karstic Cultural Landscapes": an important experience of research and education towards sustainable perspectives
Benedetta Castiglioni, Monica Celi

10.45 – 11.15 Break

11.15 – 11.30 Karstic Cultural Landscape (3 KCL project) in France
Philippe Audra

11.30 – 11.45 The role of convection-condensation processes in hypogenic speleogenesis. Study of thermal sulfidic caves of Aix-les-Bains and Daluis, France
Philippe Audra

11.45 – 14.00 Lunch break

14.00 – 18.00 Excursion to Cerkniško jezero lake
Alenka Gaberščik, Andrej Kranjc

Bus travel and short walks.

20.00 Reception at the Institute

Friday, 30 June 2006

8.30 – 19.00 Whole-day excursion to Classical Karst
Andrej Mihevc

Bus travel and short walks, no more than 1 km at a time. No lights or special equipment required, just field shoes.

Excursion will lead us from the springs of the Ljubljanica River to Škocjanske jame Caves. The excursion visits Močilnik, one of the springs of the Ljubljanica River, visit to the ponor at Logaško polje, ponors and springs at Planinsko polje and Rakov Škocjan. After lunch visit to Škocjanske jame, large unroofed cave above and collapse doline of Risnik near Divača.

Saturday, 1 July 2006

8.00 – 13.00 Morning excursion to Postojna karst
Janja Kogovšek, Martin Knez, Tadej Slabe, Tanja Pipan, Nataša Ravbar, Metka Petrič

Bus travel and short walks.

Sunday, 2 July 2006

Departure of participants

Poster session

Conditions in the Vranja Cave (Slovenia)
Viola Altova Thermal, Nikola Jurková, France Šušteršič, Simona Šušteršič

Possibilities of tourism valorisation of the Cave Gvozdenica near Karlovac (Croatia)
Neven Bočić

Show caves in Croatia - present condition and perspectives
Neven Bočić, Aleksandar Lukić, Vuk Tvrtko Opačić

KARSTERO: A specified quantitative model for predicting soil-erosion process in karst Mediterranean landscapes using Remote Sensing and GIS, case study Lebanon
Rania Bou Kheir, Abdallah Chadi, J. Chorowicz

Waste dumps modify karst surface
Mateja Breg

A first attempt in evaluating the human disturbance to Italian karst environments
Fabiana Calò

Morphometric characterization of karstic zones and indicative water erosion sensitivity. Case study Lebanon
Abdallah Chadi, Rania Bou Kheir

Posibille contamination with heavy metals in Karst see Lake of Rogoznica
Irena Ciglenečki, Srđan Pichler, Božena Ćosović

Threats to karst geo-heritage sites in undeveloped regions of Serbia
Jelena Ćalić

Aluvial Fans on karst (example from contact karst of Matarsko podolje, Slovenia)
Mateja Ferk

Sustainable management of brackish karst spring Pantan (Croatia)
Ivana Fistanić

Hydrological and hydrogeochemical monitoring of the Domica Cave (Slovakia) and its meaning for a protection of the cave
Dagmar Haviarová

Aluvial fans on karst (example from contact karst of Matarsko podolje, Slovenia)
Petra Gostinčar, Uroš Stepišnik, Luka Černuta, Tomaž Štembergar, Urška Ilič, Karmen Peternelj

Karst and main caves of Cuba
Manuel Roberto Gutiérrez Domech

Karst and more important caves of Cuba
Manuel Roberto Gutiérrez Domech

Hydrological and hydrogeochemical comparison of basins with different geological basement in Slovakia
Oliver Horvát, Zuzana Makišova

Remnant hydrothermal karst activity in light of hydrochemical studies of springs in the Cracow-Czestochowa Upland (S Poland)
Agata Koptyńska, Andrzej Tyc

Mali dol - a dry valley in Kras (Classical Karst)
Jure Košutnik

Karst water management in Slovenia in the frame of vulnerability mapping
Gregor Kovačič, Nataša Ravbar

Vulnerability of the karst - fissure hydrogeologic structures south-facing slopes of the Low Tatras MTS
Erika Kováčová

Prevention and presentation of karst phenomena - examples of geological educational trails from Biokovo Nature Park and Učka Nature Park in Croatia
Damir Lacković

Popovo polje: thirty years after drainage
Ivo Lučić

Discharge regime of karstic spring for estimation of groundwater sensitivity to pollution in the Dolný vrch area, Slovenský kras MTS., Slovak republic
Peter Malik, Silvia Vojtková

Montello karst waterground changing its perspective from the perception of drought to a strategical water resource
Francesco Ferrarese, Marta Modesto

Upper Pleistocene fauna of caves Pećina na Brehu (Ćićarija) and Baba (Biokovo) - Croatia
Kazimir Miculinić, Siniša Radović

Contribution of simply hydrogeological indicating methods in by contamination impacted environments
Slavomír Mikita

Comparison of landscape changes on karst areas in Hungary and China
János Móga, Gergely Horváth, Leél-Őssy Szabolcs, Zámbó László

Ecoturism development of the white desert "a karst tower landscape" in the western desert of Egypt
Tamer Nassar, M. I. El Anbaawy

Difficulties in the protection of karst phenomena in Croatia: example of Cave in Debeljača quarry and Cave in Tounj quarry
Dalibor Paar, Petra Ujević, Darko Bakšić, Damir Lacković, Ana Čop

The origin of Grand Shaft in the Wielka Sniezna Cave (Tatra Mountains, Poland)
Patrycja Pawlowska - Bielawska

The use of Ground Penetrating Radar to investigate the Epikarst in an alpine setting
Lukas Plan, M. Meissl, M. Andert, B. Grasemann K., Roch H.

Renaturalization of the Husak quarry in Czech karst and future
Michael Pondělíček

Palaeomagnetic research of fill of selected cave and karst sediments in Slovenia in 2005
Petr Pruner, Nadja Zupan Hajna, Andrej Mihevc, Pavel Bosák, Ota Man, Marko Vrabec, Bojan Otoničar, Petr Schnabl, Stanislav Šlechta, Daniela Venhodová

Hydrogeological characteristics of the Boka Kotorska bay (Montenegro)
Milan Radulović

Fractal dimensions of superfical karst of Middle Atlas (Morocco)
Mohamed Rouai

A review of the forest management history and present state of the Haragistya karst plateau (Hungary)
Eszter Tanács

Conceptual approaches for studying the vulnerability of karst groundwater in the South Franconian Alb, Germany
Martin Trappe, Simon Schober

Long residente time of water in unsaturated zone of Moravian Karst. Consequences for temporal behavior of nitrate content in seepage waters and karst springs (^{18}O, ^{3}H)
Helena Vysoká

Possibilities of the digital photogrammetry in mapping and management of the karst
Zoltán Zboray, I. K. Bárány

Application of remote sensing datta of ALSAT-1 to followed desertification in Algeria
Ahmed Zegrar

Groundwater vulnerability assessment and parameter sensitivity analysis - application of EPIK method in the National Park "Tara"
Vladimir Živanović

EXCURSIONS

● **AFTERNOON EXCURSION, 29 June 2006, Cerkniško jezero**

▲ **WHOLE-DAY EXCURSION, 30 June 2006, Classical karst**

1 - Ljubljanica spring/Močilnik; 2 - Logatec karst polje; 3 - Planinsko polje; 4 - Rakov Škocjan; 5 - Škocjanske jame; 6 - Risnik; 7 - Lipove doline

■ **MORNING EXCURSION, 1 July 2006, Postojna karst**

1 - karst spring Malni; 2 - oil collector on highway; 3 - Koča Mladika belvedere; 4 - city dump; 5 - military training area Poček

AFTERNOON EXCURSION, 29 June 2006

Excursion to karst seasonal lake Cerkniško jezero

Lake of Cerknica

Andrej Kranjc

Cerkniško polje is a typical karst feature – a polje. Because a great part of its bottom is practically regularly and for a longer time flooded, it is often called "jezero", which means a lake. It is polje – seasonal lake.

Maybe it is for the first time by mentioned a Roman geographer Strabo and since the 16th century this is the most frequently described and the most famous natural phenomenon of the former Carniola. In his well known work "Glory of the Duchy of Carniola …" (1689) Valvasor (by his "Letter" on the hydrography of Cerkniško Jezero he earned the membership at the Royal Society) cited about 40 authors describing or mentioning Cerkniško Jezero before him.

Cerkniško polje lies in the middle of Notranjsko (Inner Carniola), in the so called "Notranjsko Lowland" – about 50 km long and up to 7 km large depression formed along one of the main tectonic lines in Slovenia, the Idrija fault. There are other poljes up- and downstream of Cerkniško polje. This is a closed depression (Javorniki Mts. 1268 m on the SW, Slivnica Mt. 1114 m on the NE, treshold 640 m towards Loško polje on SE and 560 m towards Planinsko polje on the NW side) at 550 m above the sea level. The bottom of the polje covers about 38 km^2, little more than 27 km^2 of it can be under water during the extreme flood. At normal flood there is about 19 million m^3 of water stored in the lake, and about 87 million at extreme flood (water level at 553 m).

The region is formed by Mesozoic rocks. There is Cretaceous limestone on SW and Jurassic one towards SE. Part of the bottom itself is in limestone and part of it as well as NW and NE slopes in Triassic dolomite. The dolomite forms a hydrologic barrier which is very important both for the origin and evolution of the polje and its hydrology. The whole region belongs to the water basin of the Ljubljanica River. The basin of the Cerkniško polje covers 475 km^2. Except for the one surface stream flowing on the polje from the dolomite Bloke plateau at the East, all the tributaries are karst (underground) ones. They are flowing either from upper lying Loško polje (big karst springs Cemun and Obrh in the SR corner of Cerkniško polje) or from surrounding karst mountains and plateaus. The runoff from the polje is completely karst one, that is underground. On the part of the polje's bottom which lies on limestone, there is a lot of ponors – swallow holes in the alluvium. They are concentrated in the NW part of the polje, where besides holes in alluvium there are also ponors in limestone edge of the polje and big ponor caves.

Maximal inflow to Cerkniško polje can be 211 m^2/sec. (mean value about 20 m^3/sec.) while the outflow can reach 90 m^3 at the most. The difference, about 120 m^3/sec. is the reason for the "lake", that is for flooding. Yearly amount of the precipitation is between 1600 and 1800 mm. The Ljubljanica River as a whole has the pluvio-nival river regime with weak Mediterranean influence: primary maximum in November, secondary in March, while primary minimum is in August. In accordance with them is flooding or the stage of the lake.

In average the lake (not a very large one) persists 285 days per year, and for 80 days the polje’s bottom is dry.

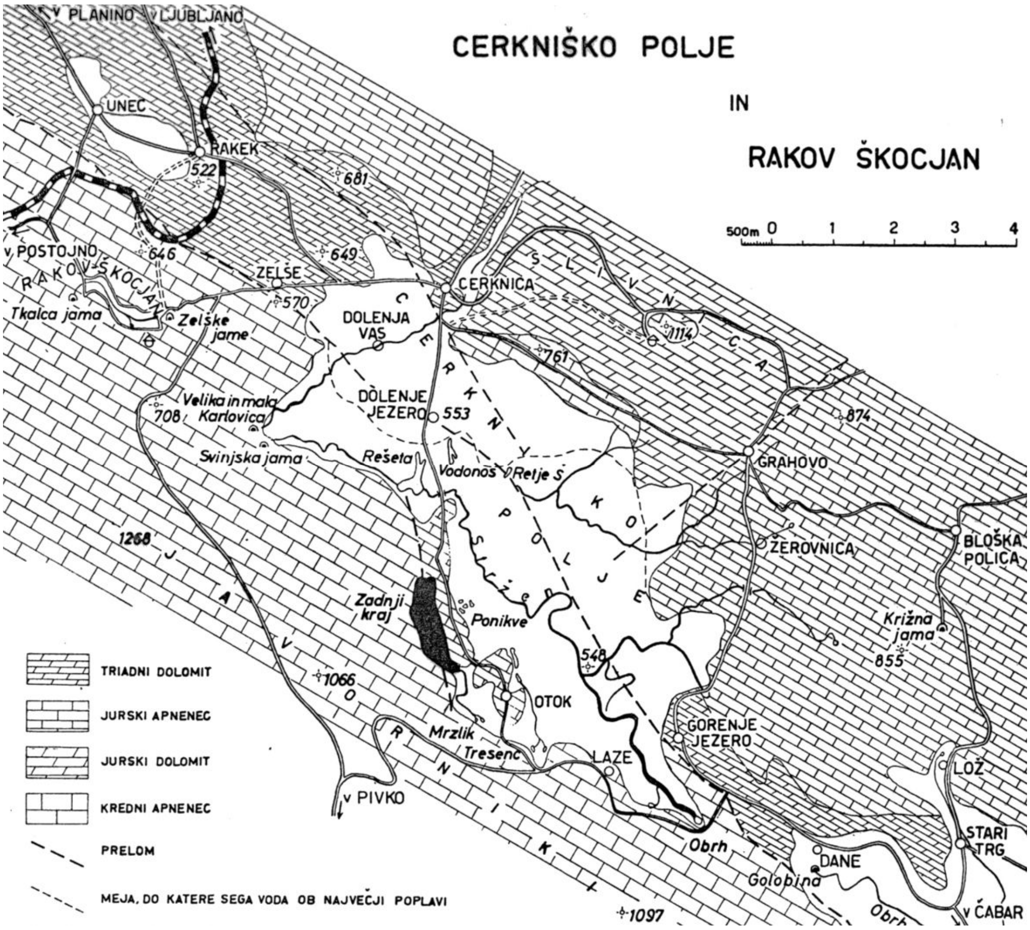
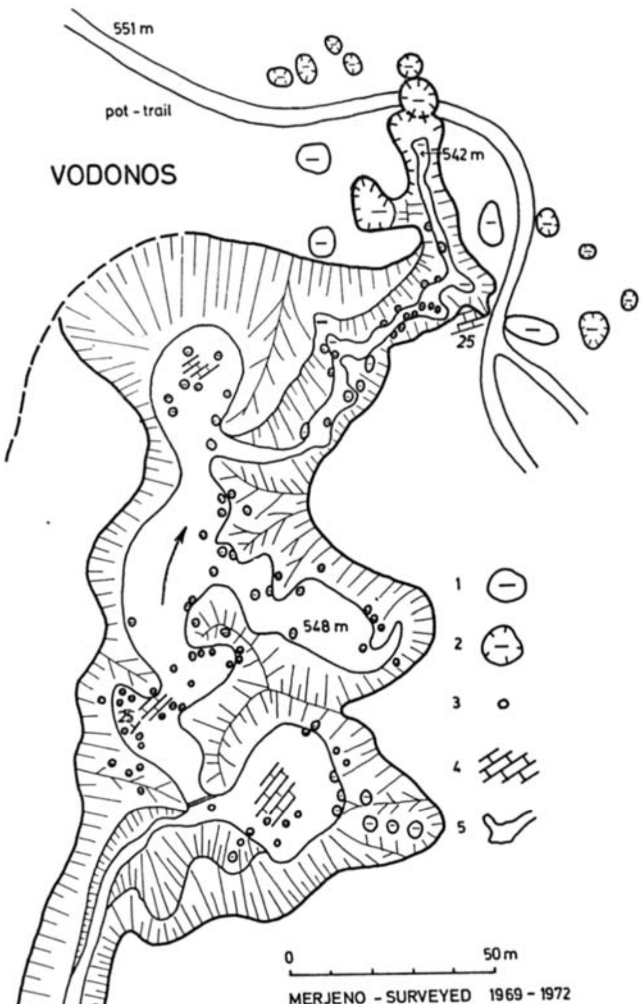


Fig. 1: Cerkniško polje (Legend: triadni dolomit = Triassic dolomite, jurski apnenec = Jurassic limestone, jurski dolomit = Jurassic dolomite, kredni apnenec = Cretaceous limestone, prelom = fault).

Older authors tried to explain the intermittence of the lake by different theories: A. Kircher (1665) by underground “hydrophilatia” by which water was “pumped” underground from the sea; J. V. Valvasor by a system of additional five underground lakes, connected with the surface lake by numerous siphons. The first who literally said that the cause of the flood is the surplus of inflow related to outflow was J. Nagel in 1748.

It is not surprising that such a large part of flat land with relatively thick soil and so well known in literature did not escape the eyes of more practical people. The first whom we know, a sympathizer of the physiocratic trend, was B. Hacquet who has made an “economic” travel in 1774 to find out how to drain the poljes of Notranjsko. Demand for the arable land was increasing and also the plans how to drain Cerkniško and other poljes of Notranjsko. These projects became more and more serious; Schaffenrath (Postojna district engineer) in the first, Witschel and Vicentini in the second part of the 19th century. To study the problem more comprehensively, “Société de spéléologie” (Verein für Höhlenkunde) was founded in 1879 on the initiative of F. Kraus, geographer from Vienna, and few years later the "Karst-Comité". In 1886 Agriculture Ministry in Vienna decided to finance the observations of precipitation and the plan itself. W. Putick was charged to prepare it. The plan included drainage works at Loško, Cerkniško, Planinsko and Logaško polje. Some works have been done (channel and tunnel to the swallow hole and blasting some siphons at Loško polje, lowering and blasting siphons and ponors of Cerkniško polje, regulation of ponors (including the construction of two "kathavotrons") at Planinsko and Logaško polje. Then the works were stopped by provincial government due to fear that faster runoff from the poljes will increase the flooding of Ljubljana, the capital of the province.



Sl. 28. Morfologija Vodonosa
1 — stari ugrezi v okolici ponikve, 2 — sveži ugrezi v okolici ponikve, 3 — grezi v ponikvi, 4 — razkrita skalna podlaga, 5 — obod ponikve

Fig. 28. Morphology of Vodonos ponor
1 — old sinkholes in the ponor vicinity, 2 — recent sinkholes in the ponor vicinity, 3 — sinkholes in the ponor, 4 — exposed rocky bottom, 5 — ponor boundary

Fig. 2: Morphology of Vodonos ponor.

During the first half of the 20th century the energy was becoming more important than the agriculture. There were more proposals and plans not to dry Cerkniško polje but to retain the water and use it as a source of energy. In 1954 "Water economy of Upper Ljubljanica" envisaged accumulation of Cerkniščica stream, tunnel from Loško to Cerkniško polje, hydroelectric power plant at Cerknica, tunnel to Planinsko polje, another plant at Planina, accumulation lake at Planinsko polje, tunnel to Vrhnika with the third power plant. The plan was abandoned but the idea of a permanent lake was kept in mind. 1969 – 1972 the project "Experimental permanent lake" was carried on: smaller ponors were closed (walled up), the largest one (Velika Karlovica) was half closed; a tunnel with sluice was made to allow the drainage of flood waters directly into inner parts of the swallow hole. It was included in a large scale tourism project "The Upper Adriatic" (the leader was a bureau from Paris), where 1000 tourist beds, hotels, marinas, floating swimming pools, etc. were foreseen. The conclusion of the project was that without huge technical works Cerkniško polje cannot be transformed into a permanent lake.

In the 80-ies and 90-ties of the last century "green" and ecological movements and parties became more important, plans and actions were turned towards the preservation of the lake and towards ideas of a natural park. Some of previous technical works were destroyed and people began to talk about "natural" or "primary" state, which of course is not a reality. Cerkniško Jezero was expected to be the core zone of future Natural Park or MAB (Man And Biosphere) region. For the moment, the part of the polje, which belongs to the Cerknica commune, is a part of "Notranjski regijski park" (Regional Park of Notranjsko), while the other parts are under different lower protection regimes.

References

Novak, D., 1965: Ljubljana – Cerknica – Postojna. In: Guide de l'excursion à travers le Karst Dinarique, 19-23, Ljubljana.

Gospodarič, R. & P. Habič, 1979: Kraški pojavi Cerkniškega polja. Acta carsologica, 8, 7-162, Ljubljana.

Ecological importance of Cerkniško jezero Lake

Janez Turk

The turnover of matter and through-flow of energy in the intermittent Lake Cerknica is facilitated by the exchanging wet and dry periods, which either promote or suppress growth and development of organisms, depending of the season of the year. Any deviation from normal floods significantly affects the productivity of reed stands. The temporally and spatially variable water regime is reflected in a variety of habitats, resulting in a rich species composition. Drainage of the lake prevents a constant presence of aquatic organisms, particularly planktonic species. Drying and wetting accelerates the decomposition of organic matter. The nutrient input into the lake by one surface tributary proved to be relatively high. The quantity of nutrients in the lake water is lower, because of the high buffering capacity of the densely vegetated ecosystem (Gaberščik, 2002; Gaberščik et al., 2003).

References

Gaberščik, A. Urbanc-Berčič O., Kržič N., Kosi G. & A. Brancelj, 2003: The intermittent Lake Cerknica: Various faces of the same ecosystem. Lakes & Reservoirs: Research and Management, 8, 159-168

Gaberščik, A. (ed.), 2002: Jezero, ki izginja : monografija o Cerkniškem jezeru, Društvo ekologov Slovenije, Ljubljana, 333 p.

WHOLE-DAY EXCURSION, 30 June 2006

Classical karst

Andrej Mihevc

Slovene Classical karst is a part of karst of Dinaric mountains. This karst has abundance of interesting karst phenomena like large sinking rivers and springs, intermittent lakes, numerous large caves and relief features like karren, dolines, collapsed dolines, uvalas, poljes and leveled surfaces and plateaus. But it was the exploration of the people that were driven first by curiosity and later by land use or water management issues and tourism that make the Kras famous. Well researched, described and mapped natural phenomena in 19th century made the area cradle of a new scientific discipline – karst studies.

Ljubljanica river system

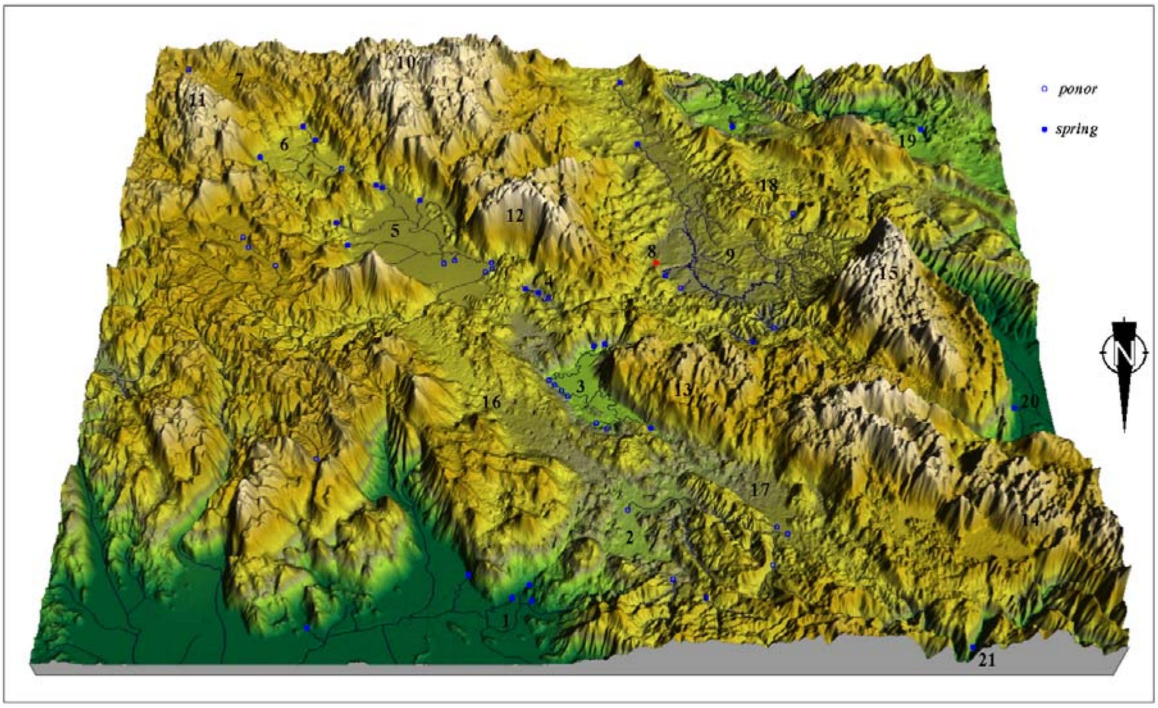


Fig. 1: Legend: 1. Ljubljanica springs at Vrhnika, 2. Logatec polje with ponor of Logaščica river, 3. Planina polje, 4. Rakov Škocjan, 5. Cerknica polje, 6. Loško polje, 7. Babno polje, 8. Postojna, 9. Pivka basin and polje. High karst plateaus: 10. Snežnik, 11. Racna gora, 12. Javorniki, 13. Hrušica, 14. Trnovski gozd, 15. Nanos. Karst levelled surfaces: 16 Logaški ravnik, 17. Hotenjski ravnik, 18. Slavenski ravnik; 19. Škocjanske jame cave, ponor of Reka river, 20. Vipava spring, 21.Divje jezero spring at Idrija.

Ljubljanica River collects the water from SW part of Dinaric karst in Slovenia and belongs as right Sava affluent to Danube and of Black Sea. The Ljubljanica water basin is about 1100-1200 km^2. Nearly all watershed of the river is in karst and therefore is not well defined. The mean annual precipitation in the basin is 1300 - 3000 mm, during 100 to 150 rainy days. The one-day maximal amount to 100 mm, in extreme cases even 300 mm.

Most of the river basin is formed on the Mesozoic rocks, mostly limestone. On these rocks the precipitations infiltrate directly into the karst and there are no surface rivers. Triassic dolomite is important, allowing some surface flow, forming bottoms of some karst poljes or forming hydrologic barriers.

The highest parts of the basin are high karst plateaus Hrušica, Javorniki and Snežnik and Racna gora. On the poljes among them surface rivers appear only, but they have different names: Trbuhovica, Obrh, Stržen, Rak, Pivka, Unica and finally after the springs at Vrhnika the name Ljubljanica. The highest lying is the karst polje near Prezid (770 m), followed by Babno polje (750 m), Loško polje (580 m), Cerkniško polje (550 m), Rakov Škocjan and Unško polje (520 m), Planinsko polje (450m), Logaško polje (470 m) and finally by Ljubljansko Barje (300 m) where the Ljubljanica springs are at 300 m a.s.l. There are several large springs are dispersed along the edge of the Ljubljana Moor, which is connected with gradual tectonic subsidence of the area. Mean annual discharge of the Ljubljanica at springs is 38.6 m^3.

There are 1540 caves, accessible fragments of underground drainage system known in the catchment area of the Ljubljanica. The average length of the cave is 48 m and the depth 18 m. However, the largest caves are the ponor or spring caves; in them we can follow the 71 km of passages of the main rivers, tributaries of Ljubljanica.

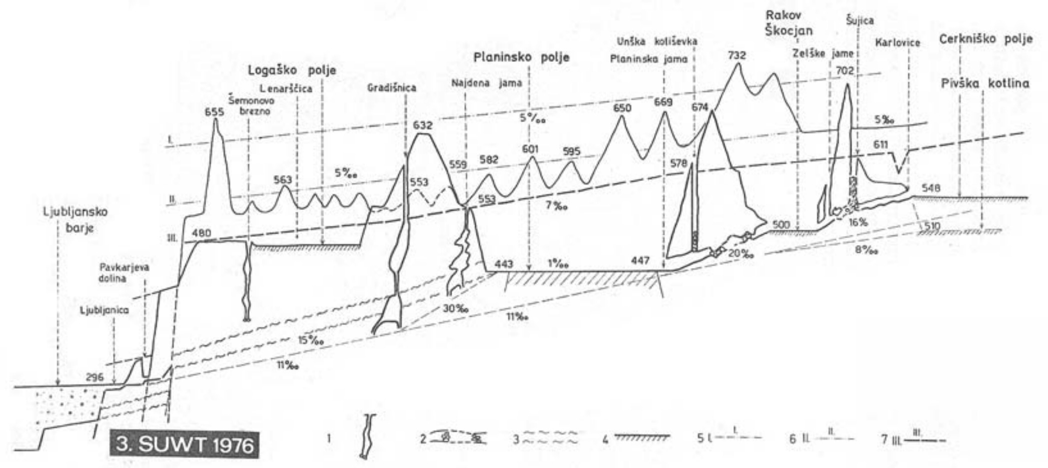


Fig. 2. *Longitudinal cross section of central part of Ljubljanica karst river basin.* 1 — active cave or pothole, 2 — unknown parts within known active caves, 3 — the supposed zone of former active caves between Planinsko polje and Ljubljansko barje (Ljubljana Moor), 4 — karst polje's bottom, 5 — Gradišče relief level, 6 — Bodiški vrh relief level, 7 — Dolina relief level.

Fig 2: Longitudinal cross section of Ljubljanica karst river basin (Gospodarič & Habič 1976).

Logatec karst polje

The Logatec polje developed on the contact of dolomite and limestone between 470 and 480m a.s.l. A number of small streams flow onto in, the largest being the Logaščica, which collects run-off from a dolomite area of 19 km^2. The mean flow is 0.3m^3/s. Short lasting floods occur at the swallow-holes Jačka on the Logaško polje when the flow exceeds 30 m^3/s.

The ponor of the Logaščica river is in the centre of the town, and there is located also the central waist water treatment plant. The water from the plant is directly flowing into the stream just 50 m before it sinks. The station located near the school, church, kindergarten, cemetery and school playground and direct injection of often not enough treated water is interesting case of understanding of sustainable use of karst resources.

Planina polje

Planina polje is overflow polje, of rectangular shape, 6 km long, 2 km wide, with two narrow pocket valleys on SW part, 50 m deep, with 16 km^2 flat surface at height of 450 m. Its wider surrounding is built by Upper Triassic dolomite, Jurassic and Cretaceous limestone. The development of closed karst depression is result of accelerated corrosion, controlled by geological structures.

It presents the most important water confluence in the river basin of Ljubljanica. Tectonically crushed and less permeable dolomite barrier along the Idrija wrench fault zone, which crosses the polje, forces the karst waters to overflow from higher karstified limestone background to the surface and after crossing Planinsko polje toward NE they can sink into the underground again. The principal Unica springs, with mean annual discharge 24 m^3/s (min. 0.3 m^3/s, max. 100 m^3/s) are situated in the southern polje's part in Cretaceous limestone, where the confluence of waters from Cerknica, Javorniki Mt. and Pivka is located. Main spring is 6656 m long Planinska jama cave.

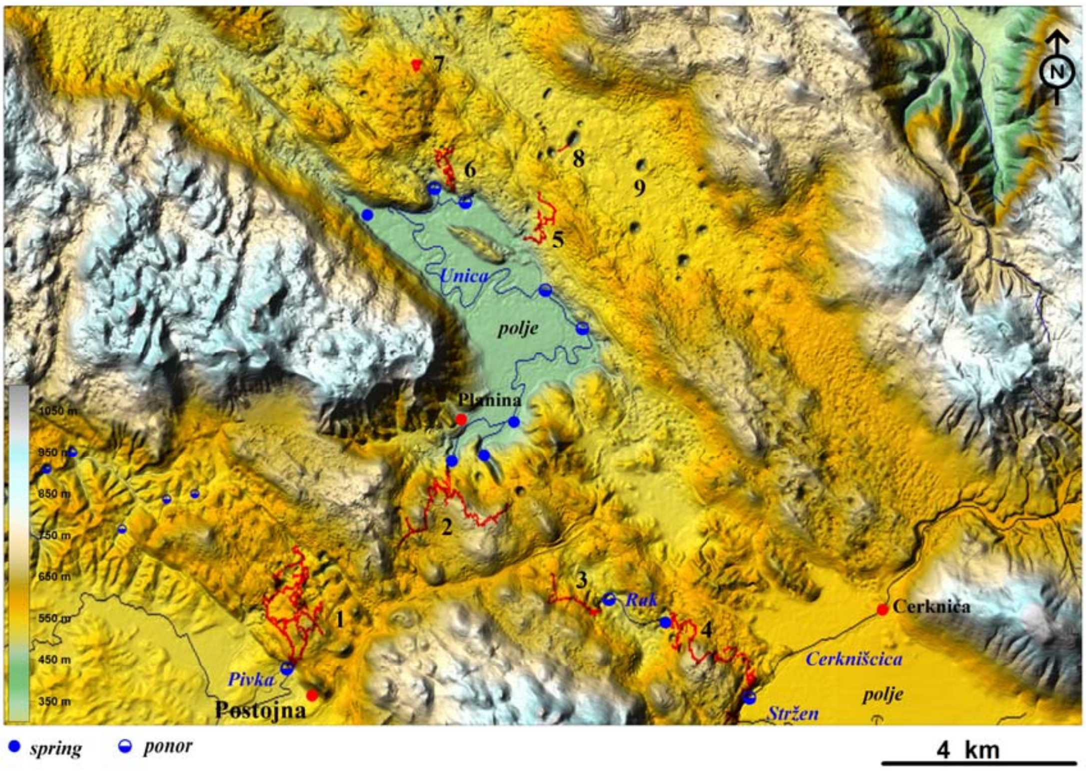


Fig. 3: Planinsko polje and the karst around it. Legend: 1. Postojnska jama cave, 2. Planinska jama, 3. Tkalca jama, 4. Zelške jame – Karlovica cave, 5. Logarček, 6. Najdena jama, 7. Gradišnica, 8. Vetrovna jama, 9. large collapse doline.

The principal Unica swallow-holes are disposed at NE edge, where mostly medium and high waters are sinking. At low waters the whole Unica is disappearing in swallow-holes at eastern polje's border. The water is sinking directly from Unica bed through the polje's bottom across more than 150 swallow-holes and impassable fissure. Only at Dolenje Loke and in Škofji lom, up to 160 long ponor caves are known, but there are several horizontal caves in vicinity of the polje, where water oscillations can be observed. Larger caves behind the ponors are over 4987 m long Najdena jama cave and Logarček.

Planinsko polje is flooded several times in a year. The minimum inflow to the polje amounts to 1.5 m^3/s; mean 23 m^3/s, maximal was estimated to 100-120 m^3/s, the total ponor capacity is about 60 m^3/s. At floods, lasting 1-2 months, the water increases up to 10 m and up to 40 millions of m^3 of water inundate the polje.

Rakov Škocjan

Rakov Škocjan is a karst depression about 1.5 km long and 200 m wide. It is situated below the N side of Javorniki Mountain at elevation about 500 m between Planinsko and Cerkniško polje. Through the depression flows the permanent river Rak. The Rak springs from Zelške jame cave, bringing water from Cerkniško polje. Zelške jame are about 5 km long; the end of the cave is in huge collapse doline Velika Šujca, where from the other side the Karlovica cave system ends. In Karlovica system is the main outflow from Cerkniško polje. Numerous collapse dolines are situated around the entrance of Zelške jame. In one of them the Small natural bridge is present. Downstream the valley widens and several springs bring additional water to the Rak River. The valley is narrowed at the Great Natural Bridge and afterwards the Rak sinks into Tkalca jama cave from where the water flows towards cave Planinska jama at Planinsko polje. The connections of the Rak with water from Cerkniško polje and with the Unica springs at Planinsko polje were proved by water tracing.

Before World war I Rakov Škocjan was owned by the Windischgrätz family and was closed as their private park; between 1st and 2nd World war, the Italians also closed the area for the public. From 1949 Rakov Škocjan has been a Landscape Park.

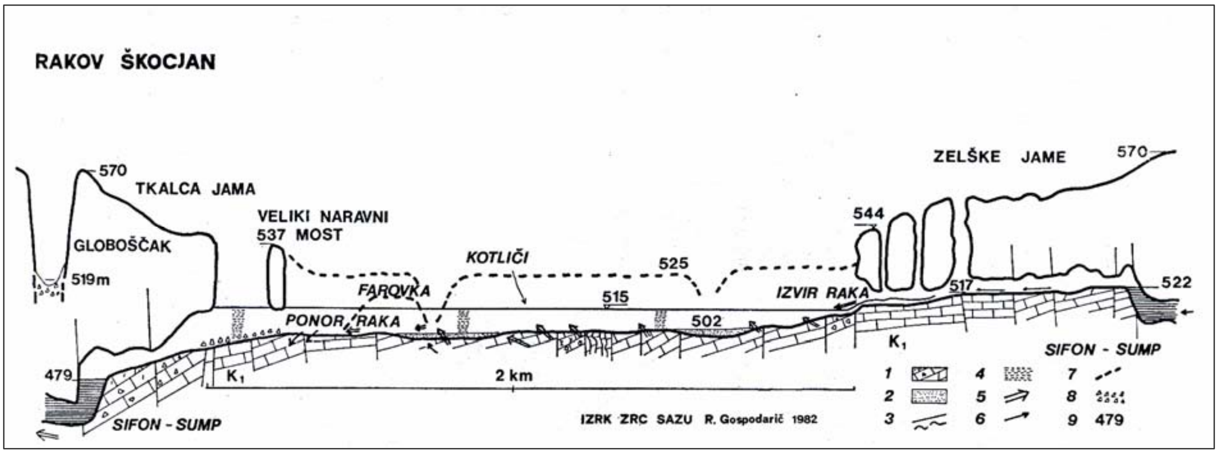


Fig.4: Cross-section along Rakov Škocjan karst depression between spring at Zelške jame and sink in Tkalca jama. Legend: 1 – rocky bottom, 2 – alluvia, 3- fault zone, 4 – flood in 1982, 5 – karst spring, 6 – water flow directions, 7 – terraces, 8 – boulder rocks, 9 – altitude (Gospodarič et al. 1983)

Cerknica polje

Cerknica polje is the largest karst polje in Slovenia. Often it is called just Cerkniško jezero (Lake of Cerknica), because of its regular floods, or intermittent lake. The intermittent lake covers 26 km^2 when is full; it is 10.5 km long and almost 5 km wide. Its hydrological properties caused that already in the beginning of New Age scholars from all round Europe were attracted to it. The lake becomes still more known through the Valvasor's description in 1689.

It is a karst polje developed in the important regional fault zone – Idrija fault. Idrija fault has "Dinaric" direction (NW-SE); in the same fault zone are developed: Planinsko polje, Loško polje and Babno polje. Bottom of Cerkniško polje covers 38 km^2 in elevation of about 550 m. Bottom is formed on Upper Triassic dolomite, which is presented also on the N, E and SE side of the polje, there are some Jurassic dolomites also presented. On W and NW the Cretaceous limestone are presented. Inflows are on E, S and partly on W sides of polje. The largest tributary to polje is Cerkniščica drained the dolomite catchments area. The important karst springs are Žerovnica, Šteberščica and Stržen. Stržen flows on the W side of polje towards the ponors in the middle of the polje, from where water flows directly to Ljubljanica springs, and towards NW side of polje, from where the water flows to Rakov Škocjan. From the foot of Javorniki mountain to the contact with dolomite in the polje bottom is 12 ponor caves. They are connected to Karlovica cave system to which also the highest waters from polje flows. It the system there is more the 7 km of passages. Passages are generally low, because they are filled by alluvia. Thickness of alluvia in Jamski zaliv, before the caves entrances, is about 8 –15 m.

During the last centuries a lot of plans for the change of polje hydrology have been made, but not any of them was realised. In 1965 was proposed to make Cerknica polje a permanent lake, in the years 1968 and 1969 entrances to the caves Velika and Mala Karlovica were closed by concrete walls and 30 m long tunnel was made to connect Karlovica with the surface, but small effect of retention in dry period and less moistened years were assessed.

The bottom of Cerkniško polje covers 38 km^2 in elevation of about 550 m. Inflows are on E, S, and partly on W polje's side. There are some small superficial tributaries to polje, the largest is Cerkniščica, with about 45 km^2 of hinterland mostly dolomite.

Flattened bottom of Cerkniško polje is regularly flooded for several months in autumn winter and spring time, at floods it alters to spacious karst lake. Lower waters are sinking mostly in marginal swallow holes and in numerous ground swallow holes and estavellas, which are disposed in central polje's bottom. Principal ponor caves and swallow holes are disposed at NW polje's border.

Next to the polje border, from the foot of the Javorniki to the contact with dolomite in the polje bottom is 12 ponor caves. They are all connected with the system of the Velika and Mala Karlovica cave. Most of caves are short; they get narrow or are blocked by breakdown

The highest waters run off through the caves Mala and Velika Karlovica, where more than 7 km of passable channels are known.

Outflow from the polje was not oriented to one channel, rather to a mesh of channels, which about 200 m from the edge of polje combine into a couple of larger galleries. They are generally low, because the bottoms are filled with sediments. The sediment fill is at 550 m a.s.l. in all the ponor caves, its thickness is possibly the same as a thickness of alluvia in Jamski zaliv, 8 - 15 m respectively.

Pivka basin

The bottom of the Pivka basin, an area of about 70 km^2, is of Eocene flysch rock. A river network has formed on the floor of the basin; the water flows into the boundary limestone rock going to different river basins (Habič, 1982; 1989).

Karstificated limestone surrounds the valley from all sides; at the contact on higher levels there is flysch. Along the 59 km long lithologic contact of flysch and limestone, 17 larger and a number of small rivers sink, transforming only 2.3 km^2 of karst.

The Pivka, with a mean flow of 6 m^3, is the largest sinking river in the basin. Most of its water flows from karst sources on the southern part of the basin, at the foot of the Javorniki, where a karst polje formed on limestone. For a large part of the year, the Pivka is dry; when waters are high, it floods the floor of the field.

The main inflow into the Pivka from flysch rock is the Nanoščica, which flows from W; it collects water in the western part of the flysch basin.

The Pivka sinks into the 20 km long Postojna Caves at about 511 m a.s.l. The caves have several levels, the main level being 520 to 530 m a.s.l. The lowest parts of the caves are located at the outflow sump at 477 m a.s.l., while sources on the edge of the Planina polje are at 453 m a.s.l. (Gospodarič, 1976).

Kras

Kras is a low carbonate plateau between Divača, Sežana and Trieste. The name itself has a pre-Indo-European origin from word karra, which means rock – stone. The ancient word for "stone" gave the origin to the ancient name for the region (Carusadus, Carsus) and this word changed according to different languages into Kras (Slovene), Karst (German) and Carso (Italian) (Kranjc, 1997). From this toponym the international term – karst – for such type of landscape is derived. The name and some other terms from the area like dolina, polje, and ponor have entered to international scientific terminology from here.

Kras is a limestone plateau, lying above the Trieste bay at 200 - 500 m a.s.l., the northernmost part of the Adriatic Sea. The climate is Mediterranean in general: hot and dry summer, cold winter with most of precipitation and NE wind "burja " (bora = borealis). Because of different land use, pasturing, in past centuries, the Karst was bare, with rocky and grassy surface. Last decades the bushes and trees are overgrow the landscape.

Kras plateau is stretching in "Dinaric" direction (NW - SE); it is 40 km long and up to 13 km wide, covering about 440 km^2, sloping towards NW. The karstification of mostly Cretaceous limestone started after its uplift in Oligocene. There is about 300 m of vadoze zone accessible and there are caves formed in all elevations from the surface to the sea level and below. The central part of Kras is built by well permeable Cretaceous limestone and partly less permeable dolomite, which may play a role of a relative isolator. Cretaceous rocks pass into well permeable Paleocene limestone, and very low permeable Eocene Flysch that acts as an important impermeable dam surrounding the carbonate massif.

Average yearly precipitation on Kras varies from 1400 to 1650 mm, and average yearly evapotranspiration from 700 to 750 mm (Kolbezen & Pristov, 1998). There are no surface streams on the Kras area, but some rivers are sinking edge of it, largest of them is Reka.

There are about 3490 caves known on the Kras plateau. In seven of them we can reach 21 km of passages of the underground Reka which flows between 2000 and 300 m below the surface.

Karst of Divača

Karst surface above Škocjanske jame, Divaški kras is a SE part of the Kras plateau between the sinks of Reka river and the village of Divača. It is built mostly by Cretaceous and Paleogene limestone. The surface is levelled in elevations between 420 and 450 m a.s.l, inclined slightly towards NW. The karst features here are exceptional; there are sinks of Reka river, 15 large collapse dolines and hundreds of dolines.

In the Divača kras there are known 64 caves with the total passages length of 18,500 m. The largest caves of the area are Škocjanske jame, 5800 m long and 250 m deep cave. They were formed by the sinking river Reka that after sinking flows towards Kačna jama, Labodnica and then to springs of Timavo.

The largest collapse doline in the area is the Radvanj double collapse doline (volume 9 million m^3). It is followed by the 122 m Sekelak, the volume of which is 8.5 million m^3 and Lisični dol (6.2 million m^3). Then there are: Globočak (4.6 million m^3), Bukovnik (1.5 million m^3), Risnik (1.5 million m^3) and others. As rooms as big are not usual in the Karst, we must assume that collapse dolines this large could develop only with simultaneous rock removal. If this were not the case, the room would fill up with caved-in rock and only collapse dolines much smaller than the primary cave would appear on the surface.

Kačna jama is the longest cave system of Reka River in the continuation of Škocjanske jame. The entrance lies west from Divača 435 m a.s.l. The total length amounts to 12.500 m. In the lower level the actual underground flow of Reka is met at 195 m respectively.

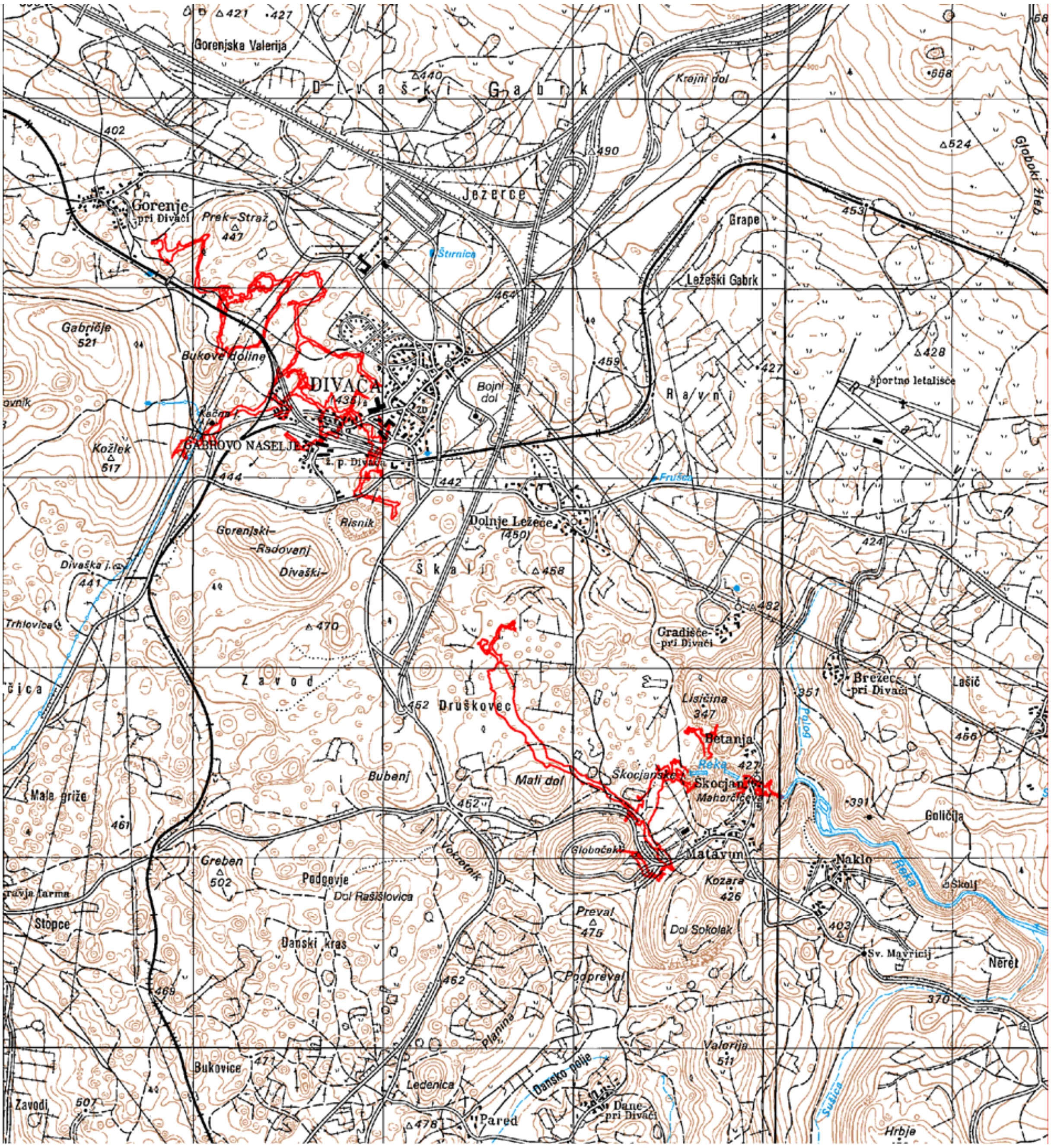


Fig. 5: Divača Karst with Škocjanske jame caves and Kačna jama cave (J. Hajna, 2002).

Reka river – Timavo

The Reka river is the main sinking river of the Kras. It gathers the water from the area of more than 350 km^2. Around 60 % of it is with surface drainage network on Eocene flysch. In the period 1961-1990 the minimal measured discharge of the Reka river was 0.18 m^3/s and the mean discharge 8.26 m^3/s. In the time of extremely high waters its discharge can reach up to more than 300 m^3/s. At such conditions the water is dammed in the underground and over 100 m high floods occur in Škocjanske and other caves.

After underground flow the Reka and rainwater from the Kras and inflows from the rivers Soča, Vipava and Raša reappear at springs as Timavo about 35 NW from Škocjanske jame. Three main springs with mean discharge 30.2 m^3/s are on the coast are connected by a network of passages that reach a depth of about 80 m below the sea level (Civita, 1995).

Škocjanske jame

The Škocjanske jame caves are 5.8 km long. The Reka river, mean annual discharge 8,26 m^3/s enters the cave at an altitude of 317 m; in the Martelova dvorana room, it is 214 m above sea level (i.e. 103 m lower). The Reka can all sink before it enters the cave. Floods usually reach up to 30 m. The largest known flood in the previous century raised the water table level for 132 m.

Morphology and development of Škocjanske jame cave are described according to Mihevc (2001). Caves are developed in a contact area of cretaceous thick-bedded rudistic limestone and Palaeocene thin-bedded dark limestone (Gospodarič, 1983; Habič et al., 1983).

Škocjanske caves are composed of phreatic tunnels, and gravitational or paragenetic reshaped galleries. The proto-channels developed in phreatic conditions, formed along tectonised bedding-planes. The water flow demanded a high degree of phreatic rising and falling between individual bedding-planes which, in the area of the chambers Svetinova dvorana and Müllerjeva dvorana, are approximately 175 m. Large quantities of water could flow through all these tunnels, but meanwhile, rubble was transported through water table caves above them. Such a cave is unroofed cave in Lipove doline at an altitude of around 450 m. A long period followed when the piezometric water table was 340-300 m above sea level and the gradient was in a SW direction. The Reka formed new or adopt old passages by paragenesis and bypassing. The large galleries Mahorčičeva and Mariničeva jama, Tominčeva jama, Schmidlova dvorana in Tiha jama were formed.

In the further development of Škocjanske caves, potent entrenchment prevailed. Cutting occurred in inner parts of the cave, in Hankejev channel for about 80 m, much less about 10 m, in the eastern, entrance part of the cave.

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 and construction of the pathways were done by cavers of DÖAV from Trieste. The most important explorer was Anton Hanke. In 1891 they reached the final sump in the cave.

The largest chambers are Martelova dvorana, with a volume of 2,100,000 m^3, and Šumeča jama (870,000 m^3). Some of big chambers collapsed forming the big collapse dolines like Velika and Mala dolina.

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

Risnik collapse doline

Collapse dolines are, by definition, relief forms which occur when ceilings above underground caves collapse. Slovenian expert literature understands collapse dolines as those with exceptional dimensions, and steep or vertical walls. Smaller collapse forms are frequently left aside because of lack of signs of collapse processes.

Risnik is about 80 m deep collapse dolina situated south of Divača village on levelled karst surface. Its edges are on elevation about 440 m, and bottom at 366 m a.s.l. Most of the doline has vertical walls in upper parts and boulders and scree in lover part of doline.

About 50 m N an E of the doline there are galleries of Kačna jama where Reka flows at 190 m a.s.l. There are no signs of connection between the doline and the gallery, so we have to suppose, that the Risnik was formed above unknown passages of Kačna jama. Only 50 m W of Risnik is dolina much larger, 800 long and 450 m wide double dolina Radvanj. Volume of both depressions is about 9.000.000 m³.

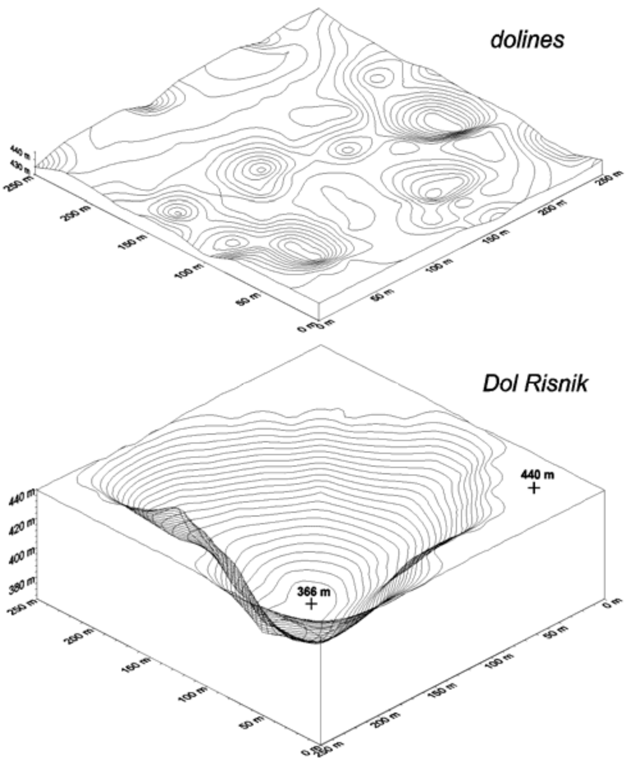


Fig. 6: The comparison between the surface with dolines and surface with a single collapse doline Risnik (Mihevc, 2001).

Unroofed cave at Lipove doline

Unroofed caves are an important part of the surface morphology of Divaški kras where 2,900 m of the unroofed caves was mapped (Mihevc, 2001).

They are caves exposed to the surface due to the surface denudation lowering which re-shapes them into the surface relief forms. In such features flowstone, allochtonous sediments and morphology are testifying their cave origin. Several unroofed caves were studied and sediments were analyzed (Mihevc & Zupan, 1996; Bosak P. et al., 1998); clastic sediments are dated to 1.6 - 1. 8 Ma or/and 3.8 to 5 Ma.

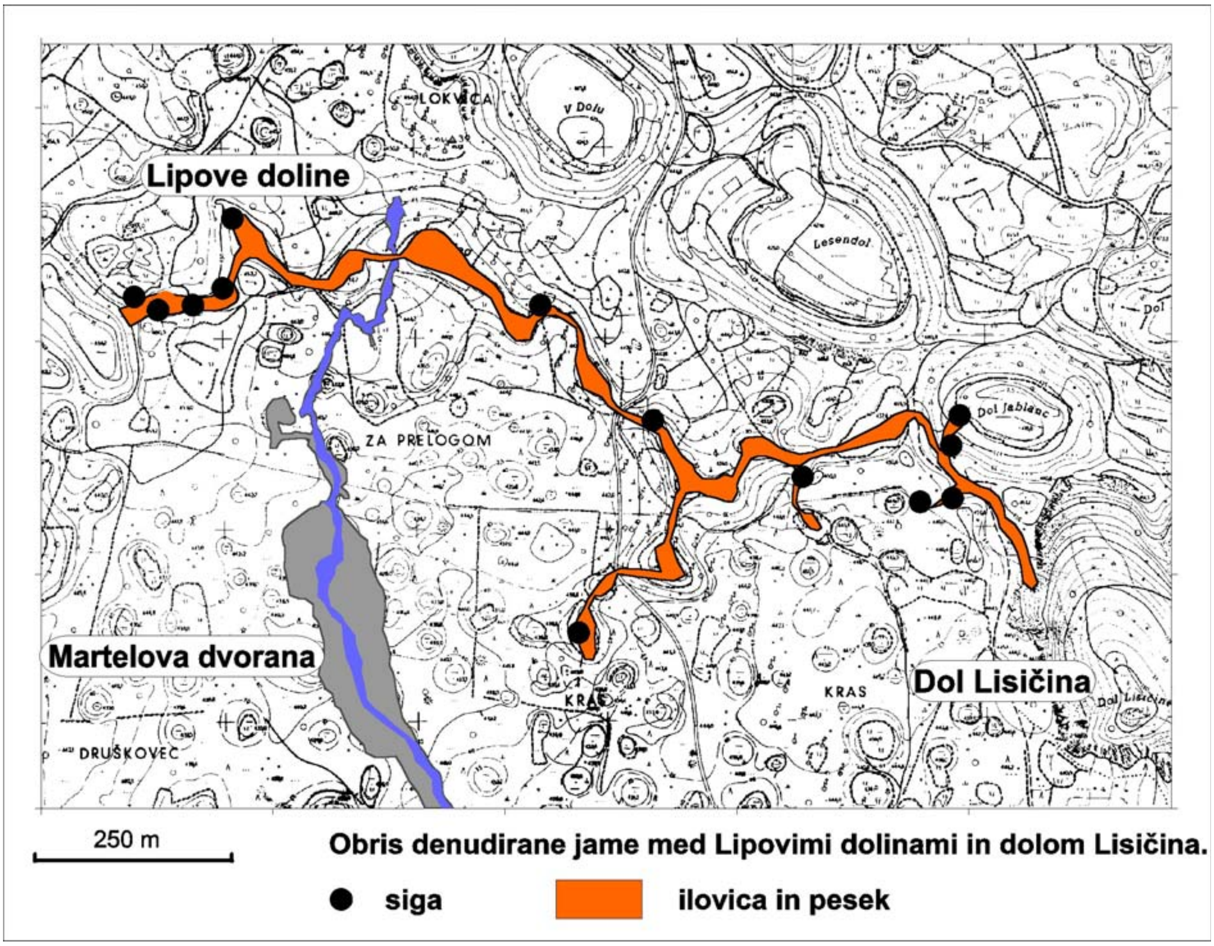


Fig. 7: Unroofed cave Lipove doline (Mihevc, 2001).

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MORNING EXCURSION, 1 July 2006

Postojna karst

During this field trip around Postojna some examples of karst landscape management will be discussed, e.g. water supply system and monitoring of water quality, fauna protection in caves, vulnerability mapping, management of city dumps and use of karst area for military training.

Hydrogeological conditions

Metka Petrič

Upper Cretaceous limestones of Javorniki massif are well karstified and form the main karst aquifer with dominant groundwater flow (Fig. 1). On its western side in the lower Pivka valley surface drainage net is developed on less permeable Quaternary alluvial sediments and Eocene flysch. In its upper stream the Pivka river flows partly on the surface and partly underground along the western edge of the Javorniki mountains. At high waters several karst springs are activated along it (Fužina, Žejski izviri, Matijeva jama, and others) and also Pivka intermittent lakes (Petelinjsko jezero, Palško jezero, and others) are filled with water. During low waters the water table decreases below the river bed and Pivka sinks underground through several ponors. In general the depth of flysch in the Pivka valley is relatively small and karst aquifer is developed also below it. Close connection between surface drainage net and underground karst flow is characteristic for the whole area.

On northern and eastern side Javorniki are bordered by the Planinsko polje, Cerkniško polje and Rakov Škocjan. These are typical karst features for which surface flow in connection with underground flow in surrounding massifs is characteristic. The bottom of Planinsko polje and Cerkniško polje are built by Upper Triassic dolomite, which is less permeable than limestones. Both poljes are cut by the fault zone of the Idrija fault, which acts as hydrogeological barrier. Along it karst waters outflow through several springs, flow on the surface across the polje, and sink again underground. The most important at Planinsko polje is the Malenščica spring, which is captured for the water supply of the municipalities Postojna and Pivka. Its discharges range between 1.1 m^3/s and 9.9 m^3/s, and the mean discharge is 6.7 m^3/s (Kolbezen & Pristov, 1997). The Unica river springs from the Planinska jama Cave. Discharges are bigger at high waters with almost 100 m^3/s, but smaller in dry periods with only several hundred liters per second (Gospodarič & Habič, 1976).

The Rakov Škocjan area is built by Cretaceous limestone, which is in the valley of the surface stream Rak covered by Holocene sediments. The biggest springs are the Kotliči and Prunkovec springs, which are left tributaries of Rak.

Underground water flow below the flysch of the Pivka basin towards the Vipava spring was proved by tracing (Habič, 1989; Kogovšek et al., 1999). This spring with discharges from 0.7 to 70 m3/s and mean discharge 6.78 m^3/s (Kolbezen & Pristov, 1997) is captured for the water supply of the upper Vipava valley. The southern border of the Javorniki karst aquifer is the karst watershed in the Snežnik mountain between Pivka and the rivers Reka, Riječina, and Kolpa.

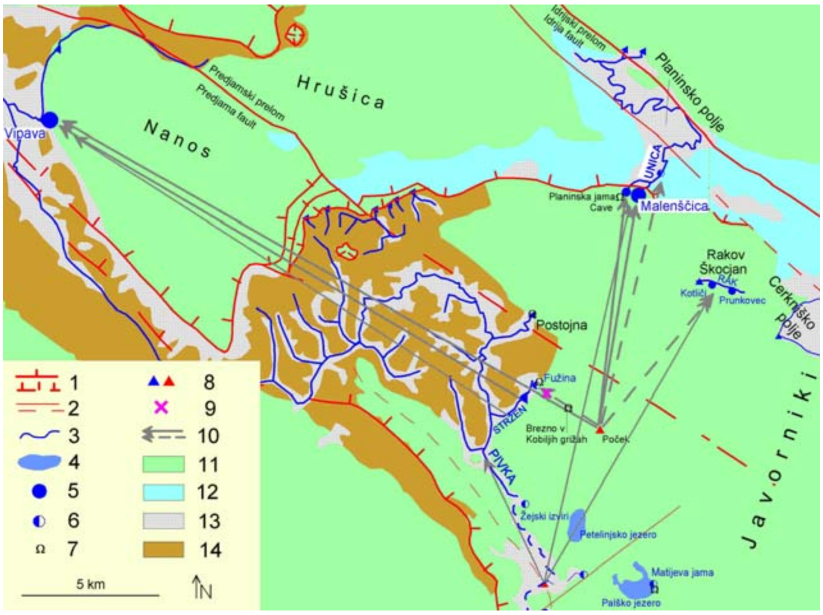

Fig. 1: Hydrogeological map of the Postojna karst area (Legend: 1.Visible and cover thrust plane, 2. Visible and covered fault, 3. Surface stream, 4. Intermittent lake, 5. Permanent spring, 6. Intermittent spring, 7. Karst cave, 8. Ponor or injection point, 9. Landfill, 10. Main and secondary underground water connection, proved by tracer test, 11. Karst aquifer, 12. Fissured aquifer, 13. Porous aquifer, 14. Very low permeable rocks).

Landfill Stara vas near Postojna

Metka Petrič & Stanka Šebela

According to the new Slovene legislation regarding the wastes it is not allowed to plan new landfills on karst and also the existing ones will have to be closed in the next years. But in the actual transitional period 9 landfills on karst are still active, among them also the Stara vas landfill near Postojna. As strong fissuration of the rock base and very good permeability is typical for karst areas, the rainwater together with harmful substances from the wastes enters quickly into the aquifer and particularly endangers the groundwater. The capacity of natural filtration in karst is very low and the dimension of possible negative impact is very high.

The landfill Stara vas is situated on the western edge of the Javorniki karst massif at the altitude around 580 m. According to the information supplied by its manager Publicus d.o.o. the landfill was opened in 1969, and after reconstruction it was activated again in 1999. Yearly around 8500 t of non-hazardous waste from the municipalities Postojna and Pivka is deposited. The landfill is planned to contain up to 90.000 m^3 of compacted waste. Waste waters are collected and transported to the central treatment plant of Postojna. Surface waters, which are not in contact with waste, are drained into a sink. According to the plans the procedures of closure will begin in 2008.

General hydrogeological characteristics of the area are described above. With the purpose to estimate the characteristics of infiltration and percolation of water in the area of the landfill the detailed tectonic-lithological mapping in the scale 1:5000 was performed (Petrič & Šebela, 2005). Most of the studied area represents Upper Cretaceous limestones $K_2^{2,3}$ (Buser et al., 1967) respectively $K_2^{4,5}$ (Rižnar, 1997). Additional to two strong faults with Dinaric orientation also several fissured, broken and fissured to broken zones were determined after the classification of Čar (1982). In fact we have a 300 m wide fissured to broken zone in Dinaric orientation, which is well permeable for water and runs directly across the Stara vas landfill. Besides this also other directions of broken zones were determined in the vicinity of the landfill.

Due to a thin soil layer, well developed fissured and broken zones, well karstified rocks and therefore very good permeability the infiltration of precipitation and in it dissolved harmful substances is fast. In the vadose zone water flows fast through main drainage paths, but partly it is slower and can be retained for longer periods in less permeable zones. According to the measured water levels in 3 boreholes in the broader area the thickness of the vadose zone below the landfill is estimated to be between 60 m and 75 m at different hydrological conditions. Results of tracer test indicate that after intensive precipitation infiltrated water can pass through the vadose zone already in several hours, but can be during dry periods also retained there for two to three months (Kogovšek, 1999; Kogovšek & Petrič, 2004). In the phreatic zone water flows mainly through karst fissures and channels in different directions towards the springs at the border. Characteristics and velocities of flow differ according to hydrological conditions. Underground flow towards the springs at the Planinsko polje (Malenščica, Unica, Škratovka) and Rakov Škocjan (Kotliči, Prunkovec), towards the springs along the Pivka river (Fužina), and also towards the Vipava spring in the Vipava valley was proved. Estimated apparent flow velocities were high (0.2 to 0.7 cm/s).

In the past the monitoring of the quality of karst waters in the influence area of landfills was not obligatory, therefore only very few data on it exist and negative impacts are difficult to quantify. But the actual Rules on landfill waste tipping (Official Journal of the Republic of Slovenia - OJ RS 5/00) regulate the performance of operational monitoring and define its dimension and the way of performance. One part of the monitoring is also the measurement of parameters of contamination of groundwater by hazardous substances, if they are in the impact area of the landfill. They are determined by Rules on monitoring the pollution of groundwater with hazardous substances (OJ RS 5/00). For all existing landfills the programs of monitoring for the groundwater are now being prepared based on hydrogeological characteristics. Also the landfills that will be closed need such program, because the monitoring will have to continue also after the closure of the landfills.

In the Rules boreholes are defined as the main observation points. But on karst their efficiency is not high enough, so instead the observation at natural objects is recommended. For the landfill Stara vas two drinking water sources Malenščica and Vipava, as well as the Fužina spring, the nearest to the landfill, were chosen as monitoring points. As one monitoring point outside the area of influence the Matijeva jama Cave is suggested. In accordance with legislation the proposed basic monitoring on all suggested sampling points will be performed four times per year during the different hydrological conditions (in summer dry period, after first autumn precipitation, at high waters in autumn, during increase of discharges in spring). But by such seasonal sampling occasional problems with water quality can be overlooked. After stronger precipitation events more intensive washing out of contaminants from the landfill as well as flushing out of previously stored polluted water from the vadose zone below the landfill can be expected, therefore additional, more detailed sampling during a selected water wave after first intensive autumn rains is suggested. The physical, as well as basic and indicative chemical parameters that need to be included into the monitoring are determined by Rules on monitoring the pollution of groundwater with hazardous substances. For monitoring points in karst aquifers also continuous monitoring of discharges is prescribed.

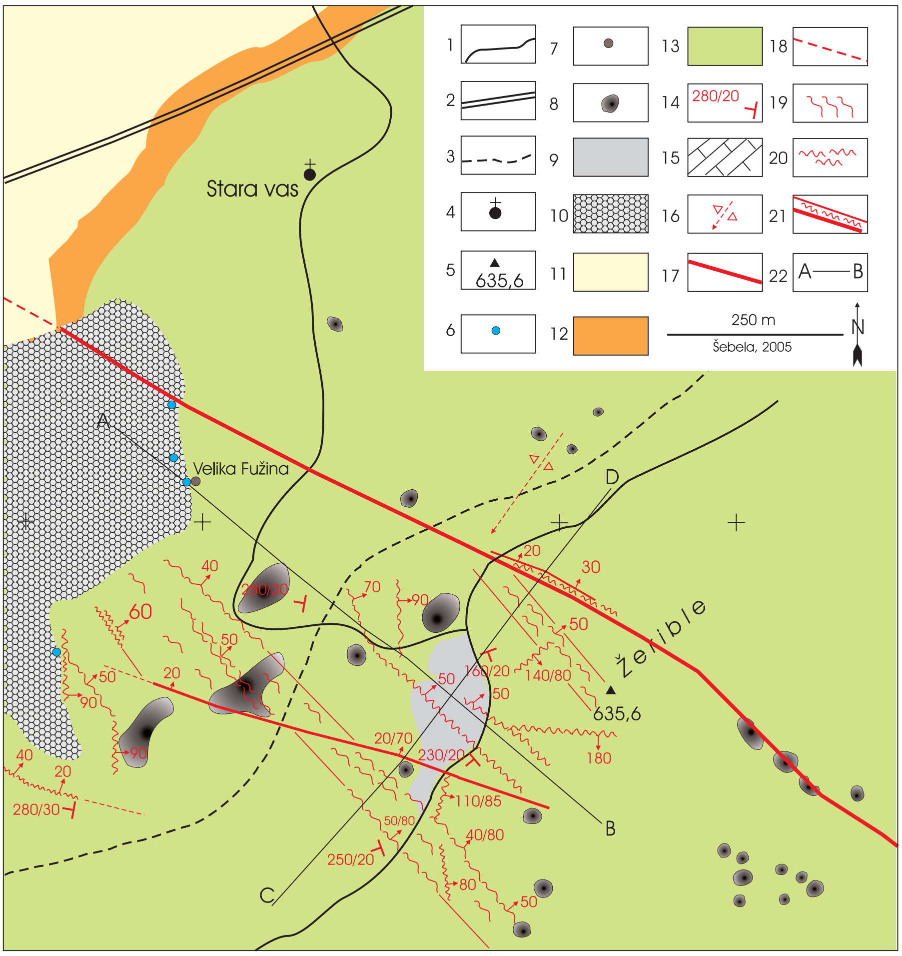

Fig. 2: Map of detailed geological mapping of the Stara vas landfill. (Legend: 1. Road, 2. Highway, 3. Railway, 4. Settlement, 5. Hill with above sea altitude in meters, 6. Intermittent spring, 7. Karst cave, 8. Doline, 9. Landfill, 10. Q alluvium, 11. E flysch, 12. Pc_2 E_1 (breccia with pieces of Paleocene limestone with conglomerate and marl layers), 13. $K_2^{2,3}$ limestone, 14. Dip direction and dip angle of limestone beds, 15. Dip direction of limestone beds in cross sections, 16. Supposed anticline axis that sinks towards SW, 17. Stronger fault, 18. Supposable continuation of the fault, 19. Fissured zone, 20. Broken zone, 21. Crushed zone, 22. Cross section).

Figure 2.

As especially bigger springs have larger recharge areas with different pollution sources, it is important to compare the results of physico-chemical analysis of water samples from all 4 sampling points in order to evaluate obtained results and interpret possible occurrences of pollution. Additional information can be obtained by comparison of data on water quality with hydrological conditions. Based on all gathered data it will be possible to improve the performance and efficiency of monitoring.

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Malenščica spring and water tracing in the military training area Poček

Janja Kogovšek

The Malenščica is very important karst spring on Planinsko Polje, near Postojna, Slovenia, captured for water supply of Postojna and Pivka communities. Its discharge ranges between 1.1 and 9.9 m^3/s (Kolbezen & Pristov, 1997). Older tracing experiments show (Habič, 1989) that not only infiltrated karst water from a vast carbonate Javorniki massif but also more or less polluted sinking streams from Cerkniško Polje and Pivka basin, dependent on hydrological conditions, flow into the Malenščica spring (Fig. 1). Less than 1 km towards the south-west the sinking river Unica reappears from Planinska Jama (underground confluence of the Pivka and Rak rivers).

In June 1997 we made a tracing test on Poček in Javorniki massif, which is distinctively karstic, without superficial streams (Kogovšek, 1999). The landscape is wooded and practically uninhabited, but there are two sources of pollution: military training area and Postojna landfill.

This tracing test was the first from the area of Javorniki and showed the drainage of water from this important part of the Malenščica aquifer. The test was ordered by the Ministry of Defence within the report related to study the impact of Poček military training site on natural environment in particular on the captured karst spring Malenščica at Planina. Within the basic programme Karst in Slovenia I, financed by the Ministry of Science and Technology and co-financed by the water supply enterprises we widened our researches to the springs in Rakov Škocjan and on Planina polje and to springs of the Vipava, thus obtaining comprehensive knowledge about the water drainage from the northern part of Javorniki.

Tracing test from military training area Poček

On June 10 1997 4 kg of fluorescent tracer uranin were injected into a doline on Poček (565 m a.s.l.) – Javorniki (Fig. 1). Before the injection we poured in 1 m3 of water and then we washed the tracer down by additional 11 m^3 of water. We observed 13 springs and water flows in a wider area: in Rakov Škocjan, on Planinsko Polje, in Pivka Basin and the Vipava springs (Fig. 1). The sampling lasted for almost one year. Annual rainfall average for the time 1961-1990 (Postojna meteorological station) is 1500 mm.

The Malenščica discharge reached at the time of injection 5.27 m^3/s and decreased slowly, and the same may be said for the Vipava where the discharge was 2.56 m^3/s. The tracing test proved the connection of the injection point with the Malenščica (446 m a.s.l. and 9290 m air distance from Poček), the Pivka river in Planinska jama and with Škratovka spring on Planinsko Polje, with the Rak, Prunkovec and Kotliči in Rakov Škocjan, with Stržen spring near Stara vas and with the Vipava springs (99 m a.s.l. and 24650 m distant from Poček).

The test showed that washing and drainage of Uranin through the Malenščica spring lasted almost one whole year when this area received 1500 mm of precipitation. The structure vadose zone in the area of injection caused slow drainage of water and tracer, and longer retention times. Seasonal intensive rainfall during the summer dry period washed out only a part of Uranin, more inportant was the intensive rain in November (Fig. 2).

The majority of uranin was washed out in 7 months, when an abundant rain of over 1000 mm appeared after the injection. After an intensive rain in June and July (117 and 126 mm) 22% and after rain in November and December (550 mm) 33% of injected uranin appeared in the Malenščica (Table 1, Fig. 2). So 55% of 4 kg of the injected tracer reappeared through the Malenščica and 19% through the Vipava spring.

According to formation of the first tracing pulse (curve) the water with tracer drained the fastest into Škratovka, Malenščica and Vipava (v_{dom} = 0.7 cm/s) and the slowest in the Stržen spring (v_{dom} = 0.27 cm/s).

Table 1: Apearence of Uranin in Malenščica spring

Appearance of Uranin	V_{max}	V_{dom}	Recovery	
	cm/s		g	%
1. tracer pulse in June	1	0.72	16	4
2. tracer pulse in July	0.3	0.27	720	18
3. tracer pulse in November	0.27	0.07	1320	33

The water tracing test was achieved in a relatively dry period this is why only an additional combined water tracing test at high waters would give an integral image of water drainage and substance transport. The Malenščica and Vipava, both captured for water supply, demand a particular attention at planning the military activities in the Poček area and also a lot of caution related to landfill. In any case a permanent and appropriate monitoring of Malenščica and Vipava springs quality is indispensable.

Physico-chemical properties of waters in the Malenščica recharge area (environmental tracing)

As the Cerkniščica and Stržen on Cerkniško polje, as well as Rak and Kotliči springs in Rakov Škocjan, show different physico-chemical properties, we were able to determine the connections of these waters (Fig. 1):

- When the water levels are extremely low – such conditions occurred at the end of August 2003 when sinkholes in Jamski zaliv - 1 and 2 (Cerknica polje) and at Zelške jame - 3 are dry, the Kotliči spring – 5 (Ca/Mg=4.5) get water only from the area of Javorniki; the composition of these waters is similar to the composition of the Malenščica (Ca/Mg=4.8). The Malenščica contains slightly more chlorides, nitrates and sulphates, indicating the possibility of wastewaters effect flowing into the swallow-hole, located in the riverbed of the Pivka near the town of Pivka.
- When water levels are low - when the Stržen on Ceknica polje does not flow into Jamski zaliv, when the Cerkniščica sinks into Svinjska jama – 1 (ponor Mala Karlovica -2 is dry), the composition of the Kotliči spring - 5 (Ca/Mg=2.6) is the closest to the composition of the Rak river – 3 (Ca/Mg=2.0); this is due to the fact that in this case Kotliči springs get most water from Cerkniščica and only a tiny part from the area of Javorniki (Fig. 3). When the conditions are as described above, then the influx coming from the direction of Cerknica decreases the Ca/Mg ratio of the Malenščica spring.
- When water levels are higher – when Stržen also sinks in Jamski zaliv – the difference in the composition of Rak and Kotliči is the biggest; the Ca/Mg ratio of the Rak was 1.6 and of Kotliči 4, 8. Big differences were recorded also when water levels were the highest and when Cerkniško polje was flooded – in such cases the flood water from Cerkniško polje, with higher Ca/Mg ratio, must flows also into the Rak river. This indicates the possibility that in this case the Rak river with low Ca/Mg ratio is fed by an unknown inflow of dolomitic water.
- When the Malenščica receives water from Pivka, we can only say that such water is characterized by higher Ca/Mg ratio and higher values of pollution indicators; infiltration water from poorly conductive part of Javorniki is characterized by Ca/Mg values around 5.

The parallel pattern of parameters typical for the Rak river and Kotliči indicates that both rivers are fed by the waters from the same area; when water levels are low, the effect of the Cerkniščica can be detected; when water levels are high, the effect of flood water from Cerkniško polje shows as well as the effect from the Javorniki area waters. During warm and cold periods the temperature is a good environmental indicator of waters from Cerkniško polje that flow into Malenščica, especially in times of floods.

Due to the complexity of the system some questions remain unanswered; the answers can only be got by carrying out additional research – combined tracing experiments, with simultaneous tracing of environmental parameters and with water balance.

Monitoring the Malenščica water pulse by several parameters in November 1997

Simultaneous monitoring of numerous parameters of the Malenščica water (temperature, pH, discharge, carbonates, Ca, Mg, chlorides, nitrates, o-phosphates and sulphates) in the autumn water pulse after abundant autumn rain in the time of tracing experiment with uranin indicated water quality of spring and partly the dynamics of water inflow from a wider recharge area (Kogovšek, 2001a; 2001b).

In the initial time of rapid increase in the Malenščica discharge (54 hours) about 250 000 m^3 more water drained through the resurgence than it would be without rise in discharge (Fig. 3). The water quality was identical than before the discharge increase. This was the old water; in particular this in more permeable part of the Javorniki aquifer although the secondary feeding was minimal. This is followed by squeezing of rapidly infiltrated rainfall and rise in secondary feeding by washing the pollution out of riverbeds and underground channels (rise of nitrates to 6.5 mg NO_3^-/l, sulphates to 11 mg SO_4^{2-}/l and o-phosphates to 0.06 mg PO_4^{3-}/l). Consecutive rise of old water out of less permeable part of the aquifer what characterise appearance of Uranin and Ca/Mg near 5 showed higher concentrations of o-phosphates (to 0.09 mg PO_4^{3-}/l) and sulphates.

It was not possible to determine more precisely the inflows from military training area Poček, from Cerkniško polje and the Pivka valley. Only a combined tracing test and mineralogical analyses of solid particles transported by the Malenščica can give us more informations.

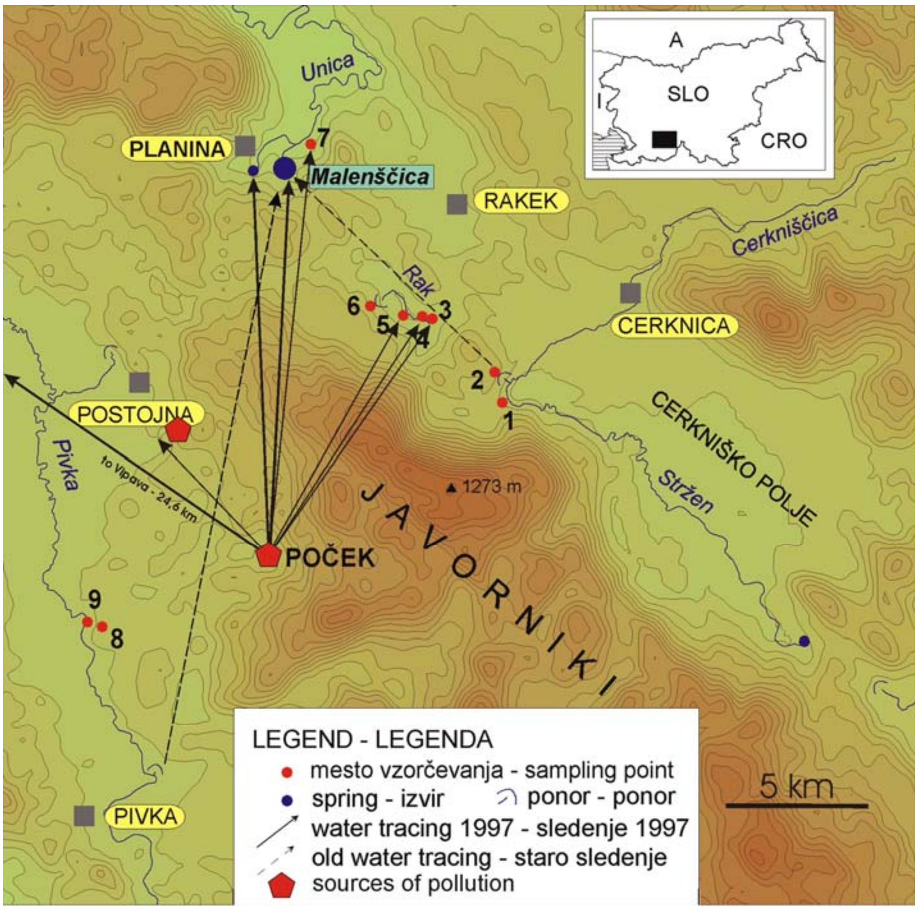

Fig.1: Tracing test from Poček and sampling points of physico-chemical properties of waters in the Malenščica recharge area: ponors in Svinjska jama (1) and Mala Karlovica (2) and springs: Rak from Zelške jame (3), Prunkovec (4) , Kotliči (5) and Rak at Veliki naravni most (6).

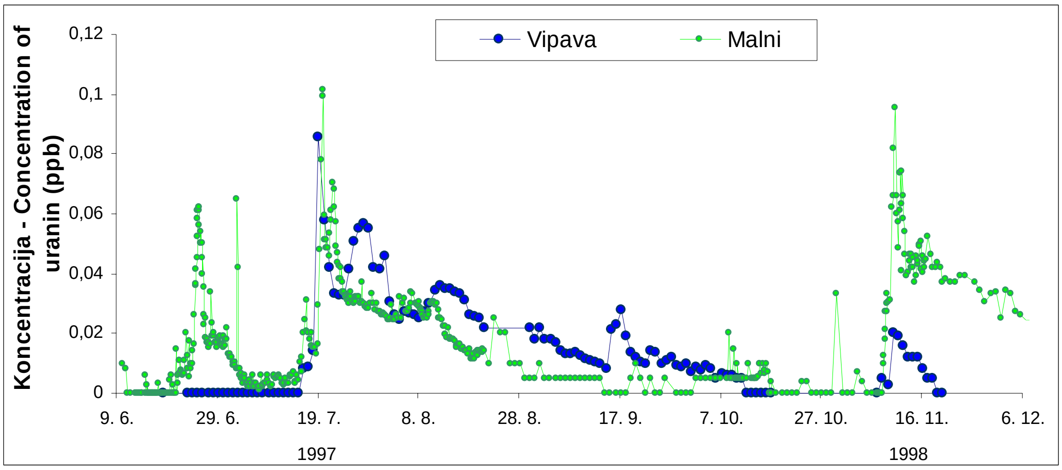

Fig. 2: Tracing pulses (tracer breakthrough curves) of springs Malenščica and Vipava.

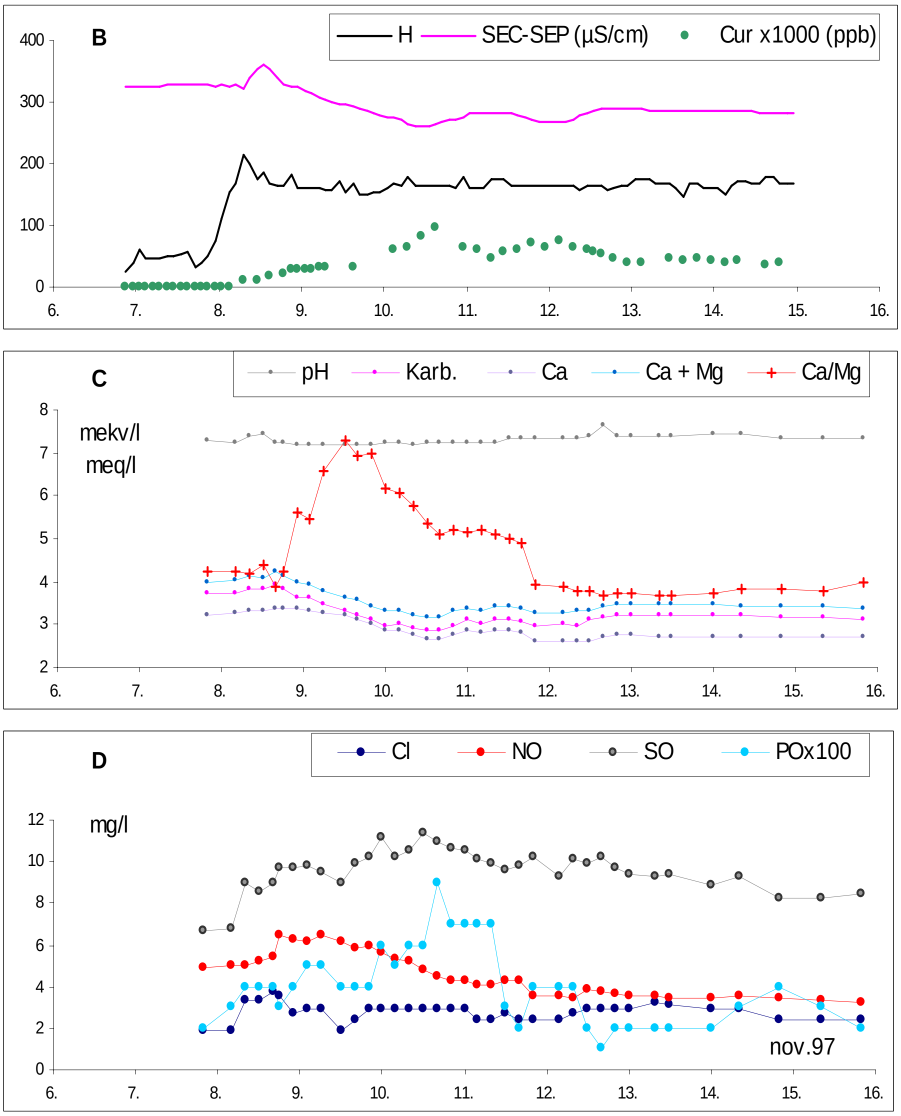

Fig. 3: The Malenščica water pulse in November 1997: B –level (H), conductivity (SEC) and Uranin concentration (Cur); C – carbonate (Karb) and calcium (Ca) levels, total hardness, pH and Ca/Mg rate; D – chloride (Cl), nitrate (NO), sulphate (SO) and o-phosphate (PO) levels.

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The Malenščica karst spring as an important drinking water source

Nataša Ravbar

Importance of the Malenščica spring

Since 1929 the main sources of drinking water of the city of Postojna and the settlements in its vicinity have been obtained by capturing of springs under the Nanos Mountain. In 1972 an additional source of the Malenščica spring that by then only supplied the Planina village has been connected to the municipal drinking water supply system. Later, in the eighties, the settlements of the Pivka municipality have been connected to the water supply network as well.

Today the extensive regional water supply network supplies nearly 20,000 inhabitants in totally 60 settlements of the Postojna and Pivka municipalities. There are only few smaller villages that use water from individual water sources and are not connected to the regional network. The whole water supply system is 300 kilometres long and is considered as a medium size system in the country.

The most important source of drinking water is the Malenščica karst spring (Fig. 1). On average 85 l/s is pumped. Additional sources are the springs under the Nanos Mountain are contributing to the total consumption only a small proportion that is 10 percent. Smaller amount, not even one percent of total consumption is contributed by local springs, which are not directly connected to the regional water supply network.

Fig. 1: Drinking water capture at Malenščica karst spring (Photo by N. Ravbar).

There are no exact data about drinking water use in the Pivka basin in the past. Habič reports that in 1968 18,755 inhabitants lived there and that the annual consumption of water reached 1.4 million m^3. In 1986 number of population increased to 20,180 and consumption in the same year was 2.3 million m^3 (Habič, 1987). In the eighties consumption of water exceeded two million m^3 of water per year and heavily declined after the country reached its independence. In the nineties consumption of annual amount of water suddenly decreased from 1.5 to 1.36 million m^3. This situation is due to great decline of the economic activities in a national scale, which affected numerous local firms and industry, large reduction of military discipline and consecutive emigration.

In 2001 the amount of water, delivered into the water supply system, was 2.7 million m^3, while the amount of sold water was 1.4 million m^3. Water losses in the system are nearly 50 percent. Average use of water in Pivka basin is 114,000 m^3 of water per month. Average quantity of water in households is 820,000 m^3, in industry and firms 650,000 m^3 of water per year. Among these the biggest users are poultry breeding and slaughterhouse Pivka in Neverke village, production of electrical household appliances, wheels, machine tools, lifting and transport gears LIV in Postojna and timber industry Javor in Pivka.

The Malenščica water source is like many other abundant karst springs in Slovenia of great national importance for drinking water supply. Namely, extensive areas on the western, south-western, southern and south-eastern parts of Slovenia are almost entirely dependent on karst water sources. Therefore karst aquifers are becoming more and more important for regional and local drinking water supply and should thus be especially carefully managed.

Protection of karst water sources in Slovenia

Karst aquifers are, due to their specific structure, particularly susceptible to contamination. Due to rapid recharge of the infiltrating water underground and its fast distribution over large distances and to high flow velocities and short residence time, a self-cleaning capacity of the karst groundwater is very low. Consequently, the remediation and neutralizing of the eventual infiltrated contaminant in the karst network would be negligible and the contamination could be without effective attenuation of its concentration transported over large distances.

The karst aquifers in Slovenia are mainly in remote areas and are due to their relief or unfavourable climate conditions less attractive for intensive settlement, industrial, farming and other activities. In general, the quality of karst groundwater is still relatively high. However, some signs of contamination have already been recorded in some of the springs (Kovačič & Ravbar, 2005).

In Slovenia despite relatively favourable conditions for karst water sources protection in comparison to some other karst areas worldwide, many of the karst water sources still remain insufficiently protected. The reason is the disorder in the previous water protection policy, conflicting interests in land use and the lack of knowledge about sustainable water management in karst regions.

Until recently environmental acts for the protection of water sources and groundwater have been very general. However, with the independence of the country and its integration into European Union a great progress in the environmental legislation has been made. Nevertheless, also in the present Slovene legislation not enough attention has been devoted to the special characteristics of water flow in karst while determining the criteria for karst water sources protection. Since the present water protection policy following European guidelines has been put in force for only a relatively short period of time, majority of the karst sources protection zones bases on the old legislation.

The situation of the Malenščica spring faces serious contamination problems. In the sources immediate vicinity the most important highway and railway routes pass. The spring is also strongly endangered by the Poček military training area on the Javorniki Mountain, by the sewage, by the Stara vas landfill near Postojna and other illegal dumping.

Despite the facts that the Malenščica spring is most important source for regional water supply and heavily endangered by various activities it has still not been properly protected yet. Neither have been the water protection zones delineated nor have been the regimes established. The reason can mainly be found in conflicting interests between the municipalities over which the protection zones would extend.

In Slovenia catchment areas of particular karst source (spring or well) are often very large, extending over several tens or even hundreds km^2. According to the criteria for protection of karst water sources the protection zones would cover large areas, often the entire catchment. However, it is impossible to require a high protection for large areas. Such spatial planning would be unreasonable and not practical. Above all, in the areas with great market value of the land rigorous land use restrictions would be controversial. Therefore the concept of vulnerability mapping would be more appropriate for land use management and protection zoning of karst water sources in Slovenia.

The concept of vulnerability mapping

The concept of vulnerability mapping has increasingly been used for protection zoning and land use planning worldwide, using different colours to symbolize different degrees of vulnerability (Vrba & Zaporozec, 1994). The objective of vulnerability mapping is to identify the most vulnerable areas and prioritise those. However, the concept of groundwater vulnerability mapping is not restricted to karst, but is most relevant when applied to karst (Goldscheider, 2005).

Several different methods for groundwater vulnerability mapping have already been proposed. In some of the countries respective vulnerability mapping approaches have also been integrated in the states legislation e.g the Irish method in Ireland (GSI, 1999), the SINTACS method in Italy (Cività & De Maio, 1997). The EPIK method (Doerfliger & Zwahlen, 1998) has been integrated in Swiss legislation only for karst sources. The GLA method (Hölting et. al., 1995) is a supplement to the German groundwater protection schemes.

Unfortunately, experiences on such application using methodologies enforced and many times tested in Europe have been very modest in Slovenia. So far only two karst spring vulnerability studies have been done; Janža and Prestor (2002) were using the SINTACS and Petrič and Šebela (2004) were using the EPIK method.

However, direct application of some vulnerability mapping methods could meet several difficulties due to specific characteristics of Slovene karst regions (very thin or mostly absent protective cover, very complex and large catchment areas, lack of quality and representative research, poor database, problem of data availability, etc.). Considering these characteristics application of the most commonly used methods should be stimulated in order to subject methodological problems that may arise during their application.

Eventually, according to adequacy of particular criteria, such as parameters selection, parameter weighting and final assessment reckoning the most satisfactory among the existing methods should be selected and improved if necessary. Finally, common method, which would be the basis for the water protection zones and regimes establishment, should be proposed (Ravbar, 2006).

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Epikarst community in Postojna-Planina cave system, Slovenia

Tanja Pipan

All subterranean habitats, whether they have large or small spaces, share several key features. First, there is a permanent absence of light. Second, productivity is extremely limited, and except for rare cases, primary productivity is absent. Third, almost all systems of water-filled or air-filled cavities have biological activity. Fourth, there is reduced environmental variability relative to surface conditions. Thus, subterranean organisms must contend with complete darkness, limited food, and at least a reduction in seasonal cues (Culver & Pipan, in press).

Caves are an important part of aquatic ecosystems in karst terrains, but are not the only component. Water enters the subterranean karst system at the rock-soil interface, which typically has many small solution pockets and cavities with complex horizontal and vertical pathways (Pipan & Culver, 2005a). Eventually water percolating through the epikarst reaches a cave stream which in turn exits at a spring and flows into a surface river. Beneath the cave stream is a permanent saturated (phreatic) zone that itself often contains large cavities.

The epikarst zone represents the karst stratum that is closest to the surface (Fig. 1). It is a perched aquifer, and water is transmitted vertically either through conduits or small fissures to the saturated (phreatic) zone. Lateral transmission occurs through poorly integrated lateral openings. The epikarst is an important part of karst for several reasons. It is a major ecotone between surface water and cave water, where water is conducted by larger fractures through the vadose zone into the phreatic zone (Pipan, 2005).

Epikarst is the initial transmission zone for contaminants that are stored in the overlying soil or in the epikarst and are leached by water flow. Contaminants are easily injected into karst aquifers through sinking streams, sinkholes, or through open fractures and shafts in the carbonate rock (Loop & White, 2001).

The epikarst zone is also the habitat for a major part of the obligate subterranean aquatic fauna. It contains both epigean and hypogean species, but in addition it also has unique species. The most common and most abundant metazoans in the epikarst are copepod crustaceans. Some terrestrial species also find suitable microhabitat in epikarst. When they occur in drips, they provide food input into the typically food poor cave environments (Pipan, 2005, Pipan et al. 2006).

Epikarst copepods that occur in the epikarst contribute a major part to the overall species richness in caves and may exceed the diversity of other stygobionts elsewhere in the karst system. Species richness and ecological specialization of copepods that occur in the epikarst show a large range of variation, although many species are not yet discovered and their distributions are incompletely known (Pipan et al., 2006).

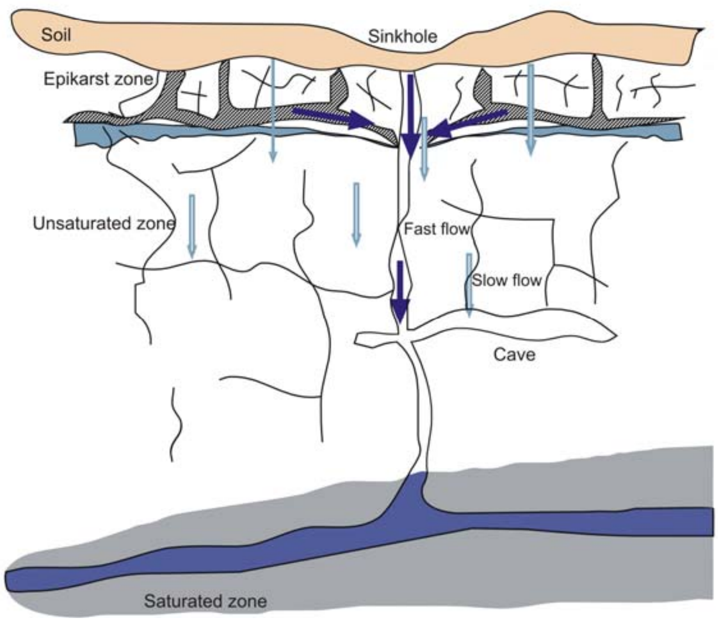

Fig. 1: Idealized cross-section of a karst area

The epikarst fauna should be explored indirectly by taking samples of the percolation water and from cave pools filled by water which seeps down the walls or drips directly from the ceiling (Fig. 2). Epikarst fauna is particularly vulnerable due to its almost direct exposure to contaminants from the surface. Aquatic copepod communities in epikarst thus may be subject to severe conditions and can potentially be used as important biological indicators for the evaluation of environmental conditions (Pipan, 2005).

Fig. 2: Epikarst fauna sampling

Epikarst is a diverse habitat and harbors exceptionally rich copepod fauna with a high frequency of endemism that particularly increases the conservation value of the epikarst. Study of the epikarst zone represents a powerful tool for understanding environmental effects on fauna, as well as vertical and horizontal movement of contaminants via epikarst water (Pipan & Culver, 2005b). An example to demonstrate a diversity of the epikarst fauna is from Postojna-Planina Cave System (PPCS) in Slovenia, where 20 drips were continuously sampled for more than one year (Pipan & Brancelj, 2004). The drips exhibited considerable environmental heterogeneity. Drip rate itself ranged between 1.7 and 202 ml/min (mean=35.3, median=8.8). Conductivity varied between 238 and 548 μS/cm, probably reflecting different residence times of the water in the subsurface. A total of 23 copepod species (4 Cyclopoida and 19 Harpacticoida) were found in the drips, including eight undescribed species. Six of these 23 species are endemic to PPCS. A total of five species were in a single genus—*Bryocamptus* (Fig. 3). Species composition was extremely heterogeneous; differences in drip rate, ceiling height and nitrate concentrations were correlated with differences in species composition. Included among the terrestrial species, presumably ones washed in through the epikarst, were Gastropoda, Acarina, Diplopoda, Collembola and Coleoptera. The small but interesting category of stygobionts included the crustaceans Ostracoda, Amphipoda, Isopoda and Bathynellacea. Nematoda and Oligochaeta were among the terrestrial accidentals well represented, since these benthic dwellers presumably find suitable microhabitat in epikarst and in the sediment of drip pools.

Fig. 3: An image of the epikarst crustacea from the group of Copepoda

There was also a strong distance effect, with drips closer than 100 m being more similar than those farther away (Pipan et al., in press). The scale of variation of epikarst communities is remarkable—even drips less than 100 m apart often have different species. This likely reflects the semi-isolated nature of the small cavities that comprise the epikarst (Fig. 1).

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Karstology applied in motorways and railways construction

Martin Knez & Tadej Slabe

Karstologists take part in motorway constructions planned in karst. In preliminary studies we have chosen laying out together with planners and by regular karstological control during the construction we studied newly discovered karst phenomena and helped builders to overcome the karst properties; at the same time we tried to preserve as much as possible of these phenomena. During the construction of the recent part of motorway more than 350 caves opened on 60 km of a foreseen roadway. Different types of caves reflect the evolution of through-flow and outflow aquifer due to underground water table and karst surface lowering. When planning and choosing the alternatives of laying out one must consider geological, geomorhological, speleological and hydrogeological circumstances and the integrity of karst regions where motorways and railways (Fig. 1) are constructed. We tried to avoid important karst phenomena as are collapse dolines, large dolines, caves and karst walls and by impermeable construction of a roadway we tried to prevent the pollution flowing from it into underground waters (Fig. 2).

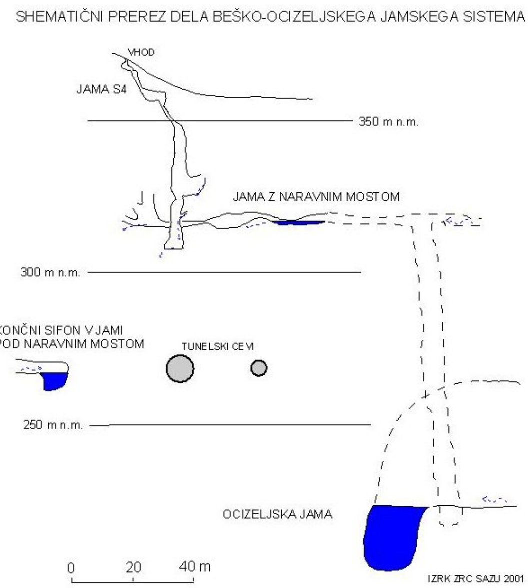

Fig. 1: Planning of the railway tunnel in the area of the large cave system.

Fig. 2: Construction of an impermeable roadbed through a cutting where a breached cave has been walled off.

During the motorway construction after earthworks uncovered the karst surface and in places the roadway is cut deeper into it or rocks excavated by tunnels, numerous karst caverns opened (Figs. 3, 4, 5) reflecting the development of aquifer. We investigated all the caves, we studied sediments and flowstone in them and we tried to preserve more important ones as caves are an important part of our natural heritage. These researches supplemented new knowledge related to formation and evolution of karst. In particular important are new achievements related to roofless caves and to their shape on the karst surface which can be usefully applied by planning new road sections. According to new experiences we may recognize them on the karst surface even before the earthworks started.

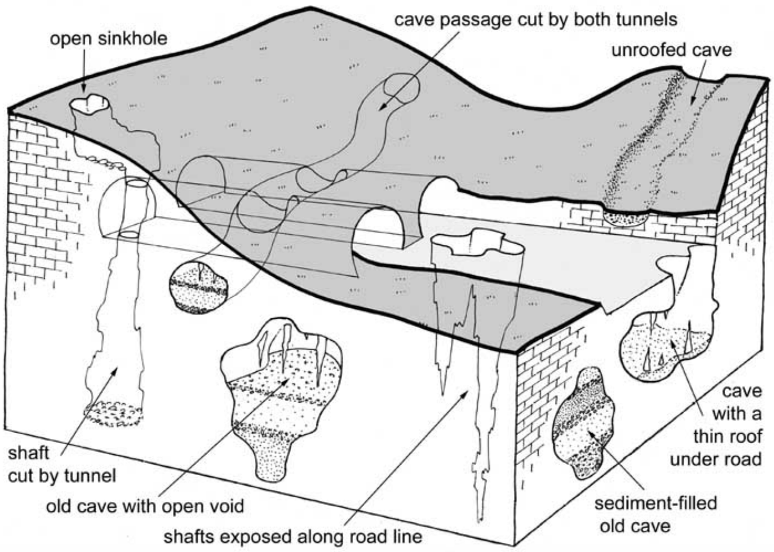

Fig. 3: Various forms of caves, sinkholes and shafts that can be encountered during construction of cuttings and tunnels for motorway.

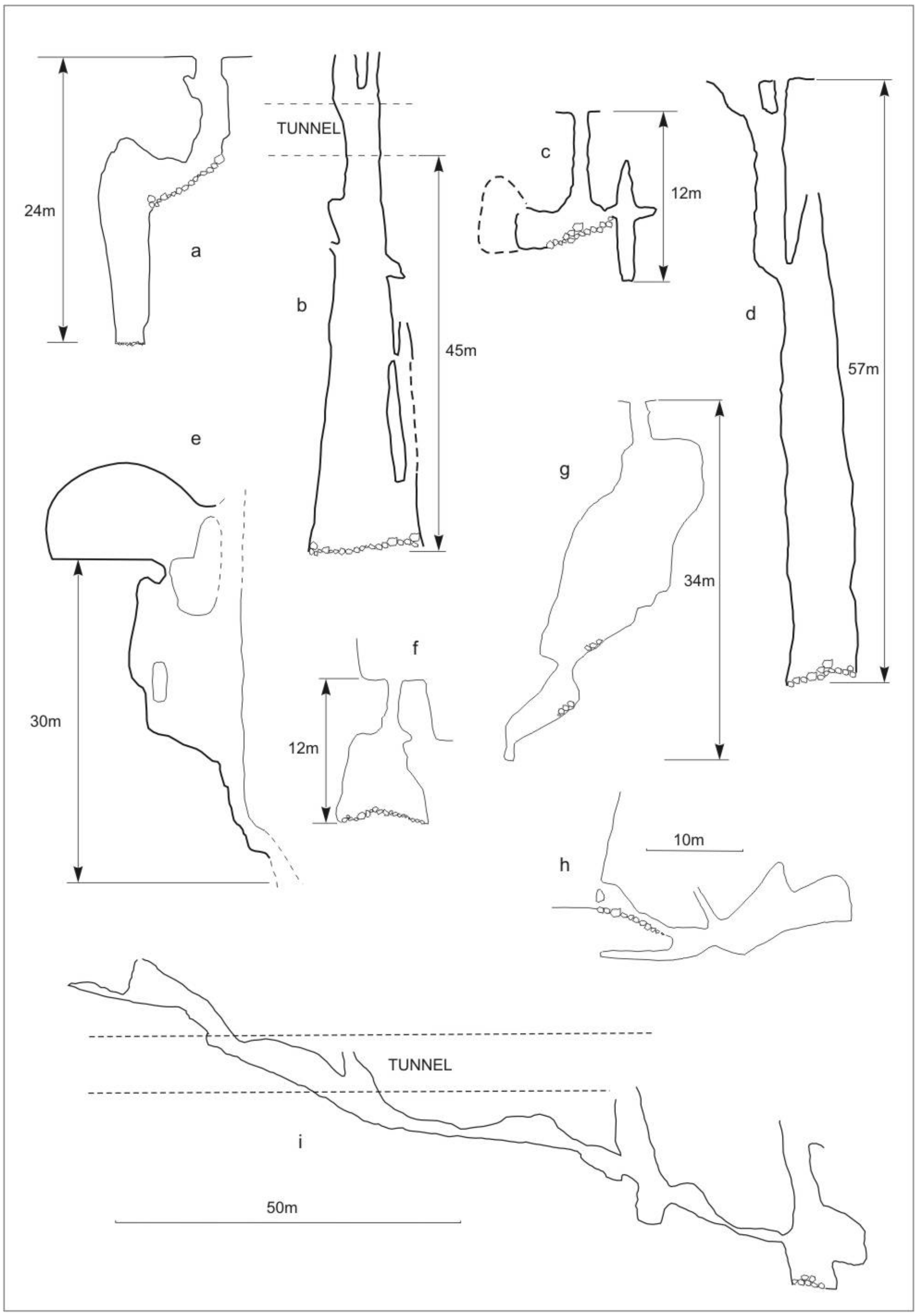

Fig. 4: Cross-sections of discovered caves during motorway construction.

As has been stated the cooperation of karstologists at motorway construction on karst is useful. It is important that we are involved both in planning and in construction, and, of course, in later control of impacts of motorways on the environment which means an integral impact on the sensible karst landscape. In such a way the control is reasonable, the natural heritage is safeguarded, basic knowledge of origin and development of karst augments and construction of motorways in a delicate karst environment is less hazardous. Different types of karst are known and each one requires a proper approach, this is why the cooperation with builders must be permanent and simultaneous. In the last ten years this cognition is largely put into effect in Slovenia and cooperation between planners - builders and karstologists may serve as a model example also at future planning and realization of other interventions in karst.

Fig. 5: Entrance to a newly discovered cave.

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