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KRASOSLOVNI ZBORNIK

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2nd and 3rd International Karstological School

"CLASSICAL KARST"

Postojna, 1994 and 1995

2. in 3. Mednarodna krasoslovna šola

"KLASIČNI KRAS"

Postojna, 1994 in 1995

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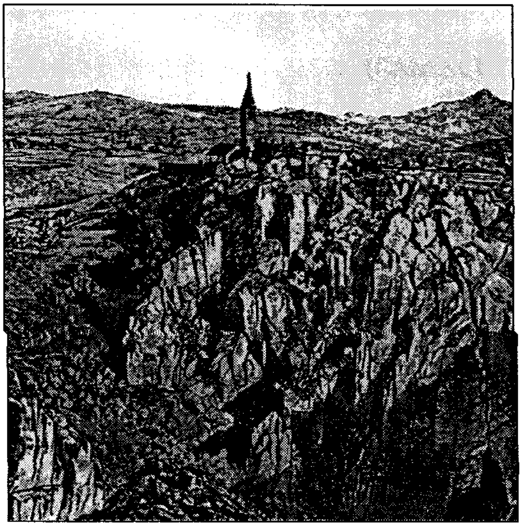

2. in 3. Mednarodna krasoslovna šola

"KLASIČNI KRAS"

Postojna, 1994 in 1995

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VSEBINA

UVODNIK

Pobudnik mednarodnih krasoslovnih šol "Klasični Kras", ki jih od leta 1993 pripravlja in vodi Inštitut za raziskovanje krasa ZRC SAZU iz Postojne, je Slovenska nacionalna komisija za UNESCO.

Do sedaj so sodelavci inštituta pripravili štiri mednarodne krasoslovne šole. Četrta je bila junija letos. S pestrim programom šol želijo približati krasoslovje širšemu krogu ljudi, od študentov in strokovnjakov do vseh ljubiteljev krasa. Tema prve krasoslovne šole so bile površinske in podzemeljske značilnosti klasičnega krasa, predvsem Kras, druge kraška polja, tretje vrtače, četrte pa brezna.

Dosedanjih krasoslovnih šol so se udeleževali strokovnjaki z vsega sveta: iz Rusije, iz cele Evrope, ZDA in celo iz Japonske. Skupaj se je zbralo prek 150 raziskovalcev iz 12 držav. Na teh krasoslovnih šolah so predstavili preko 70 strokovnih prispevkov. Med predavatelji so bili tudi ugledni akademiki in profesorji krasoslovja. Dopoldanske predstavitve so bile v popoldanskih urah in na celodnevnih ekskurzijah popestrene z bogatim terenskim delom in ogledom značilnosti ter znamenitosti klasičnega slovenskega krasa: Škocjanskih jam z okolico, kontaktnega krasa Brkinov, Cerkniškega, Planinskega in drugih kraških polj, vrtače nad Postojnsko jamo, na Hrušici, Trnovskem gozdu, Snežniku ter na Dolenjskem in pomembnejša brezna na Krasu.

Gradivo prve krasoslovne šole "Klasični Kras" je izšlo kot posebni separat inštitutskega zbornika Acta carsologica, letnik XXIII (1994). Gradivo Druge in Tretje krasoslovne šole pa je objavljeno v tej številki. Tisk objave predavanj s krasoslovnih šol finančno podpira tudi Slovenska nacionalna komisija za UNESCO. Četrto, letošnjo, mednarodno krasoslovnno šolo je kot del Slovenskega parka znanosti in tehnologije sofinansirala tudi Slovenska znanstvena fundacija.

Veseli nas, da ravno zdaj, ko praznuje UNESCO svojo petdeseto obletnico, velik del tega letnika Acta carsologica predstavlja gradivo z mednarodnih krasoslovnih šol "Klasični Kras". Tako tudi mi prispevamo k seznanjanju z dejavnostjo organizacije UNESCO, z duhom Združenih narodov in s Škocjanskimi jamami. Škocjanske jame namreč tudi praznujejo - letos je ravno deset let, kar so bile vpisane v svetovni seznam naravne dediščine UNESCO.

Urednik

PREFACE

The Slovene National Commission for UNESCO was the initiator of the International Karstological Schools "Classical Karst", that since 1993 have been organised and conducted by the Karst Research Institute of Postojna.

So far the co-workers of the Karst Research Institute have organised four international karstological schools. This year in June the fourth have taken place. By interesting topics they try to represent karstology to a wider circle of people, from students to experts on karst and amateurs of nature. The main topic of the first karstological school was the superficial and underground properties of the Classical Karst, the second dealt with karst poljes, the third with dolines and the fourth with shafts..

Experts from all over the world attended the karstological schools; they came from Russia, the whole of Europe, United States of America, and even from Japan. Altogether more than 150 researchers from about 12 countries have taken part. At the fourth karstological schools more than 70 professional papers were presented. Among the lecturers were distinguished academicians and professors of karstology. The morning presentations were complemented by extensive field work, either in the afternoon or during the whole day by visiting the sites and famous sights of the Classical Karst such as Škocjanske jame and vicinity, the contact karst of Brkini, the karst poljes of Cerknica, Planina and others, the dolines above Postojnska jama, on Hrušica, Trnovski gozd, Snežnik and Dolenjska, and the important shafts of the Classical Karst.

The papers held at the First Karstological School "Classical Karst" were published in a special off-print from the Institute's periodical Acta carsologica, volume XXIII (1994). The material of the Second and the Third one is published in the present Acta carsologica. The printing expenses of the papers from the karstological schools are sponsored by the Slovene Commission for UNESCO. The fourth international karstological school was co-financed by the Slovene Scientific Foundation within the frame of the Slovene Park of Science and Technology.

We are very glad that just now, when the UNESCO is celebrating it's 50th anniversary, the great part of the present volume of Acta carsologica consists of the material of our international karstological schools "Classical Karst". Thus we are contributing to promote UNESCO activities, the spirit of United Nations and Škocjanske jame. Also Škocjanske jame have an anniversary - 10 years being on the UNESCO list of World's natural heritage.

The editor

AKAD. DR. JOŽE BOLE (1929 - 1995)

Po dolgotrajni in težki bolezni je 26. decembra 1995 umrl akad. dr. Jože Bole, doma in v svetu priznan in spoštovan biolog in naravoslovec, član uredniškega odbora zbornika Acta carsologica (od 1983 pa do smrti) in član oziroma predsednik znanstvenega sveta postojnskega Inštituta za raziskovanje krasa (1983 - 1994).

Raziskovanje podzemeljskih mehkužcev mu je bila vseskozi rdeča nit, ki ga je vodila po številnih jamah nekdanje Jugoslavije. Pridružil se je pionirjem speleobiologije, ki so začeli sistematično raziskovati in odkrivati zakonitosti podzemeljskega življenja. V bogati znanstveni poti je prispeval pomemben delež k svetovni znanosti na področju malakologije in speleobiologije. Izjemno je bilo njegovo poznavanje problematike kopenskih in sladkovodnih mehkužcev in povezovanje le te z drugimi vejami znanosti, kot so hidrologija, krasoslovje in druge. Njegovo raziskovalno in znanstveno delo je bilo usmerjeno v malakofavno, posebej še v problematiko podzemeljskih mehkužcev.

Rodil se je 17. junija 1929 leta v Ljubljani. Diplomiral je 1953 na Prirodoslovno-matematični fakulteti Univerze v Ljubljani. Jeseni 1954 leta se je zaposlil v Biološkem inštitutu Medicinske fakultete, kjer je delal do leta 1959. Še istega leta je bil sprejet na Inštitut za biologijo Slovenske akademije znanosti in umetnosti kot asistent pri akad. dr. Jovanu Hadžiju, kjer je delal vse do upokojitve. Doktorsko nalogo z naslovom "Morfološki, ekološki, taksonomski in filogenetski problemi naših subteranih gastropodov" je zagovarjal 1960. leta v Ljubljani. Naslednjega leta je bil izvoljen za znanstvenega sodelavca in 1972 za znanstvenega svetnika na Biološkem inštitutu Jovana Hadžija. V dopisnega člana Slovenske akademije znanosti in umetnosti je bil izvoljen 1977 leta. Redni član Slovenske akademije znanosti in umetnosti pa je postal 1985 leta.

Od 1973 do 1987 je bil upravnik Biološkega inštituta Jovana Hadžija. Bil je tajnik Medakademijskega odbora za floro in favno Jugoslavije, urednik zbirke "Catalogus faunae Jugoslaviae", urednik Razprav IV. razreda SAZU, urednik zbornika Acta carsologica, član znanstvenih svetov Biološkega inštituta Jovana Hadžija, Inštituta za raziskovanje krasa in Paleontološkega inštituta Ivana Rakovca ter član izvršnega odbora Društva biologov Slovenije.

V več kot 60 znanstvenih razpravah in drugih znanstvenih prispevkih je razpravljal o taksonomskih, filogenetskih in zoogeografskih problemih mehkužcev (polžev in sladkovodnih školjk) z malakološko pomembnejših območij v Sloveniji in nekdanji Jugoslaviji. Vnesel je nove poglede v ekološko klasifikacijo podzemeljskih vrst polžev. Razvoj vrstno bogate in zaradi endemitov svojevrstne favne mehkužcev z zahodnobalkanskega območja je razložil glede na geomorfološka dogajanja v preteklosti. Opisal je več kot 40 novih vrst in podvrst. Na podlagi anatomskih odkritij je marsikateri vrsti določil nov položaj v sistemu.

Ogromen je njegov prispevek k svetovnemu poznavanju podzemeljskih vodnih in izvirskih vrst polžev iz družine Hydrobiidae. Zelo odmevno je bilo tudi odkritje podzemejske školjke *Congeria kusceri*.

Vrednost njegovega raziskovalnega dela se odraža s številnimi citati njegovih del v najpomembnejših svetovnih malakoloških in zooloških znanstvenih revijah. Velik je tudi njegov prispevek pri reševanju problemov varstva narave.

Z referati je sodeloval na številnih mednarodnih kongresih in zborovanjih (mednarodni speleološki kongres na Dunaju (1961), Jugoslovanski speleološki kongres v Splitu (1958), Sarajevu (1962), Skopju (1968), Lipici (1972), kongresa biologov Jugoslavije v Beogradu (1962) in v Ljubljani (1969), simpozij biosistematikov v Rovinju (1974) ter na mnogih zborovanjih slovenskih jamarjev in raziskovalcev krasa.

Jože Bole se je uveljavil tudi kot odličen pisec poljudno znanstvenih člankov (Naše jame, Planinski vestnik, Proteus, razni vodniki,...) ter kot avtor številnih odličnih ilustracij v raznih učbenikih, ključih za določanje živali ter znanstvenih razpravah.

Pomembno je bilo njegovo pedagoško delo. Kot izredni poznavalec malakofavne na balkanskem polotoku ter izvrsten taksonom in predavatelj, je bil mentor številnim diplomantom kot tudi doktorantom, ki so se posvetili študiju mehkužcev.

Za raziskovalno in znanstveno delo je prejel številne nagrade in priznanja. Že kot študent je leta 1954 prejel Prešernovo nagrado. Leta 1966 je prejel nagrado iz Sklada Borisa Kidriča. Podeljeno mu je bilo tudi Jesenkovo priznanje za dosežke na biotehniškem področju, ki ga podeljujejo najzaslužnejšim slovenskim naravoslovcem.

Bil je po srcu in duši jamar. Že 1956 je postal član Društva za raziskovanje jam v Ljubljani. Od 1977 pa do 1982 leta je bil tudi član uredniškega odbora Naših jam.

Z Egonom Pretnarjem sta raziskovala v številnih jamah po dinarskem krasu nekdanje Jugoslavije. Njegovo poznavanje jam je bilo izjemno. Druženje z njim je bilo polno prijetnih presenečenj. Zelo duhovita so bila bila njegova pripovedovanja o doživetjih iz časov, ko so z velikim entuziazmom in zagnanostjo pričeli sistematično raziskovati slovensko podzemlje.

Akad. dr. Jože Bole bo zapisan v zgodovino kot človek z izjemno osebnostjo, ogromnim znanjem ter skromnostjo, ki ga je naredila velikega.

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PAPERS PRESENTED AT

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"KLASIČNI KRAS"

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MAN AND KARST

ČLOVEK IN KRAS

BRANKA BERCE - BRATKO

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Branka Berce-Bratko: Človek in Kras

V projektu Človek in Kras avtorica izhaja iz antropološke definicije kulture, predstavlja vse človekove dejavnosti in način življenja. Deli se na življenski stil, ki je oseben in odvisen od ožje kulturne identitete ter vsakdanji način življenja, ki predstavlja splošen ali biološki del, značilen za neko skupino oziroma kategorijo ljudi. To je lahko družina, socialno-ekonomska skupina, vaška skupnost ali prebivalci ene ulice. Projekt je predstavljen skozi raziskave identitete, predvsem identitete človeka in prostora, ekovasi in ekostavbarstva na konkretnem primeru za vas Žerovnica ob Cerkniškem jezeru. Ostali trije podprojekti so omenjeni v navezavi na imenovani primer. Kot rezultat te študije je bil prijavljen projekt Vzpostavitev Notranjskega parka in Biosfernega območja Notranjski Kras na program EU-Life, (1995-1997).

Ključne besede: identiteta, kras, kultura, varstvo okolja, varstvo narave, planiranje, ekostavbarstvo, biološko kmetovanje, ekoturizem.

Abstract: UDC 504.75(24)

Branka Berce-Bratko: Man and Karst

In the project Man and Karst the starting point was a man and the culture used in widest definition relevant for the cultural anthropology. The way of life and life style of people was used as terminus techniques. The basic unit is either family neibourhood, or local community. In the article the study of identity relating to man and place is presented in detail using the example of Žerovnica village for all aspects of identity. The project has different aspects dealt with in sub-projects. As a result of these studies the application to EU Programme Life was sent and approved for the Project: Establishment of Notranjski Park and Biosphere Reserve Notranjski Kras (1995-1997).

Key words: identity, Karst, culture, protection of nature, protection of environment, town and country planning, eco-housing, eco-village, bio-farming, eco-tourism.

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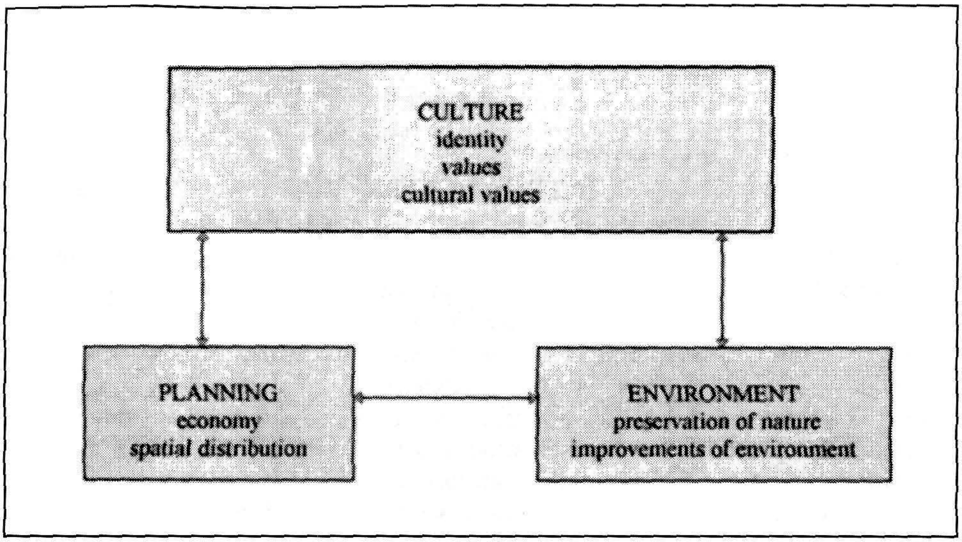
INTRODUCTION

The project Man and Karst was research based knowledge accumulated as a platform to establish nature consevation and environment protection criteria for the designation and establishment of the Notranjski Regional Park and UNESCO-Biosphere Reserve Notranjski Kras. The research of the project was inter-disciplinary, and more than twenty researcheres were involved in the project team. The basic aim was to establish the required knowledge, values and problems concerened nature conservation and development. The participation of inhabitants and the research of their culture was the main target of the study.

The research was based on identity study and understanding of culture typical for anthropology. Culture is defined from the way of life; i.e. all man's activities. The terminus techniques way of life is divided into life-style identifiable individually and typical for an individual, and every-day life defining common; i.e. biological needs representing a group, a family, a neighbourhood, a street community. The study of identity is a basic element and the key tool for methodology which is comprised of culturological aspects in planning. For the purpose of planning the culturological concept is a model and in practical cases in planning are cultural patterns originating from the system of cultural values. Cultural values are incorporated into planning at first as a concept and in practice by the system of criteria, and values are the concept defining either individual or group. Cultural patterns are a system of norms, assessments, evaluations, knowledge, acceptability, and the environment is the identifier (M. Mead, 1970, 24, B. Berce-Bratko 1990 a) 18, B. Berce-Bratko 1993 b) 16). The system of cultural values has a direct impact on planning, originating from first phase of information gadering, phase of analyses and evaluation to the final phases of implementation. These values are criteria for the selection of possible and suitable development strategy. The culturological concept operates on a feed back basis, particularly for the proper evaluation of needs. In the preparation and adoption phase of the plan the culturological concept has indirect impact, but a direct and integral one for the procedure of planning.

The importance of culture and culturological concept in planning are evident from the scheme below representing connections between planning as a procedure and environment. The concept is integral although is limited to physical planning in Slovenia.

Scheme:



Both, nature conservation and environmental protection are closely linked to Country and Town Planning. Most of the procedures in protected areas depend on planning aspects, criteria, tools and procedures.

The protected areas have been constantly in conflict between actions of protection and development. When protection of nature and landscapes is taken as potential for development of the area in accord with Agenda 21, it represents a partnership approach to conservation and development. The step forward is made from competition to co-operation in a balanced natural and economic environment. The right for development is formalized in the Wienna Declaration on Human Rights and particularly in Action Programme 1993 from the World Conference on Human Rights - Article 10.

The *human right* to development is needed to equalize and balance required needs for development and environment for this and future generations.

The protection and conservation strategies can be incorporated into development proposals and programmes on the partnership and stewardship basis. In such approach to national and regional parks, especially to Biosphere Reserves which are based on man's culture as equal element to nature conservation, inhabitants are stewards and partners with Protection Agency. The protection of nature and environment is not a narrow discipline but is rather a process comprised of many sectors of life, including planning and identity.

In areas of special significance; i.e. protected areas, among those are the most important national and regional parks, the nature conservation identity is of prime importance and equals to habitats, red list of flora and fauna, and culture of man - inhabitants of the area. The core of this identity are: bio-diversity of species and landscapes including culture. The former one is expressed in different kind of identity: personal, regional, economic, spatial-identity of place, societal, social, and cultural proper identifying the most important ones.

IDENTITY OF PEOPLE AND PLACE

The spatial identity is divided into local and regional identity. Regional identity on the level of cultural region defined by local identity coprised of proper local identity, social economic and cultural proper. The cultural patterns are the higher level of the regional identity. Local identity is a physical identity of the place; i.e. settlement, village and cultural landscape of the place. The physical identity is comprised of these elements: settlement morphology, architectural and building identity. Particular archetypes of houses are either values or problems. The quality of local identity is highly dependent on local-spatial identity as a part of local cultural identity. Social identity is the identity of social environment in the area. On regional level is expressed as inter-neighbour relations, self help and friendliness among inhabitants of the area. The quality of social identity mainly depends on the capacity of social identity. Economic identity are all the economic relations and activities in the area, local economy, economic organisation scheme within spatial and societal identity. Proper cultural identity is on individual level based on traditions and change of the society and is expressed by the life style of an individual and groups in the area. Spatial-identity of place, societal, social, economic and cultural proper identity are pointers and criteria for the comparative evaluation of settlements and areas on the basis of expert assessment which is an evaluation of the area by anthropologist-ethnologist.

The identity of place and people is integral, continuous and changing with generation and culture. The aim of this research is to have a solid base for preservation of culture in the area and proper development as a part of the human rights campaign, particularly the one of Article 10 and 11 of the Action Programme 1993. For this purpose of partnerships in development and conservation the expert assessment of places on the basis of their culture-identity is introduced. The method was developed as a qualitatively originated quantitave tool.

Expert Assessment

The area selected was assessed by following categories:

1. ECOLOGICAL BALANCE

ecological balance is comprised of spatial deteriorations and vulnerability of the environment to be affected.

2. THE CAPACITY FOR SANITATION-RESTORATION-RENATURATION (SRR)

The SRR capacity is comprised of socio-economic capacity of inhabitants, particularly important is the psychological capacity, the capacity to use and acquire knowledge, and economic potentials as a sintetic criteria for technical, psychological and the state of preparation for sanitation, restoration and restoration.

3. THE LEVEL OF DEVELOPMENT OF IDENTITY

The level of development depends on:

3.1. local-spatial identity
3.2. architectural identity
3.3. architectural pollution
3.4. capacity of social identity
3.5. capacity of cultural identity

4. LOCAL IDENTITY

The local identity is a sintetic pointer comprised of the average from categories 3.1 to 3.5.

5. THE LEVEL OF VULNERABILITY

The pointer showing how vulnerable and the level of flexibility for different development proposals.

6. DEVELOPMENT POTENTIAL OF THE AREA-COLLECTIVE ASSESSMENT

The development potential is a sintetic pointer comprised of average value of ecological balance and capability for SRR and the value of local identity. All mentioned pointers are assessed by a mark from 0 - 100. All of them have critical value- a threshold. The value below threshold are pointing to limitations of development and values above the threshold level are incentives for development.

CRITICAL VALUES - THRESHOLDS

1. ECOLOGICAL BALANCE (60)
2. CAPACITY FOR SANITATION-RESTORATION-RENATURATION (SSR)

CAPACITY FOR (SRR) (50)
3. IDENTITY (50)
3. 5.THE LEVEL OF DEVELOPMENT OF CULTURAL IDENTITY (70)
4. LOCAL IDENTITY (50)
5. THE LEVEL OF VULNERABILITY (50)
6. DEVELOPMENT POTENTIAL OF THE AREA (50)

These critical values allow us to evaluate and compare different settlements in terms of their capacity for the development. In this manner twenty settlements were evaluated. Among them the Žerovnica Village had the highest score in all elements of identity, including the final development potential assessment, and therefore this village was selected as a pilot example for all six aspects of the project MAN AND KARST carried out in sub-projects.

Example of Assessment for the Žerovnica Village:

Žerovnica Village at Cerkniško lake was assessed by expert evaluation according to critical values.

CRITICAL VALUES - THRESHOLDS
1. ECOLOGICAL BALANCE (60)
2. CAPACITY FOR (SRR) (50)
3. IDENTITY (50)
3. 5.THE LEVEL OF DEVELOPMENT OF CULTURAL IDENTITY (70)
4. LOCAL IDENTITY (50)
5. THE LEVEL OF VULNERABILITY (50)
6. AREA DEVELOPMENT POTENTIAL (50)

Conclusions and guidelines from the assessment for Žerovnica:

Village has a relatively high local identity, particularly the architectural identity. The level of architectural pollution in general is low. The two most important factors for a positive development in the future are relatively very high; the capacity of cultural and social identity which both are rather unique for the area around the Cerkniško lake. The development potential mark is the highest in the region and therefore has the best chances for the development of tourism and economy related to cultural heritage preservation and development of nature conservation aspects of every-day life in the place.

• level of damage to identity	33
• level of vulnerability	98
• ecological balance	75
• capacity for SRR	67

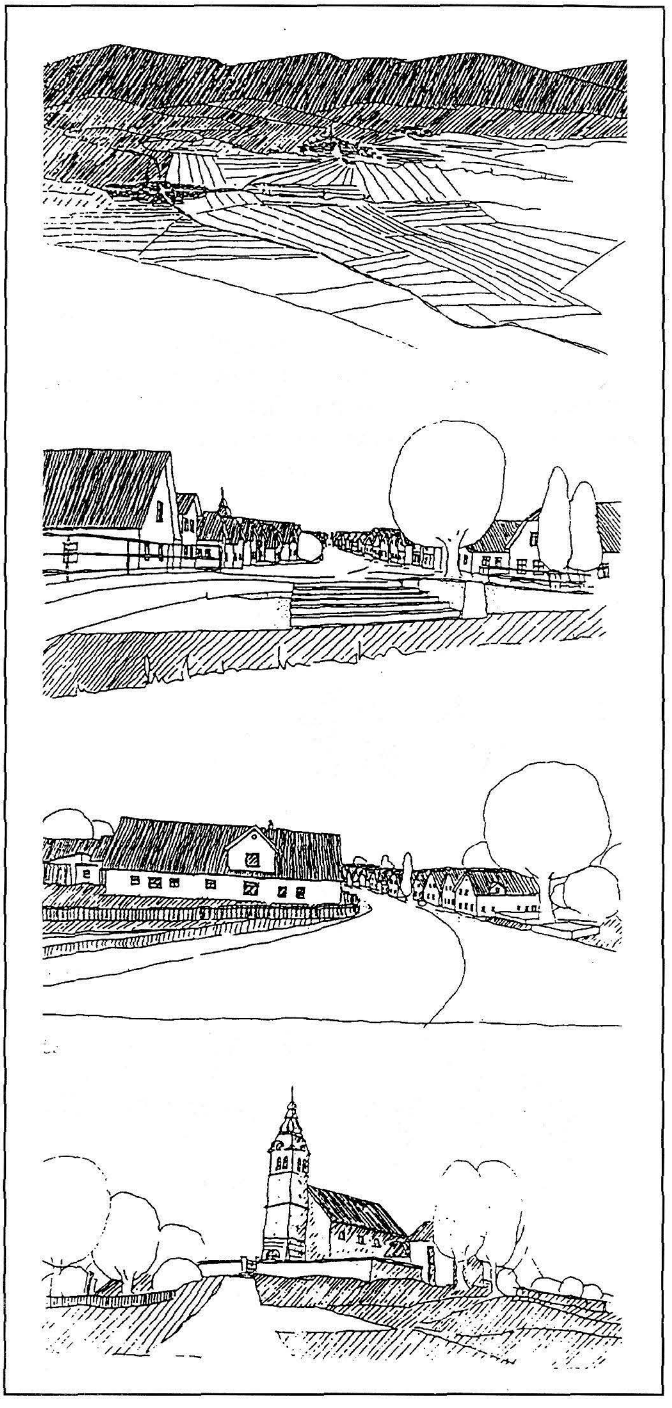
The Level of Development of Identity

• local-spatial identity	83
• architectural identity	73
• architectural pollution	25
• capacity of social identity	79
• capacity of cultural identity	92
LOCAL IDENTITY	75

DEVELOPMENT POTENTIAL OF THE AREA -
- COLLECTIVE ASSESSMENT 63

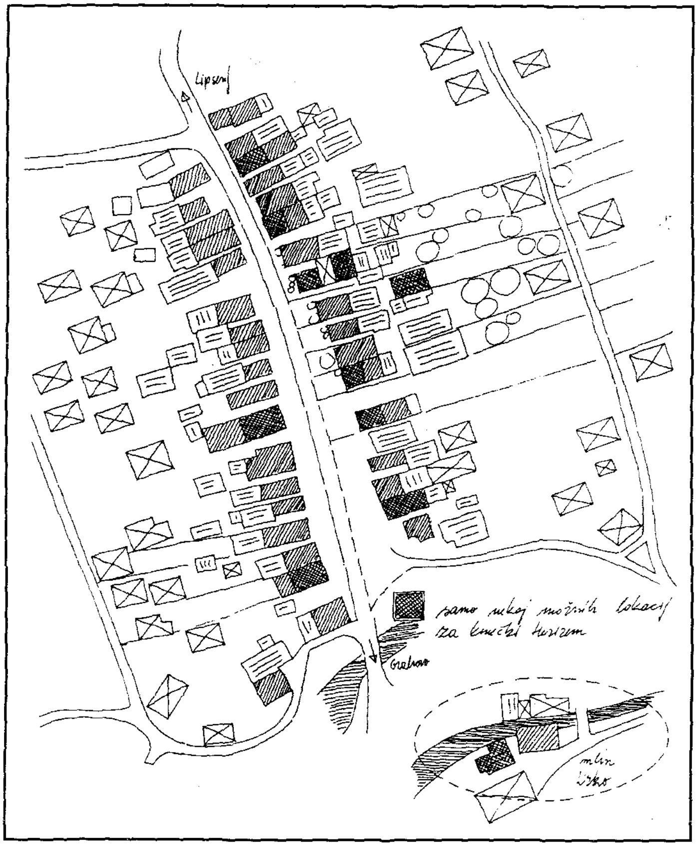
ECO-VILLAGE

The research of ecologially balanced urban development of settlements harmonised with land use. The majority of inhabitants are traditional farmers, they have in operation some mills which need to be re-introduced along the bank of Žerovnica stream. The particular emphasis was given to energy conservation in traditional village, organisation of buildings and village as settlement, farm production, market place and housing and social environment. See the illustration (P. Gabrijelčič) of wider and inner settlement below:



ECO-HOUSING

The main purpose of this kind of identity was to establish the design criteria of architecture, particularly for the vernacular one. The hypothesis was that people in that area were living sustainable, and we can re-discover and re-introduce the patterns of sustainable living in this area of special nature conservation importance. The result of the research were design guidelines for local plans, building permits and availability of some pilot housing designs for rehabilitation of buildings and built environment in villages which served as pilot examples. For Žerovnica detailed analyses were made for: the morphology, land use, inner spaces use, organisation of space, the quality of built environment. From the graphics below it is evident what are the site-seeing rarities and particulars of the settlement. The Žerovnica Village is particular in the morphology of the settlement beside the main village street. The organisation of farm and mills is also unique to the Žerovnica Village. See the illustration below (P. Gabrijelčič):



ECO-AGRICULTURE OR BIO-FARMING

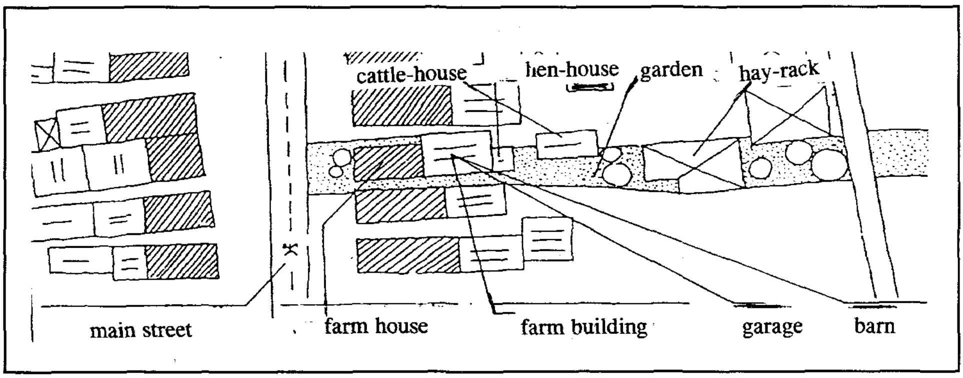
In this research we evaluated different farming methods, economic aspects against nature conservation, legislative background in the country and abroad. Assessment of traditional and industrial farming in the Notranjska region with special emphasis on Cerkniško lake region as a protected region with limited and bio-farming production methods to be permitted in the place.

The legislation on industrial farming was studied and comparisons made to suggestions and requirements for agriculture in Agenda 21.

The map was produced were the qualitative data and natural resources and obstacles were identified for agricultural use. Industrial farming is damaging to the area, therefore traditional farming methods and agricultural endemic sorts of plants and their yearly distribution was studied.

The result of the study were general and special guidelines for traditional and bio-farming with proposals for the legislation to change and a Reader on bio-farming in Notranjski park was prepared.

The traditional organisation of space, housing environment and farm production utilities space is illustrated below for the Žerovnica Village (P. Gabrijelčič).



CONCLUSIONS

The eco-sanitation project dealt with infrastructure and Eco-tourism pilot examples were developed. For conclusion we can state the achievements, i.e. results of the project.

The final result of the project were maps on:
- agricultural use,
- homogeneity of the proposed Notranjski Regional Park,
- place names,
- settlement patterns of the region,
- eco-tourism farms to be developed.

The legislation change was presented for agriculture and Country and Town Planning and Design Guidelines.

The method of participation and formation of partnerships was suggested according to in-depth identity study of people and places.

Conservation and preservation strategies were suggested in order to gain public support for the designation of the area as Regional Park.

Proposal to the European Union Life Programme was made for the Project: ESTABLISHMENT OF THE NOTRANJSKI REGIONAL PARK AND UNESCO BIOSPHERE RESERVE NOTRANJSKI KRAS.

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MAN AND KARST - ČLOVEK IN KRAS

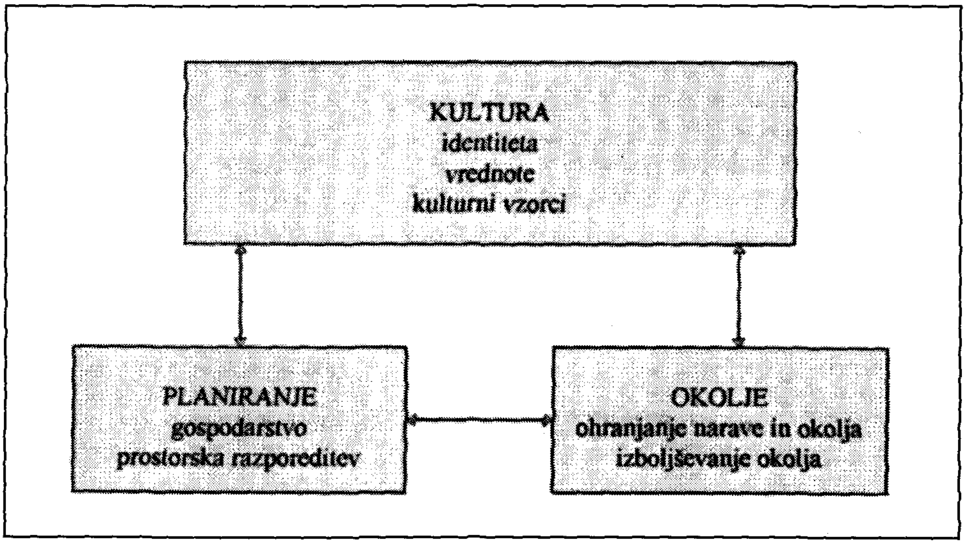
Povzetek

V projektu ČLOVEK IN KRAS smo izhajali iz najširše definicije kulture, in sicer antropološke definicije. Kultura predstavlja vse človekove dejavnosti in jo lahko enačimo z načinom življenja. Le ta se deli na življenski stil, ki je oseben in je odvisen od ožje kulturne identitete ter vsakdanji način življenja, ki predstavlja splošen ali biološki del, ki je značilen za neko skupino oziroma kategorijo ljudi. Ta skupina je lahko družina, lahko je socialno-ekonomska skupina, ali pa vaška skupnost ali pa prebivalci ene ulice.

Preučevanje identitete ljudi in prostora v območjih posebnega pomena kot so zavarovana območja je pomembno zaradi ugotavljanja pripravljenosti prebivalcev območja, da sprejmejo park kot del njihovega načina življenja in gosodarjenja s prostorom. Preučevanje identitete v najširšem pomenu te besede, ki zajema: osebno, krajevno, lokalno, regionalno, prostorsko, socialno, gosporarsko, ožje kulturno in širše kulturno identiteto. Le to navezujemo na planiranje in urejanje prostora, ker bodo zavarovana območja, ki nimajo kategorije nacionalnega parka v največji meri odvisne prav od prostorske zakonodaje in pravil igre ter kontrole, ki bodo veljale v navezavi na urejanje prostora.

Kot metodološko podstat uporabljamo kulturološki koncept, in sicer kulturološki koncept za planiranje. Znotraj planiranja je kulturološki koncept model za posamezne praktične primere pa se pojavlja kot sistem kriterijev. Kot kriteriji rabijo kulturni vzorci, le ti pa izvirajo iz sistema kulturnih vrednot. Pomembost kulture znotraj procesa planiranja so razvidne iz okrnjene sheme povezav med planiranjem in okoljem, ki ga razumemo integralno, čeprav je trenutno pri nas okrnjeno na zgolj fizično planiranje.

Shema:



V območjih posebnega pomena je pomembna naravovarstvena identiteta, ki je istovetna s habitati in s seznamom zaščitenih vrst ter rdečih seznamov flore in faune.

Bistvo te identitete predstavlja biološka raznovrstnost in endemičnost vrst. S tovrstno identiteto se ukvarjajo naravovarstveniki in naravovarstvene službe.

Skladno z mednarodno sprejetimi konvencijami se naslanjamo na "RIO 1992" in njeno Agendo 21:

1. socialno-ekonomski razvoj mora biti ustrezen razmeram družbene skupnosti,
2. zagotovljeno mora biti varovanje naravnih virov (resursov),
3. zagotoviti moramo okrepljene socializacijske funkcije - partnerstva,
4. razvoj mora slediti kriterijem trajnostnega razvoja (načini naj sledijo ciljem).

Iz tega izhaja, da sta točki 1. in 4. osnovi za planerja in pravni sistem družbe - države.

Sklicujemo se tudi na Dunajsko Deklaracijo in Akcijski program, 1993 na Svetovni konferenci o človekovih pravicah, kjer je pravica do razvoja ena temeljnih človekovih pravic točka št. 10... "Kot je določeno v Deklaraciji o pravici do razvoja, je človekova osebnost središčna točka razvoja. Države morajo medsebojno sodelovati pri zagotavljanju razvoja in odpravi ovir za razvoj. Trajni napredek v smeri uresničevanja pravice do razvoja terja učinkovite razvojne politike na državni ravni, pa tudi enakopravne gospodarske odnose in ugodno gospodarsko okolje na mednarodni ravni." Ter v točki št. 11... "Pravico do razvoja je treba uresničiti zato, da bi enakopravno zadostili razvojnim in ekološkim potrebam sedanjih in prihodnjih rodov." Torej varstvo okolja ni samostojna disciplina, mora pa biti sestavni del vseh sektorjev življenja in dela, in s tem tudi planiranja.

V vseh šestih podprojektih projekta ČLOVEK IN KRAS smo skušali preko raziskav različnih oblik identitete, in sicer v ekokmetijstvu ali biološkem kmetijstvu, ekostavbarstvu, ekovasi postaviti temelje kulturološkega vidika planiranja in soudeležbe in partnerstva prebivalcev in drugih akterjev prostora, ki so pomembni za uspešno delovanje zavarovanega območja bodisi narodnega bodisi regionalnega parka, ki ga razglaša država oziroma parlament. Ta del smo nadgradili z infrastrukturnim podprojektom o ekosanaciji in ekoturizmu. Slednji je poleg kmetijstva in gozdarstva, najpomembnejša dopolnilna gospodarska dejavnost v zavarovanem območju.

Zastopamo stališče, da sta področji varstva in razvoja v nasprotju samo takrat, ko ju gledamo "sektorsko" po posameznih vejah konservatorstva, ko pa pogledamo varstvo kot razvojni potencial nekega območja ob omejitvah, ki nam jih nalagajo naravovarstveni režimi in sprejete mednarodne konvencije, pa je mogoče varstvo vkomponirati v strategijo trajnostnega razvoja in menimo, da je tako pojmovano varstvo možno izvajati preko sistema celostnega in odprtega planiranja. Na teh območjih pa žal veljajo tudi resorni zakoni, poleg Zakona o urejanju prostora.

Ines Ožbolt

MENTAL PERCEPTION OF THE KARST

From the work in the project of Notranjski Park the difference between general perception in a certain area and the perception of same area on individual levels is clearly evident.

Where spatial managment or planning is concerned the mental image is ignored, although it is well known that the particular image is of vital importance for the people living in the area. This is the main reason that we propose the preliminary study of the perception of the place from the point of view of the inhabitants and visitors before any planning procedures take place.

The perception in one of the basic functions of mans orientation in a place and has great impact. Its importance should be considered in the procedure of physical planning.

The identity of territory has impacts on visual and sensual perception of specific area.

The Notranjski Park has great diversity of landscapes and is interesting either for research or exploration in the view of professionals responsible for the establishment of the Park. The project begins with the testing of karst landscape. One method is used for the entire area of Notranjski Park. We intend to determine, weather the karst, as a land, has an identity of it is own which is different from the identity of other regions both in the natural and social point of view. We intend to determine, whether the people of this region differentiate their home from other landscapes both visualy and mentally. It also concerns us, how karst is interpreted by the natives and the tourists and what are the differences between the impressions of professionals and others.

The participants of the International Karstological School will be asked to fill in questionnaires on recognition and mental image of the karst. They will represent the first pilot group, the one representing professionals, second group are visitors, the third are indigenous people.

Task of the project:
- to establish the existence or non-existence of difference between mental image of the karst phenomena and other geological features and areas.
- to establish which are basic expressions interconnecting the karst as such and the karst phenomena,
- to establish the mental image of the Notranjski Park according to their professional experience and knowledge,
- to evaluate the karst as the place of pleasant or non-pleasant experiance,
- to establish which elements of the karst are the most important for its recognition; elements of macro-reliefs or micro-reliefs,

- to establish the existence or non-existence of differences between mental images among three pilot groups.

Method used:
1. "knowledge questionnaire" (open and closed questions)
2. scales of measures for cognition (semantic differental)
3. association test
4. photo questionnaire

Sample:
Group of professionals (people researching or studying karst)
Group of visitors (enthusiasts, tourists enjoying the karst)
Group of indigenous people (people living in the karst area perceiving it as home environment).

Procedure:
The results will be reached by questionnaire, which is the same for all pilot groups with contents: knowledge, association, perception, recognition and assessments.

Results:
Mathematical and statistical methods will be used to generate research result and to establish the level of achieved aims (factor- analysis, variance analysis with F test used...).

Bojan Žnidaršič

GEOGRAPHICAL NAMES IN NOTRANJSKI PARK

As the basis for the research in the area of Notranjski Regional Park computer aided data base was formed in which available geographical names were used a base. All parameters important for the context and statistics of geographical names ware analytically assessed.

Particular names ascribed by people were either for the purpose of orientation or rational - logical organisation of space. For the purpose of this particular research project two divisions were made:

- visual (structure and relief)
- substance (structure and quality).

The most important characteristics (i.e.use of place) are evident in place names. Nomination of names for certain parts have different background as they have continuing history and could be ascribed to different circumstances as well. Geographical names represent the use of the place, predominantly its use in the past. As such they are a part of a cultural heritage.

In the introduction the purpose of the research was presented as well as the hypothesis. The applicability of such kind of the research in different levels was evaluated. In the disposition of the research the contents of inventory phase and analytical levels chosen were justified.

Following the description of the procedure the detailed structuring of parameters was presented. The method of data collection and assessments pursued were described precisely. The instructions are given for relations and connections of geographical names in the data base.

All important parameters are evaluated (there are 72 parameters), 11 content, structures: level of altitude, exposition, use, partitions, peaks, valleys, waters, microrelief features, routes, settlements, objects - buildings.

The main part of the research consists of contents analysis by statistical assessments. The findings are shown in graphs and charts, in five charts all available geographical names (5392) are stated, different names of places (4446) and the difference between those two categories (946). The Chart of most common place names and the chart of "naming" diversity of places was produced (149). With the help of 14 graphs the percentage of each parameter were presented.

The summary of inventory work used as the basis for the continuation of the research - second phase definition. Three new substances were suggested: spatial, socio-economic and linguistic. In the first phase one of the possible structural results is presented.

For the one of the possible structure research the study of the impact for the karst phenomena on naming geographical places. Therefore for the second International Carstological School the research results are summarized, and geographical names steaming from karst phenomena are presented. As a starting point was a question: where, how much, and with which elements of the area studied the karst phenomena appear as the basis for naming the places. This way 306 names based on karst phenomena were identified.

The study has appendix supporting the transparency of the approach, summary and literature used, where all available bibliography is collected. The aim of the study was to put together all available knowledge, experiences, and achievements of all authors dealing with this particular problem of geographical names in Slovenia.

HYDROLOGY OF THE GRADOLE KARST SPRING (ISTRIA - CROATIA)

HIDROLOGIJA KRAŠKEGA IZVIRA GRADOLE (ISTRA - HRVAŠKA)

OGNJEN BONACCI

Izvleček UDK 551.435.85 (497.5)
556.36 (497.5)

Ognjen Bonacci: Hidrologija kraškega izvira Gradole (Istra - Hrvaška)

Prispevek predstavlja rezultate hidroloških analiz izvira Gradole. Glavni namen raziskav je bil določiti meje in obseg zbirnega področja, da bi lahko zavarovali kakovost vode. Podzemeljska razvodnica je določena z geološkimi in hidrogeološkimi metodami. Za kontrolo je bila uporabljena analiza vodne bilance. Obseg zbirnega območja je bil določen na 104 km^2. Voda izvira Gradole se uporablja kot vir pitne vode. Pretok izvira je omejen in ne presega 12 m^3/s. Višek vode priteka na površje skozi občasne izvire v soseščini. Minimalni, srednji in maksimalni pretoki 1987-1992 so: 0.28 m^3/s, 1.8 m^3/s, 8.68 m^3/s. Napravljen je bil poizkus, da bi v suši dodatno napolnili kraški podzemeljski vodonosnik.

Ključne besede: kraška hidrologija, kraški izvir, Hrvaška, Istra, Gradole

Abstract UDC 551.435.85 (497.5)
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Ognjen Bonacci: Hydrology of the Gradole karst spring (Istria - Croatia)

The paper discusses the results of a hydrologic analysis of the Gradole karst spring. The main goal of the investigations was the determination of the catchment boundaries and area in order to protect the spring water quality. The underground watershed has been determined by geologic and hydrogeologic methods. The control used was the hydrologic water budget analysis. The catchment of Gradole spring is defined as 104 km^2. The Gradole spring water is used as a drinking water supply. The capacity of the spring is limited and does not exceed 12 m^3/s. All discharges which exceed this amount flow to the surface through other intermittent springs in the vicinity. Minimum, average and maximum discharges in the 1987-1992 period are: 0.28 m^3/s, 1.8 m^3/s, 8.68 m^3/s respectively. In dry period an attempt to recharge the karst underground aquifer was made.

Key words: karst hydrology, karst spring, Croatia, Istria, Gradole

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INTRODUCTION

The Gradole karst spring is located in the northern part of the Istria peninsula (Fig. 1) in Croatia. It is an ascending or vauclusian karst spring (Flandrin and Paloc, 1969; Bögli, 1980; Bonacci, 1987; Bonacci and Magdalenić, 1993). Since 1973, the water from the main Gradole spring has been used as a water supply. The water demand in this area is increasing due to the intensive development of tourism. Human activities in the catchment area have increased which has resulted in serious pollution threats to the present high quality of the groundwater. Consequently it has been necessary to carry out investigation to define the catchment area and its boundaries.

The Gradole spring belongs to a group of karst springs with limited outflow capacity (Bonacci and Magdalenić, 1993). These springs have a maximum discharge limited by the dimensions of karst conduits, especially their exits. Therefore, a few temporary karst springs generally appear immediately after heavy rainfall which causes a sudden increase in the groundwater levels in the catchment. At least two of these springs have been found in the vicinity of the Gradole spring. Their hydrologic hydrogeologic function is to accept the excess discharge of the main Gradole spring during a short period with high and sharp flood hydrographs. It has been stated that these temporary karst springs appear when the outflow discharge exceeds 6 m^3/s, which occurs once in five years.

There are no permanent open streamflows in the Gradole spring catchment. Intensive rainfall is followed by the short-lasting flows whose water quickly sinks underground through the large karst fissures. The average elevation of the catchment is 330 m a. s. l., and the opening of the Gradole spring is at 4.6 m a. s. l. The inflow to the spring is formed exclusively by underground water circulation through a karst aquifer.

The whole hydrological analysis performed in this paper is based upon data on the discharge measurements carried out during a six-year period from 1987-1992. The available data refer to the rainfall measurements carried out in the immediate vicinity of the catchment from 1949-1992, the water temperature measurements from 1957 to 1962, and the air temperature measurements from 1950-1992. The study also includes data on pumping and quality of drinking water from 1980-1992.

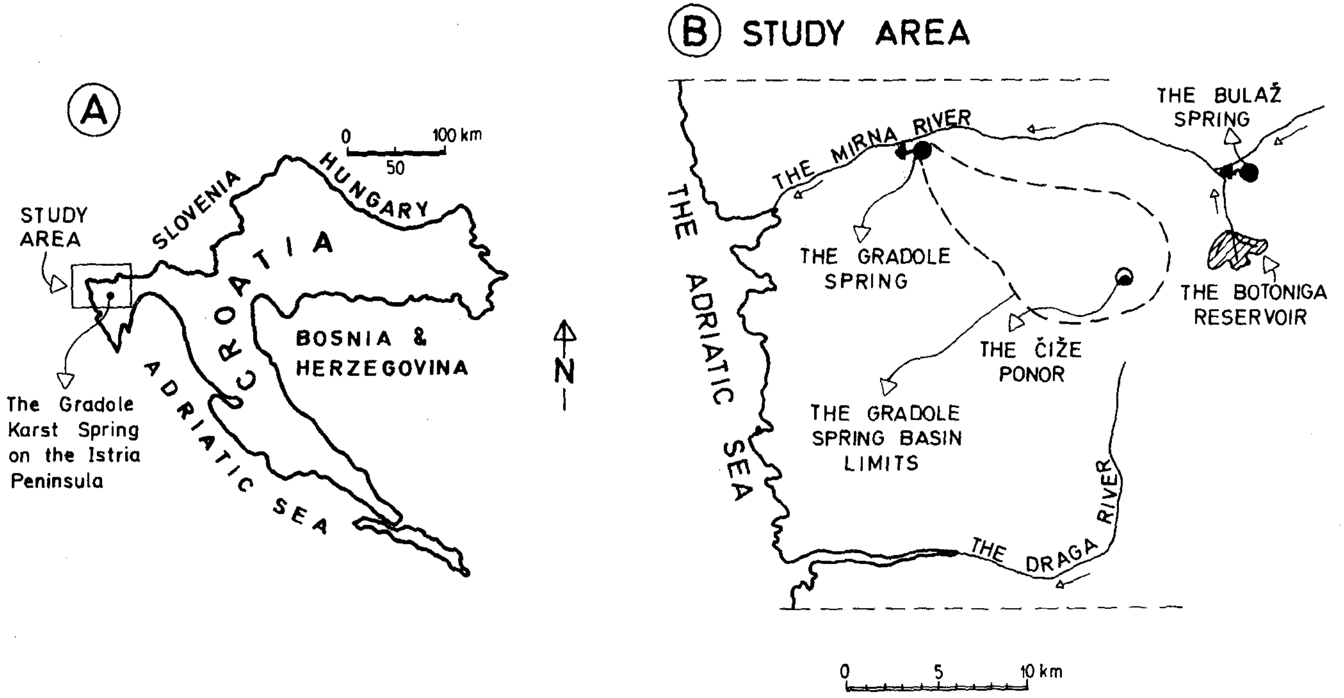

Figure 1 LOCATIONS MAPS

GEOLOGY, HYDROGEOLOGY, CLIMATOLOGY AND WATER TEMPERATURE

The Gradole spring catchment is mainly formed of carbonate rocks and partly of impermeable flysch (Magdalenić and Bonacci, 1993). The carbonate layers differ in age, lithological composition, bedding and in their structural-tectonic position. A great number of the faults, fissures, sinkholes and shafts exist in the carbonate layers which are very permeable to water. The main direction of circulation is SE-NW, towards the Mirna river (Fig. 1b) which corresponds to the direction of the structures and main fault systems.

The number of sinkholes varies within the boundaries of the catchment. It is estimated there are on average 20 sinkholes per square kilometer. Tracings of the Čiže ponor (Fig. 1b), on several occasion during low and high ground water levels, have proved that this ponor is directly connected to the Gradole spring. The ponor is 14.5 km from the spring. Various types of tracers thrown into the Čiže ponor appeared at the Gradole spring with 92 % to 100 % of the initial quantity. The velocity of the tracer ranged from 0.33 cm/s is the dry period to 3 cm/s in the wet period (Magdalenić, 1988). The time necessary for the tracer to reach the spring in the wet period, when the aquifer was saturated, was from 10 to 18 days, and in the dry period through the unsaturated aquifer it took the tracer about 90 days to travel to the spring. By geologic and hydrogeologic analyses it was possible to determine that the catchment area of the Gradole spring covers 104 km^2. About 85 km^2 is covered by carbonate rocks and 19 km^2 by flysch layers (18 % of the entire area).

The climate of the catchment is North Mediterranean. The average annual temperature is 11.1°C with a minimum daily average temperature in December-February period of -2°C and a maximum average temperature in July and August of 30°C. There are six pluviographs in the vicinity of the catchment. The annual rainfall in the period from 1949-1992 ranged from a minimum of 769 mm in 1956 to a maximum of 1569 mm in 1960. The average annual rainfall is 1132 mm. The maximum rainfall occurs in November and the minimum in July.

The water temperature of the main Gradole spring varies from 11.6 to 15.2°C. The extreme air temperature range in this region is 40°C. Since the water temperature in the spring varies around 3.6°C it is evident that air temperature affects the water temperature very little or only indirectly. This is consistent with the idea that the groundwater in karst underground conduits is retained for a long period of time.

At the Gradole spring it is possible to monitor the quality of the untreated and treated water (Buttignoni, 1990). The water turbidity ranges from 10 to 2000 NTU. The pH value varies from 7.2 to 7.3 and in the rainy period is reaches 8. The total hardness ranges from 17.4 to 19.6 dH. Chlorides vary from 10 to 28 mg/l Cl and sulphates from 8 to 43 mg/l SO_3. The water is transparent during the great part of the year and it is very turbid only during short periods after abundant and intensive rainfall.

HYDROLOGIC ANALYSIS

Table 1 presents the characteristic discharges measured at the Gradole spring. The ratio between the minimum and maximum annual discharges ranges from 1 : 9.9 to 1 : 22.3, which confirms that it is a karst spring with a balanced hydrologic regime. This balance can be explained by the fact that the volume of the underground karst aquifer is large in comparison to the catchment area.

Ord. numb.	Year	Q [m^3/s]	Q_{min} [m^3/s]	Q_{max} [m^3/s]	Q_{min} : Q : Q_{max}
1.	1987	1.87	0.45	5.92	1 : 4.16 : 13.2
2.	1988	2.15	0.45	5.61	1 : 4.78 : 12.5
3.	1989	1.21	0.28	4.50	1 : 4.32 : 16.1
4.	1990	1.45	0.51	5.05	1 : 2.84 : 9.90
5.	1991	1.93	0.39	8.68	1 : 4.95 : 22.3
6.	1992	2.18	0.43	6.15	1 : 5.07 : 14.3
7.	Average	1.80	0.42	5.99	1 : 4.29 : 14.3

Table 1: Characteristic Discharges of the Gradole Spring.

Further analysis includes the study of the increase in the discharge hydrographs (ΔQ) caused by rainfall (P) in the spring Gradole catchment. Figure 2 gives a graphical presentation of this relationship for the 1987-1992 period. It can be seen that the intersection of the line $\Delta Q = a + b \times P$ with the x axis is $P_0 = 12$ mm which suggests that rainfall below this quantity does not lead to an increase in the spring discharges. Generally a rainfall quantity below 12 mm (up to 50 mm in dry period) is evidently retained underground in the karst. Assuming that the catchment is 104 km^2 the total volume which can be retained in the karst aquifer, in average conditions, is estimated to range from 1.3 x 10 m^3 to 5.2 x 10 m^3.

The lowest measured discharge was 0.28 m^3/s. It occurred on February 26-27/1989, after an eight-month drought with only 30 % of the average rainfall. It should be noted that there was no rain during eighty days in the period

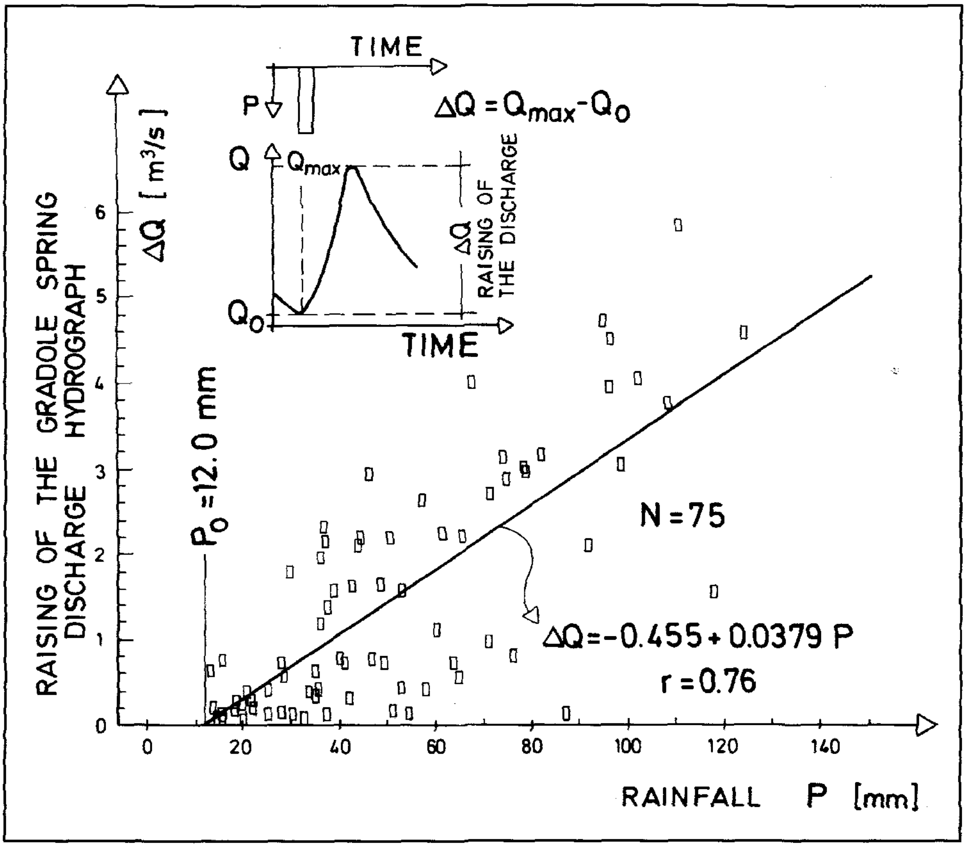

Fig. 2: Raising of the Gradole spring discharge hydrograph ΔQ versus rainfall P in 1987-1992 period

from December 1988 to February 1989. Considering the drought intensity and that these low water discharges appeared in the winter period, which is otherwise wet, the discharge of 0.28 m^3/s can be regarded as close to the absolute minimum. It is probable that the low water levels of the Gradole spring hardly can go below 0.25 m^3/s.

In order to satisfy the water supply demand it is necessary to ensure a quantity of 1.00 m^3/s, particularly in the dry summer period during the tourist season. Table 2 presents the values of the minimum discharges Q_{min} for each month from 1987-1992 and the average number of days N with discharges lower than 1.00 m^3/s.

It can be concluded that the greatest problem in the water supply occurs in August at the peak of the tourist season. Therefore a pipeline 17 km long has been built which delivers untreated water from the Bulaž spring to the Gradole spring where it is pumped and chemically treated. In addition, water was delivered twice to the Čiže ponor from the Butoniga reservoir through the component pipeline about 3 km long. Figure 1 shows all these springs, ponors and reservoirs. Bonacci (1992) described the effects of recharging the karst aquifer of the Gradole spring by delivering water to the Čiže ponor.

Month	Q_{min} [m^3/s]	N [day/month]
Jan.	0.33	10.0
Feb.	0.28	6.7
Mar.	0.77	4.8
Apr.	0.97	0.16
May	0.72	2.2
Jun.	0.67	7.0
Jul.	0.72	12.8
Aug.	0.52	20.5
Sep.	0.46	20.0
Oct.	0.43	17.5
Nov.	0.39	9.2
Dec.	0.45	5.16
Year	0.28	116.0 day/year

Table 2: Minimum Discharges of the Gradole Spring per Month Q and the Average Number of Days N per Month with a Discharge Lower than 1000 l/s. Measured from 1987 to 1992.

The available hydrometric data measured during a six year period did not make it possible to draw detailed and reliable conclusions related to the high water levels of the Gradole spring. It was mentioned in the introduction that this spring belongs to a group of karst springs with a limited maximum outflow capacity. Such springs are frequent in the Dinaric karst. The maximum annual discharges ranged from 4.5 m^3/s in 1989 to 8.68 m^3/s in 1991. These maximum discharges are too low for a catchment covering an area of 104 km^2 and for the rainfall in that area. For example the maximum discharge at the Bulaž spring, with an area of 105 km^2, reaches 40 m^3/s. The catchment of the Bulaž spring is only 15 km from the Gradole spring so that their climatic and geologic characteristic are almost identical. The only significant difference is that the Bulaž spring does not belong to springs with limited outflow capacity. The dimensions of its outflow opening (exit) do not represent an obstacle for releasing the greatest discharges caused by heavy rainfall in the catchment. Consequently, there are no temporary springs in the vicinity of the Bulaž spring, whereas there are at least two of these springs located near the Gradole spring. Their discharges cannot be measured at high water levels since the entire area is flooded during that period 1987-1990. In 1991 they appeared only briefly and the water volume discharged through them is estimated to be about 1 % of the total annual volume of the Gradole spring. In 1992 the water volume released from the temporary springs did not exceed 5 % of the total annual volume of the Gradole spring.

A simple and approximate hydrological approach was used in an attempt to determine the catchment area of the Gradole spring since a lot of necessary hydrologic data were not sufficient. A catchment area defined in this way must either confirm or question a catchment area defined by geologic and hydrogeologic analyses. Srebrenović (1970) and Bonacci (1988) used regional analyses, proving that the average annual runoff coefficient for flysch is 0.35 and for carbonate rocks 0.6. Considering the previously mentioned sections of the Gradole catchment area, it can be stated that its average runoff coefficient is:

$$\bar{\alpha} = 0.35 \times 0.18 + 0.60 \times 0.82 = 0.555$$

The average annual rainfall in the Gradole spring catchment in the 1987-1992 period was P = 941 mm and the average annual discharge in the same period was Q = 1.8 m^3/s. Using the expression for the runoff coefficient which is:

$$\bar{\alpha} = \frac{\bar{Q}}{(\bar{P}xA/t)}$$

where A expresses the catchment area and t the time of one year duration. When the expression is derived in the function of the catchment area A expressed in km^2, and after all units have been brought into accordance, by introducing the previously stated values for rainfall P and measured discharge Q, the following catchment area can be defined:

$$A = \frac{1.8x(86400x365)}{0.941x0.555x1000^2} = 108.7km^2$$

This value confirms the value defined by geologic and hydrogeologic analyses. It can be stated that hydrologic analysis confirmed the results obtained by geologic and hydrogeologic investigations.

CONCLUSIONS

The Gradole spring is a karst spring with a limited outflow capacity. Springs with similar discharge characteristics are frequently found in the Dinaric karst. The limited capacity results from the dimension of the outflow karst conduit. Consequently, intensive rainfall in the vicinity of the Gradole spring is followed by the appearance of several temporary springs. Hydrologic analyses have been performed over a relatively short (six-year) period between 1987-1992. Due to the short measurement period certain data, particularly those related to extremely dry or wet conditions are not sufficiently reliable. This refers in particular to the maximum discharges of the Gradole spring. The highest measured discharge was 8.68 m^3/s. It is assumed that in the most extreme conditions the discharges can reach 12 m^3/s and that this value can hardly be exceeded. The minimum discharge which occurred in February 1989, i. e. 0.28 m^3/s, is probably close to the absolute minimum.

The ratio between the minimum, average and maximum discharges ranges from 1 : 2.84 : 9.9 to 1 : 5.07 : 22.3 which confirms the large capacity of the karst aquifer of the Gradole spring.

The catchment area determined using geologic and hydrogeologic investigations (A = 104 km^2) was confirmed by simple and approximate hydrologic computation (A = 108.7 km^2).

The water supply demand during the tourist season amounts to 1000 l/s. In the warm period of the year, i. e. in the tourist season from July to September, the number of days with discharges smaller than 1000 l/s is greater than in any other time of the year, and it ranges from 12.8 to 20.5 days per month. The water shortage during those periods is solved by delivering water from the Bulaž spring to the Gradole spring and from the Butoniga reservoir to the Čiže ponor.

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HIDROLOGIJA KRAŠKEGA IZVIRA GRADOLE (ISTRA - HRVAŠKA)

Povzetek

Gradole je kraški izvir z omejenim pretokom. Izviri s podobnimi pretočnimi značilnostmi so v dinarskem krasu pogosti. Zaradi dimenzij kraškega prevodnika so količine pretoka omejene. Zato se po intenzivnih padavinah v okolici Gradol pojavi več občasnih izvirov. Hidrološka opazovanja so potekala razmeroma kratek čas (6 let), 1987 - 1992. Zaradi kratkega časa opazovanj so nekateri podatki, predvsem tisti, vezani na izredno sušo ali izredno namočeno leto, nezanesljivi. To se nanaša predvsem na maksimalne pretoke Gradol. Največji izmerjeni pretok je bil 8.68 m^3/s. Domnevamo, da se v izjemnih razmerah ta količina lahko poveča na 12 m^3/s, ta vrednost pa najbrž ne more biti presežena. Minimalni pretok je bil februarja 1989, 0.28 m^3/s, kar je najbrž blizu absolutnega minimuma.

Razmerje med minimalnimi, srednjimi in maksimalnimi pretoki je med 1 : 2.84 : 9.9 in 1 : 5.07 : 22.3, kar potrjuje velike kapacitete kraškega vodonosnika, ki napaja izvir Gradole.

Z geološkimi in hidrogeološkimi raziskavami določeno zaledje (A = 104 km^2) je bilo potrjeno s približnim hidrološkim izračunom (A = 108.7 km^2).

Med turistično sezono je potreba po vodi okoli 1000 l/s. V toplem letnem času, to je v turistični sezoni od julija do septembra, je število dni s pretokom pod 1000 l/s večje, kot v drugem delu leta in sicer med 12.8 do 20.5 dni na mesec. Pomanjkanje vode v tem času rešujejo tako, da v Gradole dovajajo vodo iz izvira Bulaž, iz rezervoarja Butoniga v ponor Čiže.

THE EVOLUTION OF KARST AND CAVES IN THE KONĚPRUSY REGION (BOHEMIAN KARST, CZECH REPUBLIC) AND PALEOHYDROLOGIC MODEL

PALEOHIDROLOŠKI MODEL RAZVOJA KRASA IN JAM V KONĚPRUSYH (ČEŠKI KRAS, ČEŠKA REPUBLIKA)

PAVEL BOSÁK

Izvleček UDK 556.3(437.1)

Pavel Bosák: Paleohidrološki model razvoja krasa in jam v Koněprusyh (Češki kras, Češka republika)

Z novim modelom paleohidrološkega razvoja jam v Koněprusyh je treba opustiti stari model, po katerem naj bi se jamski "nivoji" razvijali neprekinjeno, v skladu z razvojem teras ob glavnih rekah, od miocena dalje. Model "spuščajočega zakrasevanja" je treba zamenjati z modelom "zakrasevanja navzgor", ki temelji na globoki freatični cirkulaciji kraških voda tekom glavne faze razvoja jam v paleocenu spodnjem miocenu. Dviganje kraških voda je povzročala hidravlična bariera (nariv), ki omejuje sinklinalno zgradbo proti severu.

Ključne besede: paleokras, paleohidrogeologija, razvoj krasa in jam, Koněprusy, Češki kras, Češka republika

Abstract UDC 556.3(437.1)

Pavel Bosák: The evolution of karst and caves in the Koněprusy region (Bohemian Karst, Czech Republic) and paleohydrologic model

The new paleohydrological model of the evolution of caves in the Koněprusy region abandons up to now model based on the continual development of cave "levels" in accordance to the evolution of the terrace system of main rivers since Miocene. Descending model of karstification is substituted by the "ascending" model based on deep phreatic circulation of karst water during the main phase of cave evolution in Paleocene-Lower Miocene. Upwelling of groundwater was caused by hydraulic barrier (overthrust) limiting synclinal structure at the north.

Key words: paleokarst, paleohydrogeology, karst and cave evolution, Koněprusy region, Bohemian Karst, Czech Republic

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INTRODUCTION

The Koněprusy region is typical by special facies development of the Lower Devonian of the Barradian Basin. The reefal and organodetrital Koněprusy Limestones (Pragian) is overlain by the Suchomasty Limestones (uppermost Zlíchovian to Dalejan), Acanthopygae Limestones (Eifelian) and siliciclastics of the Srbsko Formation (Givetian, Chlupáč et al. 1992). Limestones show good lithification in the stage of deep burial to weak metamorphosis. The are folded into the system of open synclines and squeezed anticlines, often with overthrusts. Tectonization by faults and fissure systems is dense.

Up to now, the origin and development of karst forms in the whole Barradian region has been connected with the evolution of the terrace system of main rivers, i.e. Berounka and Litava Rivers and their paleoequivalents. The origin of caves has been linked with especially with the Quaternary geomorphological cycle.

The evaluation of exploration in the Koněprusy region (1952 to 1993) and of the speleological investigation of active and old quarries brought some new knowledge and interpretation possibilities (Bosák 1993) for the whole Barrandian Basin, whose limestones landscapes are known as the Bohemian Karst.

KARST FORMS IN LANDSCAPE AND BOREHOLES

Since 1950, totally 329 fully cored boreholes have been drilled, from with a total length of about 20 km. In them, more than 420 of karst cavities have been discovered concentrated in about 23 detectable altitudinal levels between 470 and 125 m a.s.l.! (Bosák 1993).

Register of the Czech Speleological Society contains total of 64 caves in two karst region. Karst region No. 11 contains 39 numbered caves, together with the larges caves in the region - the Koněpruské Caves with 2 km of passages. Karst region No. 18 totals of 25 numbered caves. From that number only 14 caves have been found by the speleological activity outside quarries.

The presence of caves in the northern part of the region, in the Zlatý Kůň Hill, is concentrated to the belt situated somewhat to the S-SW from the line of the Očkov ovethrust, limiting limestone outcrops. There are situated not only the Koněpruské Caves developed in 3 levels, but also about 19 smaller caves in levels corresponding to the middle and lower levels of the Konìpruské Caves. Caves in other smooth hills (Na Voskopì, Plešivec) are relatively small. The common feaures of all smaller caves can be summarized as follows: (1) they are more or less isolated without distinct known interconnection, (2) they have character of upward blind and inclined phreatic channels or irregular phreatic corrosional spaces. The part of caves is completely colmated by sediments as old as Upper Sarmatian to Lower Pliocene (Horáček 1980a, b).

Karst features in boreholes can be characterized into several categories: (1) *karst cavities*, i.e. space mostly filled with sediments - reworked Upper Cretaceous and Tertiary deposits and in situ Tertiary and Quaternary deposits, sometimes with speleothems. Only small percentage of cavities is completely or partially empty; (2) intergranular karstified carbonates represent in situ decomposed wackestone and grainstone into calcareous sandy eluvium during very intensive process deeply below the base level; (3) karstified zones, without detailed specification are reprezented by widened fissures, bedding planes or cracks, often representing the epikarst zone; (4) infiltration kaolinization when the carbonate rocks is altered to clayey-silty material by in situ cold metasomatosis with the transport of clayey-silty particle during calcite dissolution as a result of aggresive water percolation under wet-hot climate on the surface, and (5) epigenetic reddening caused by weathering processes and Fe transport. The process was tectonically controlled and influenced by lithology/porosity and its products occur in distinctive levels as the marker of fossil piezometric levels. The terms intergranular karstification, infiltration kaolinization and egigenetic reddening were introduced by Bosák, Cílek and Tipková (1992) and explained by Cílek, Bosák and Bednářová (1995).

KARST EVOLUTION

Evolution of karst forms has a long lasting trend. Here, only basic points will be summarized, having connection with discussed problem or influencing younger karstification "efforts".

Devonian

Local paleokarsts originated during Lower to lower Middle Devonian. Freshwater vadose and phreatic karstification was connected with reef emersions and the origin of freshwater lens. Several phases can be dated to the interval of Pragian (Lower Devonian) to Givetian (Middle Devonian). Originated macroporosity (vuggy and cavern types) was filled with clayey dolostone to dolomitic claystone, dark coloured (Bosák 1993). Connnected features of neptunic dikes filled with several generation of all lithostratigraphic units can be connected with blue holes of recent Bahamas (Smart et al. 1988). It seems that the system of this paleoporosity influenced all following subsurface karstification processes.

Carboniferous to Cenomanian

Pre-Cenomanian karstification period started in the Upper Carboniferous. No known subsurface karst forms have been known. There are only some relics of surface forms and sediments (kaolinic sands in depressions). The period was finished by extensive marine transgression.

Paleogene to Lower Miocene

Paleogene to Lower Miocene karstification was connected with gradual but rapid erosion of Upper Cretaceous platform sediments (siliciclastics prevail). Intensive subjacent karstification started when the Cretaceous cover was substantially thinned by intensive weathering (Paleocene and Eocene) and backward erosion to highly permeable Cenomanian sands and gravels. Ponors in multiple rank (Ford and Williams 1989) appeared at the margins of limestone subcrops and outcrops. The development of basic network of passages led in prolonged karstification period to the origin of extensive caves which presently contain various fill sometimes reworked completely. The time of cavern origin can be linked with the main phase of cave evolution defined by Bosák (1991) for the whole Bohemian Massif and dated to Middle to Upper Paleogene.

The evolution of caves was connected with prolonged periods of stabilized base level (cf. Palmer 1987) represented by the origin of extensive aluvial plains in the Bohemian Karst (Bosák, Cílek and Tipková 1992). This evolution was indicated also by older morphological analyses (e.g. Ovčarov 1973 or Lysenko 1987).

The morphology of caverns shows, that they mostly originated in the phreatic regime. The cavern shapes have typical morphological features of batyphreatic caves or phreatic caves (sensu Ford and Eweres 1978) with multiple loops, and inclined ascending and descending passages connected by shorter or longer subhorizontal tunnels or channels. Phreatic corrosional fetures and widening of channels is also typical leading to the origin of irregularly shaped smaller or larger domed caverns. The horizon equivalent to the middle level of the Koněpruské caves was later morphologically reworked at oscillating piezometric level in the vadose regime. The concentration of cave close to the thrust limit of limestones at the north is most probably caused by paleohydrogeological and paleohydraulical fetures of underground drainage and hydraulic head towards the hydraulic barrier of the Očkov overthrust. Phreatic caves discovered in quarries and boreholes represented inflow channels connecting the ponor area with the barrier along tectonic directions of N-S and W-E directions.

Miocene

The gradual diminution in the karstification can be observed. It was caused by tectonic/morphological features leading to the shift in the position of the

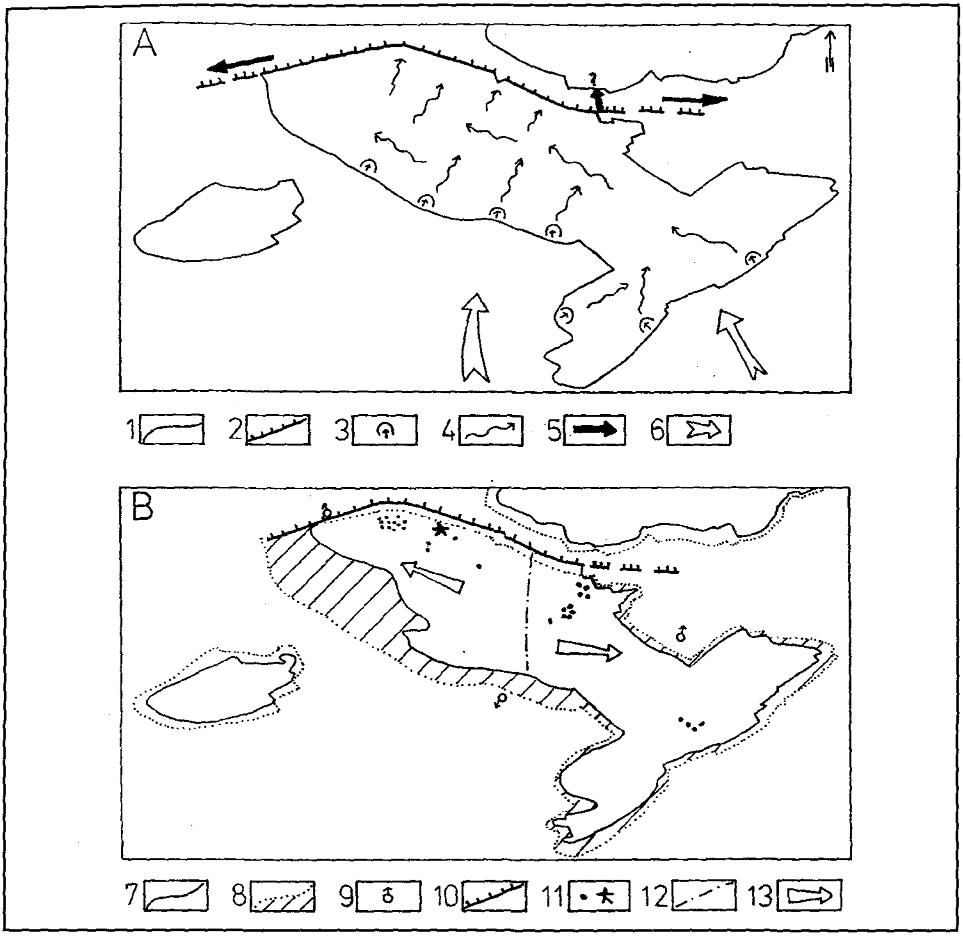

Fig. 1: Evolution of drainage in the Koněprusy region in plan

A. The main phase of cave origin; 1. limits of limestone subcrops and outcrops, 2. Očkov overthrust, 3. ponors (schematically), 4. main directions of water inflow to karst, 5. flow direction of karstwater

B. Present situation; 7. present limits of limestone outcrops, 8. limestone slope retreat, 9. karst springs, 10. Očkov overthrust, 11. caves, 12. water divide, 13. flow direction of groundwater

Sl. 1: Razvoj odtoka v Koněprusih, tloris.

A. Glavna faza nastanka jam; 1. rob apnenčevih izdankov, 2. Očkov nariv, 3. ponori (shematizirano), 4. glavne smeri vodnega odtoka v kras, 5. smer toka kraške vode

B. Sedanje stanje; 7. sedanje meje apnenčevih izdankov, 8. odmik apnenčevih pobočij, 9. kraški izviri, 10. Očkov nariv, 11. jame, 12. razvodnica, 13. smer podzemeljskega toka piezometric level. Gradual decrease of the base level led to the fossilization of some of inflow channels, the evolution of vertical connections and vadose invasion caves. The main periods of fossilization can be dated since upper Middle Miocene (Sarmatian and younger colmatage of Oligo-Miocene caves). Younger caves were connected with mixing corrosion under further about two to three phases of the stabilization of broad alluvial plains. Large lakes

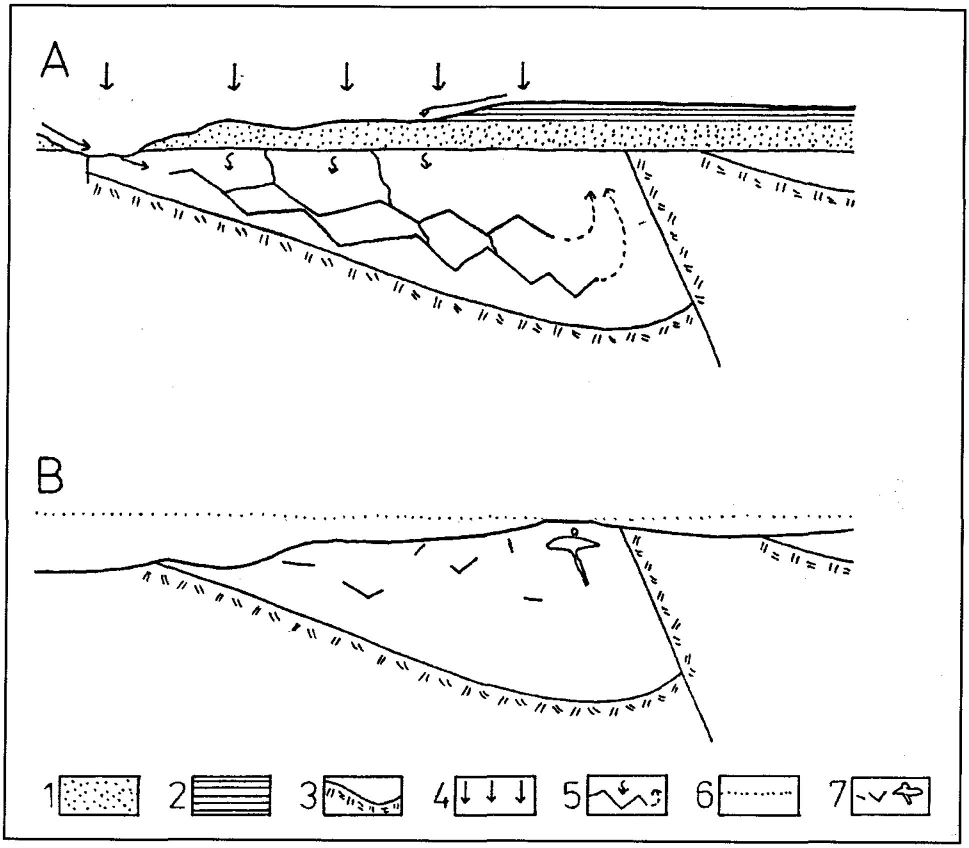

Fig. 2: Schematic section of the syncline structure of the Koněprusy region in the time of the main phase of cave origin
1. Silurian and Devonian limestones, 2. Cretaceous siliciclastics, 3. Očkov overthrust, 4. ponors, 5. groundwater circulation paths, 7. caves (known at present)

Sl. 2: Shematski prerez sinklinalne strukture Koněprusev v času glavne faze nastajanja jam
1. silurski in devonski apnenci, 2. kredni silikatni klastiti, 3. Očkov nariv, 4. ponori, 5. poti podzemeljske cirkulacije, 7. jame (znane danes)

developed in caves. Some older ones were dissected and somewhat displaced by neotectonic movements (Ovčarov et al., unpubl. 1972).

Pliocene to Early Pleistocene

The continuing fossilization with Middle Pliocene and Biharian phases is typical for this phase.The last neotectonic movements are dated back to Biharian (cca 1.1 Ma) in the Konìpruské Caves (Horáček 1980a).

Quaternary

Pleistocene to Holocene was characterized by intensive backward erosion owing to rapid entrenchment of main river of the region (Berounka) some 90 m down at the end of Biharian and by continual evolution superficial karstification (epikarst zone). Some minor caves were maybe inserted during shorter stabilization of base levels.

PALEOHYDROGEOLOGICAL MODEL

The presented paleohydrogeological model of the evolution of caves in the Konìprusy region abandons up to now prefered theory on continual evolution of cave levels in the connected with the origin of terrace river system (e.g. Hromas 1968). It is based on following postulates:

(1) The predisposed network of Lower - Middle Devonian diagenetic porosity was several times utilized by younger karstification phases influencing the space arrangement of subsurface karstification processes. Strong tectonic controll can be stated.

(2) The evolution of some karstic porosity to macroporosity during pre-Cenomanian (mostly Upper Jurassic - Lower Cretaceous) evolution of landscape cannot be completely excluded. It was connected with the stabilization of broad alluvial plains characterized by mixing corrosion of river and ground waters in limestones.

(3) The destruction of Upper Cretaceous platform sediments underwent in wet and hot climates during Paleocene to Oligocene. This was connected with the evolution of (a) ponors at margins of limestone core of synclines; (b) infiltration routes under a cover of permeable Cenomanian sediments (mostly sandstones), and (c) ponor network in multiple ranks and multiple lines at the margins of Silurian and Devonian subcroops and outcrops.

(4) The evolution of cave systems was in deep phreatic zone with cave horizons with multiple loops and local horizontal features. The cavern origin (and the karst groundwater circulation) followed main tectonic scheme, i.e. NNE-SSW to NNW-SSE tension open fractures and faults and WNW-ESE to WSW-ENE compressional faults to overthrusts. The main characteristics of caverns can be summarized as follows: (a) in areas close to ponors cave have mostly character of circular, mostly phreatic tunnels.

Their diametre increases with the distance from ponor areas, and (b) in area close to the main hydraulic barrier, caves are irregular, vertical with subhorizontal "levels". They are characterize by maze to labyrinth nature and irreular morphology of shallow phreatic to vadose lake-filled rooms.

(5) The main hydraulic barrier has been representing by the Očkov overthrust forming the NE closure of limestone syncline. It caused the upwelling of water, the increase in piezometric level and water discharged along the thrust line in NW and SE directions. The zone, tens to first hundreds of metres wide along the overthrust is typical by the absence of caves due to the compressional nature of fissure network.

(6) The evolution of lower deep phreatic cave horizons was later dependent on the decrease of piezometric level as a consequence of climate aridization and/or change of regional base level. Base level subsided due to uplift connected with Miocene volcanic phases. Old piezometric levels are marked by precipitates of Fe inside the carbonate massif. Complete removal of Cretaceous platform cover led to formation of carbonate outcrops and resulted in the retreat of limestone slopes and shift of ponors in the centripetal manner.

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PALEOHIDROLOŠKI MODEL RAZVOJA KRASA IN JAM V KONĚPRUSYH (ČEŠKI KRAS, ČEŠKA REPUBLIKA)

Povzetek

Analiza temelji na popolnih jedrih 329 vrtin v skupni dolžini okoli 20 km, na preko 420 kraških votlinah, odkritih ob vrtanjih in na 64 jamah iz registra Češkega speleološkega društva. Jame v severnem delu ozemlja so zgoščene v pasu, ki je približno severo - severozahodno od črte nariva Očkov, ki omejuje izdanke apnenca. Jame so druga od druge bolj ali manj ločene in kažejo značilnosti strmih in nagnjenih slepih freatičnih kanalov ali neenakomernih freatičnih korozijskih votlin različnih velikosti; največje med njimi kažejo sledove vadoznega preoblikovanja.

Kraške oblike kažejo dolgotrajno smer razvoja s temeljnimi fazami in periodami v devonu, pre-cenomaniju, paleocenu-spodnjem miocenu, miocenu, pliocenu do spodnjem pleistocenu in v kvartarju.

Predstavljeni paleohidrogeološki model razvoja jam v Koněprusih temelji na sledečih predpostavkah:

(1) Domnevna mreža spodnje - srednje devonske diagenetske poroznosti je bila večkrat ponovno uporabljena med mlajšimi fazami zakrasevanja in je tako vplivala na prostorsko razporeditev podpovršinskih procesov zakrasevanja. Opazen je močan vpliv tektonike.

(2) Nastanka kraške poroznosti do makroporoznosti v času, ko je nastajal predcenomanijski (največ zgornjejurski - spodnjekredni) relief, ne smemo v celoti izključiti. Povezan je bil z ustalitvijo velikih aluvijalnih ravnin, kjer je na apnence delovala mešana korozija rečne in talne vode.

(3) Razpad zgornjekrednih sedimentov platforme je potekal v vročem in vlažnem podnebju tekom paleocena in oligocena. S tem je bil povezan nastanek (a) ponorov na robu apnenčevega jedra sinklinal; (b) smeri prenikanja pod pokrovom prepustnih cenomanijskih sedimentov (največ peščenjakov) in (c) mreže ponorov v več vrstah in več nivojih na robu silurskih in devonskih izdankov.

(4) Jamski sistemi so se razvijali v globoki freatični coni z jamskimi horizonti s števila zankami in lokalnimi vodoravnimi oblikami. Nastanek jam (in kraške podzemeljske cirkulacije) je sledil glavni tektonski zasnovi, to je

SSV-JJZ do SSZ-JJV usmerjenim odprtim nateznim razpokam ter prelomom in ZSZ-VJV do ZJZ-VSV usmerjenim prelomom in narivom. Glavne značilnosti jam lahko strnemo kot: (a) na področjih blizu ponorov so okroglega prereza, pretežno freatični tuneli. Z oddaljenostjo od ponorov se njihov premer povečuje in (b) na področjih, blizu hidravličnih pregrad so jame nepravilnih oblik, navpične, s subhorizontalnimi nivoji. So mrežaste do labirintaste narave in so plitvo freatične do vadozne votline nepravilnih oblik, zapolnjene z jezeri.

(5) Očkov nariv, ki s SV strani zapira apnenčevo sinklinalo, predstavlja glavno hidravlično pregrado. Povzročil je dviganje vode, naraščanje piezometričnega nivoja in vodni odtok vzdolž narivnih črt v smeri SZ in SV. Za to cono, široko od nekaj deset do prvih sto metrov vzdolž nariva, je značilna odsotnost jam zaradi stisnjene mreže razpok.

(6) Kasnejši razvoj spodnjih globokih freatičnih horizontov je bil povezan z zniževanjem piezometričnega nivoja kot posledice sušnejšega podnebja in oziroma ali spremembe lokalne erozijske baze. Ta se je znižala zaradi dviganja ozemlja, povezanega z miocenskimi vulkanskimi fazami. Stare piezometrične nivoje označuje odloženo Fe znotraj karbonatnih masivov. Zaradi popolne odstranitve pokrova kredne platforme, so se pokazali izdanki apnencev, apnenčeva pobočja so se odmikala, ponori pa se centripetalno oddaljevali.

COMPARISON OF MORPHOMETRIC ASPECTS OF DOLINES BETWEEN TWO ZONES IN BERICI HILLS (VICENZA, ITALY)

PRIMERJAVA MORFOLOGIJE VRTAČ IZ DVEH DELOV GRIČEVJA BERICI (VICENZA, ITALIJA)

BENEDETTA CASTIGLIONI

Izvleček UDK 551.435.83(450.343)

Benedetta Castiglioni: Primerjava morfologije vrtač iz dveh delov gričevja Berici (Vicenza, Italija)

Gričevje Berici so skupina planotastih gričev nad benečijsko ravnino; na planoti so vrtače, zaradi katerih ima pokrajina svojstven značaj. Opisana sta dva različna dela gričevja in narejena je medsebojna primerjava morfologije vrtač. Avtorica nekatere razlike posebej poudarja in podaja hipotezo o vzrokih teh razlik.

Ključne besede: morfometrija vrtač, nastanek vrtač, kraška planota, kraško površje, Italija, gričevje Berici

Abstract UDC 551.435.83(450.343)

Benedetta Castiglioni: Comparison of morphometric aspects of dolines between two zones in Berici Hills (Vicenza, Italy)

The Berici Hills are a limestone hilly group rising with plateau features above the Venetian plane; on the top of the plateau many dolines have developed, giving peculiar characters to the landscape.
Two different parts of the Berici Hills have been considered, to describe and compare morphometric aspects of their dolines. Some differences between the two zones have been identified and some hypotheses about their cause are given.

Key words: morphometry of dolines, evolution of dolines, karst plateau, karst landscape, Italy, Berici Hills

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INTRODUCTION

The Berici Hills are situated in the Venetian plain, south of the town of Vicenza, in the north-east of Italy. This group is mostly formed by Eocene and Oligocene limestones (marly limestone in the west, pure and sometime massive limestone in the east); it appears like a table-land, unitary in some parts, cut into by large valleys in others. It has very steep slopes on the eastern side, while on the western it degrades more gently to the plain.

Karst morphogenesis is active on the plateau surface, and the most frequent karst form we meet is the doline. Therefore dolines represent a very important element to determine the typical characters of Berici Hills landscape; dolines are an expression both of natural environmental aspects and also of changes of human land use and impact.

Since the doline bottom is always filled by sediments (terra rossa), perhaps several tens of metres deep, it is the best place of the plateau for farming. So in the landscape we can note many scattered farmhouses, each in front of one doline; in the bottom there is cultivation or meadow, while the slopes are covered by wood. The north slope, that is exposed to the south and has better microclimatic conditions, is often used for cultivation too, with terraces supported by dry stone walls.

DATA COLLECTION

The aim of this research is to compare the features of dolines in two different parts of Berici Hills with the help of statistical analysis.

So I considered two zones of the plateau: the first (Fig. 1) is a lengthened and narrow ridge in the northern part (I called it "north zone"), while the second (Fig. 2) is a piece of the south-western table-land (I called it "south zone"). I observed all the dolines included in the two zones (34 in the north zone, 63 in the south zone), and I collected morphometric data with the help of the topographic map on the scale 1:5000.

I considered on one hand the real doline by the isohypse that passes through the lowest rim, and on the other hand the catchment-basin pertaining to the doline. Therefore I studied in particular the following variables:

- position: UTM coordinates of the lowest point of the doline, bottom altitude

- doline dimensions: longest axis length, perpendicular axis length, area, lowest depth (the difference between the rim altitude and the bottom altitude)
- basin dimensions: longest axis length, area, highest depth (the difference between the altitude of the highest point of the basin and the bottom altitude)
- distance from the nearest doline (between the lowest points).

I compiled two tables, one for each zone, with all the data collected (tab. 1 and tab. 2).

DATA PROCESSING

The first observation is about the distribution of dolines: while in the south zone dolines' catchment-basins cover completely the plateau, in the north zone they take up only the 33% of the surface. The remaining 67% of the north zone belongs to catchment-basins connected with the hydrographic network of the slopes; some suspended dry valleys are present too.

Moreover, most of dolines of the north zone are situated at an altitude between 200m and 300m, while the south zone is at a lower altitude, between 100m and 160m.

Looking at the frequency distribution histograms it is possible to make some remarks. First of all it is possible to note that dolines are generally medium-small, but they are smaller in the north zone (Fig. 3); the average values for the variable "longest axis length" are 75m in the north, 104m in the south.

It can be also noted that there are some wider dolines (perhaps uvalas), expecially in the south (Fig. 4).

Regarding (Fig. 5) the depth of the doline (lowest depth), there are no big differences between south and north zone; in both zones dolines are not very deep, with values that go from 0,3m to 12,5m in the northern sample, and from 0,4m to 14,9m in the southern one.

On the other side, catchment-basins are quite wide, and their dimensions are similar in the two zones; rather, there are bigger values for "highest depth" in the north zone (Fig. 6 and Fig. 7)

At the end, looking at the variable "distance", we note that in the south zone dolines are closer each other than in the north one; the average values are 102m south, 158m north.

The second part of the statistical anlysis consists of the correlation of the variables (with the principal components analysis), and the comparison of the results of the two zones.

It can be noted that in both zones there is a strong link between the variables "doline longest axis length" and "doline area" (correlation coefficient: 0,95 north; 0,94 south) (Fig. 8) and quite a good correlation also with "perpendicular axis length". It means that the doline shape is quite regular, nearly round, and that there are not many dolines with lengthened or different shapes.

On the contrary, doline depth is not strongly correlated with doline dimensions, especially in the south zone: wide dolines are not really correspondingly deep (Fig. 9).

There is good correlation between doline dimensions and basin dimensions in the south zone, in particular between "doline area" and "basin area"; correlation is worse in the north zone (Fig. 10): it means that it is not always true here that a large basin pertains to a large doline and vice versa.

Also the variable "distance" is differently correlated in the two zones (Fig. 11). South there is quite good correlation with doline dimensions and less good with basin dimensions; therefore smaller dolines are nearer each other. On the contrary, north there is no correlation between the distance among dolines and dimensions, and it is principally because the area is not completely covered by dolines.

CONCLUSIONS

We have seen that there are some differences in doline shape and development between north and south zone. It is possible to try to understand on what these differences can depend.

Probably we have to research the cause principally in the different lithology of the two zones: marly limestone south, back-reef limestone north. Moreover the different kind of relief landforms (plateau or ridge) can contribute to the doline characters in the two zones too.

Actually, the results of measurements allow us to say that probably doline development is more difficult in the north zone, because on a ridge more dolines are situated on the plateau edge, opened toward the plateau escarpment. So there are smaller dolines with bigger, highest depth, on this ridge, where we found higher relief energy than in the south zone. It could be possible to study in depth the reciprocal interactions between slope and doline development, between karst and, broadly speaking, fluvial morphogenesis.

Many other conditions that are involved in karst evolution are very similar in the two zones (for instance altitude, climate conditions, length of time of karst morphogenesis), so they cannot be determining factors for the identified differences.

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	long.	lat.	bottom alt.	rim alt.	high. p. alt.	dol.axis	basin axis	dol.area	bas.area	low.depth	high.depth	perp.axis	distance
1	9787	3609	319,70	320,00	358,50	45	280	1119,78	12800,00	,30	38,80	35	165
2	9795	3623	312,50	317,50	344,40	100	180	4956,88	20690,69	5,00	31,90	65	145
3	9786	3635	311,40	317,50	327,70	75	220	3032,40	12628,96	6,10	16,30	57	145
4	9815	3642	291,50	302,50	330,00	215	305	13086,91	40497,20	11,00	38,50	85	267
5	9803	3666	281,20	282,00	324,50	40	330	1131,06	44706,15	,80	43,30	33	232
6	9781	3669	272,80	285,30	325,00	175	455	15289,06	90237,55	12,50	52,20	125	203
7	9776	3689	280,00	284,00	317,50	90	240	3428,45	31145,95	4,00	37,50	55	195
8	9773	3708	283,50	284,00	317,50	65	250	1397,57	40744,30	,50	34,00	30	130
9	9782	3717	267,60	272,00	315,20	62	245	2171,45	22636,50	4,40	47,60	50	130
10	9793	3729	254,50	257,50	315,20	50	265	1637,84	28747,40	3,00	60,70	40	95
11	9799	3736	246,30	247,50	270,00	50	190	1379,84	15431,25	1,20	23,70	37	95
12	9787	3737	262,00	263,00	285,00	65	180	2215,81	15218,69	1,00	23,00	42	100
13	9750	3731	284,50	287,00	315,20	80	280	4095,01	31105,60	2,50	30,70	70	150
14	9753	3747	290,60	292,50	306,07	40	100	706,57	4713,90	1,90	15,47	25	120
15	9775	3745	269,20	271,50	310,00	85	320	2501,40	37418,20	2,30	40,80	37	135
16	9761	3755	280,50	281,00	302,00	50	125	1796,60	9207,07	,50	21,50	40	83
17	9754	3759	277,20	287,50	301,00	57	130	2080,07	6586,90	10,30	23,80	45	83
18	9783	3755	253,40	257,50	280,00	50	190	1852,93	14983,66	4,10	26,60	43	95
19	9788	3764	238,20	242,50	266,00	80	190	3378,91	16199,09	4,30	27,80	55	95
20	9731	3762	265,00	277,50	300,00	115	240	5549,36	18736,76	12,50	35,00	60	165
21	9751	3769	269,60	272,50	290,00	50	125	1641,69	9969,50	2,90	20,40	43	107
22	9744	3778	253,50	257,50	285,00	75	165	2686,15	11758,12	4,00	31,50	50	90
23	9735	3778	246,20	252,50	306,70	120	465	6457,18	55738,77	6,30	60,50	65	90
24	9758	3787	249,80	252,00	285,00	85	220	3818,15	21351,93	2,20	35,20	55	170
25	9744	3798	238,80	241,50	280,00	65	265	3035,54	22837,84	2,70	41,20	55	180
26	9698	3803	219,90	221,50	263,10	60	285	2266,51	18674,15	1,60	43,20	50	110
27	9710	3802	224,00	227,50	263,10	75	265	3504,63	17231,68	3,50	39,10	65	80
28	9716	3808	218,50	221,10	250,00	75	210	3368,83	9088,12	2,60	31,50	65	80
29	9763	3814	222,80	224,00	266,20	42	315	1267,56	48110,02	1,20	43,40	35	90
30	9766	3823	213,50	217,50	254,00	70	300	2279,95	26986,30	4,00	40,50	40	90
31	9752	3833	202,00	207,00	225,50	65	150	2443,35	12432,82	5,00	23,50	40	170
32	9758	3876	156,00	159,00	207,60	57	375	1709,48	46386,20	3,00	51,60	40	435
33	9828	3899	144,20	144,50	164,20	80	185	3314,88	16700,07	,30	20,00	50	435
34	9816	3941	105,90	106,50	111,60	40	115	996,84	6452,57	,60	5,70	30	435

Tab. 1 - Collected data for north zone

	long.	lat.	bottom alt.	rim alt.	high.p.alt.	dol.axis	basin axis	dol.area	bas.area	low.depth	high.depth	perp.axis	distance
1	9129	2710	129,8	136,5	164,1	93	270	4967	17986	6,7	34,3	70	92
2	9133	2713	137,0	139,0	148,8	60	160	2069	10274	2,0	11,8	47	85
3	9141	2714	136,2	143,0	164,1	95	275	5869	20409	6,8	27,9	80	85
4	9150	2704	147,3	147,9	164,1	50	225	1251	14877	,6	16,8	33	95
5	9159	2703	146,5	146,9	164,1	55	300	1286	15704	,4	17,6	30	70
6	9160	2696	142,3	146,9	164,1	90	350	4946	36936	4,6	21,8	75	70
7	9180	2664	125,8	132,5	172,0	135	530	9890	78744	6,7	46,2	105	140
8	9109	2800	140,5	146,5	166,0	170	410	12390	39578	6,0	25,5	100	100
9	9100	2798	144,0	146,5	159,4	72	350	3119	14706	2,5	15,4	55	100
10	9083	2798	137,7	142,0	159,4	95	260	5976	24780	4,3	21,7	80	120
11	9075	2792	134,6	138,0	152,1	85	280	4252	14591	3,4	17,5	65	85
12	9067	2791	134,1	138,0	151,0	70	200	3640	11186	3,9	16,9	65	85
13	9067	2776	125,4	132,5	141,0	92	205	6128	18838	7,1	15,6	85	65
14	9056	2775	130,0	132,5	136,7	60	130	1997	7160	2,5	6,7	45	65
15	9077	2782	132,0	133,0	141,0	50	225	1452	9779	1,0	9,0	40	90
16	9183	2776	153,2	162,0	170,0	160	260	12800	28172	8,8	16,8	100	90
17	9196	2762	157,0	164,0	172,0	85	200	5359	17203	7,0	15,0	80	115
18	9204	2752	162,8	168,0	175,9	67	135	3145	10023	5,2	13,1	62	65
19	9192	2750	151,6	162,5	170,0	125	165	9111	14023	10,9	18,4	95	95
20	9177	2754	151,0	158,5	170,0	165	240	12460	28751	7,5	19,0	110	152
21	9175	2769	156,9	159,5	170,0	90	200	3106	9621	2,6	13,1	40	85
22	9170	2776	160,7	162,5	171,0	70	150	2699	12072	1,8	10,3	50	85
23	9160	2762	147,0	155,1	174,2	150	420	10980	46168	8,1	27,2	115	162
24	9146	2755	139,0	143,0	174,2	240	430	9062	64571	4,0	35,2	57	162
25	9132	2764	140,4	143,0	174,2	140	380	7398	45475	2,6	33,8	68	105
26	9124	2782	146,4	151,0	171,3	175	300	12950	45233	4,6	24,9	110	115
27	9121	2766	143,5	147,0	155,5	60	140	2011	7648	3,5	12,0	45	105
28	9104	2755	127,8	138,0	155,5	160	350	12810	45421	10,2	27,7	110	130
29	9093	2763	124,4	135,3	150,0	125	270	11190	28633	10,9	25,6	115	130
30	9091	2780	128,7	129,5	157,1	110	280	4421	42114	,8	28,4	50	62
31	9085	2784	124,7	129,5	152,0	80	270	4404	25029	4,8	27,3	70	62
32	9075	2765	124,5	128,0	142,5	55	250	1960	19554	3,5	18,0	40	90
33	9067	2767	124,5	128,0	140,0	50	160	1804	8308	3,5	15,5	45	90
34	9064	2759	122,3	127,4	140,0	240	340	18350	46939	5,1	17,7	95	92
35	9045	2756	116,6	119,0	136,7	80	250	3669	26036	2,4	20,1	62	58
36	9039	2755	117,0	119,0	126,5	60	210	1942	13517	2,0	9,5	43	58
37	9041	2769	122,8	128,0	136,7	65	180	3086	14877	5,2	13,9	60	112
38	9035	2764	116,1	122,5	135,6	105	230	7297	17343	6,4	19,5	92	100
39	9036	2776	129,3	132,0	136,0	60	120	2143	6800	2,7	6,7	50	73
40	9028	2776	124,9	127,0	145,8	75	285	3436	20640	2,1	20,9	60	73
41	9024	2762	116,9	117,8	145,8	50	370	1075	18797	,9	28,9	30	95
42	9020	2753	111,1	114,5	124,3	70	225	2676	13733	3,4	13,2	55	100
43	9012	2759	109,7	111,5	145,8	80	470	3412	33091	1,8	36,1	63	100
44	9001	2760	105,4	106,5	137,0	48	300	704	16982	1,1	31,6	20	80
45	9072	2740	124,6	133,5	140,0	110	240	8662	19887	8,9	15,4	110	155
46	*9090*	*2736*	*117,0*	*131,9*	*144,7*	*190*	*290*	*19216*	*43446*	*14,9*	*27,7*	*130*	*170*
47	9113	2742	134,0	141,0	146,0	115	190	8173	14962	7,0	12,0	95	155
48	9130	2745	132,1	140,8	158,6	220	330	20366	58508	8,7	26,5	120	170
49	9086	2740	156,6	163,9	173,9	140	260	7028	24169	7,3	17,3	70	105
50	9201	2747	157,9	163,0	183,2	90	310	2742	17182	5,1	25,3	45	65
51	9196	2731	162,2	164,5	181,1	65	170	2497	13711	2,3	18,9	55	70
52	9200	2726	164,0	166,5	183,2	65	200	2942	15231	2,5	19,2	57	70
53	9193	2711	157,0	164,8	173,9	85	200	4189	17618	7,8	16,9	67	145
54	9177	2714	150,6	155,5	173,9	100	275	5833	33311	4,9	23,3	85	97
55	9176	2705	156,3	160,5	173,4	70	150	3637	13531	4,2	17,1	65	97
56	9166	2717	141,1	144,5	170,0	65	270	2868	17862	3,4	28,9	60	65
57	9161	2722	139,2	144,5	160,0	80	200	4259	17455	5,3	20,8	65	65
58	9165	2730	144,3	148,0	171,0	95	230	3947	24817	3,7	26,7	55	95
59	9154	2736	145,3	148,0	159,8	60	160	1635	13189	2,7	14,5	35	125
60	9139	2727	135,2	140,8	159,8	160	320	9035	35635	5,6	24,6	80	102
61	9111	2721	119,8	131,9	164,1	340	650	27540	104375	12,1	44,3	130	195
62	9092	2717	123,5	132,5	141,2	90	170	5076	17357	9,0	17,7	75	140
63	9072	2723	116,5	127,0	138,2	140	260	11720	27429	10,5	21,7	105	140

Tab. 2 - Collected data for south zone

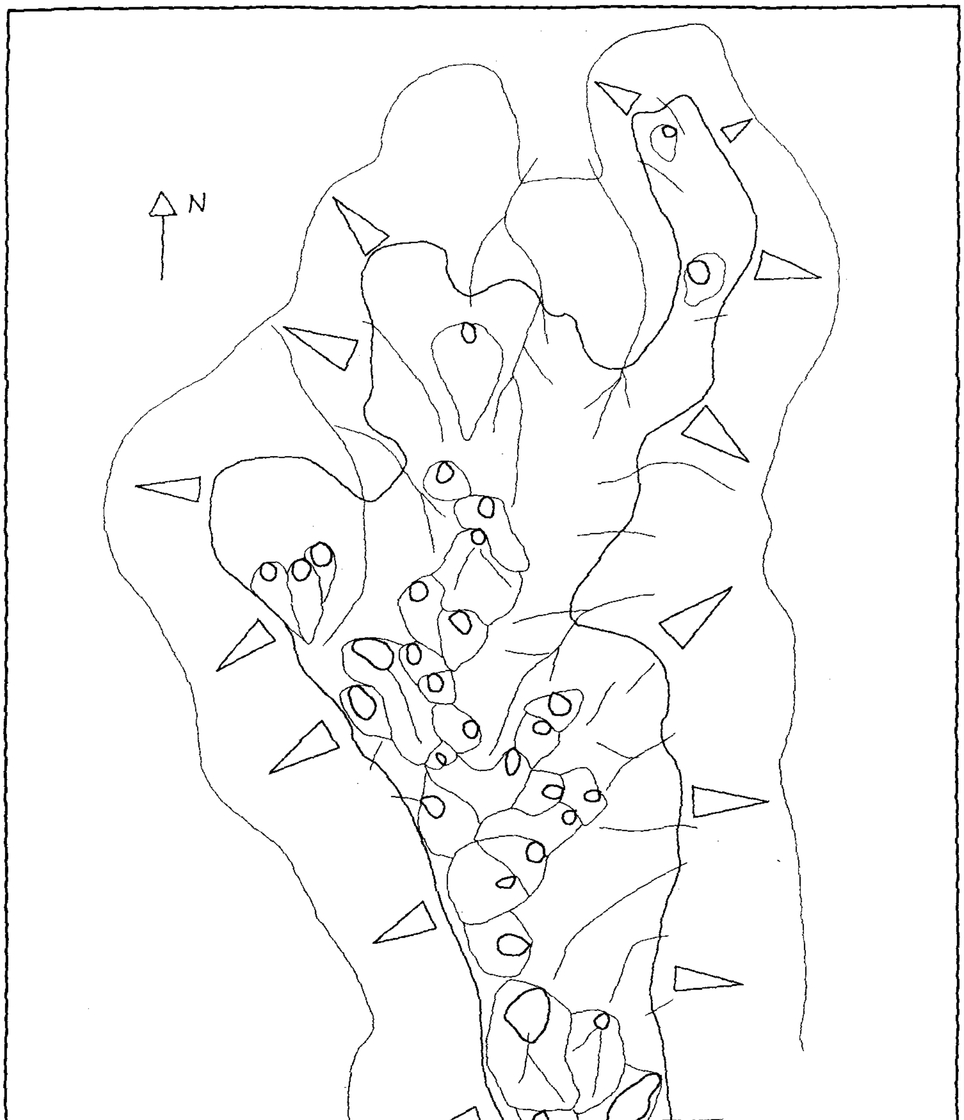

Fig. 1: North zone: dolines, catchment-basins, plateau escarpment, suspended dry valleys and hydrographic network are shown

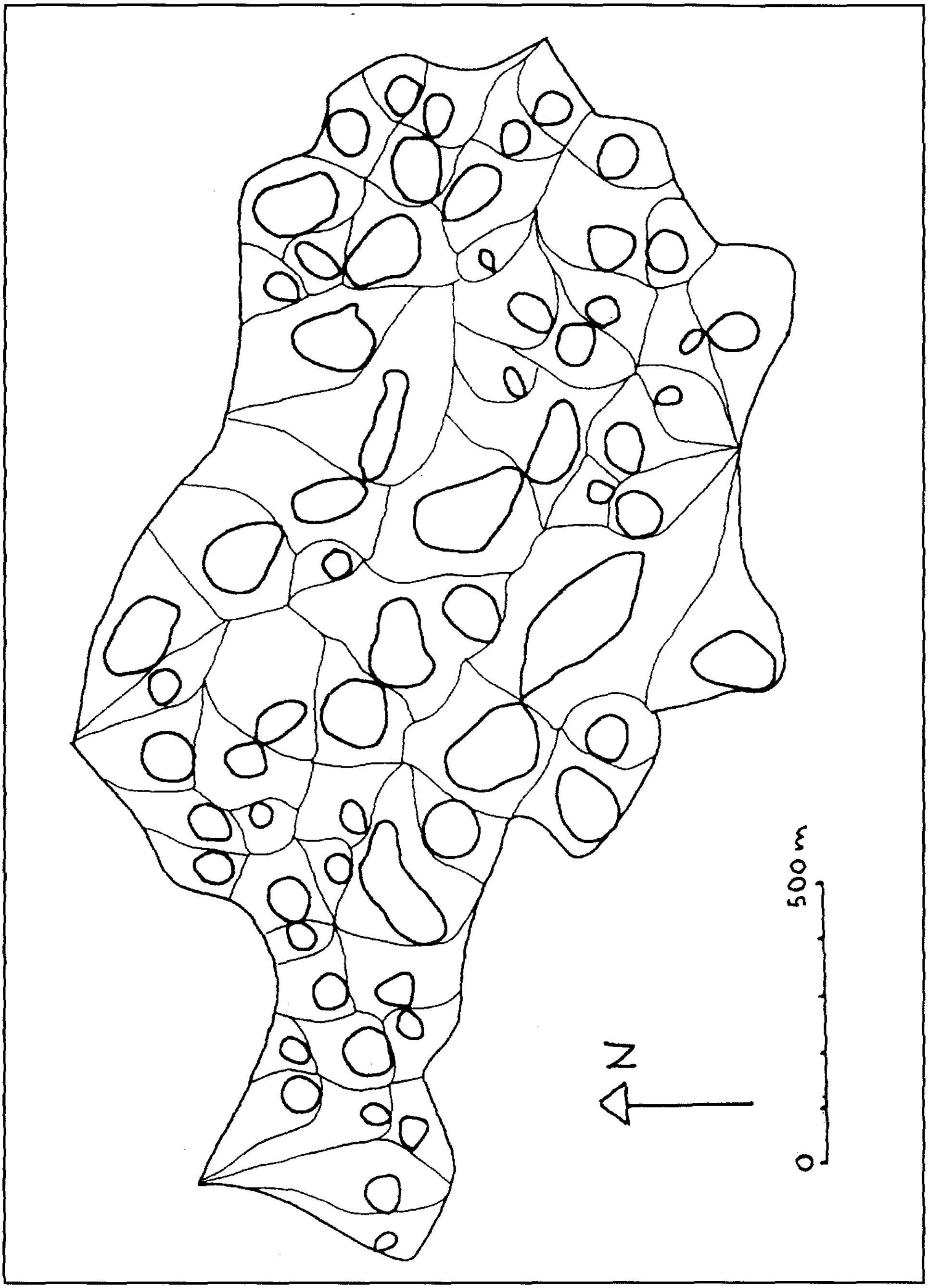

Fig. 2: South zone: dolines and catchment-basins are shown

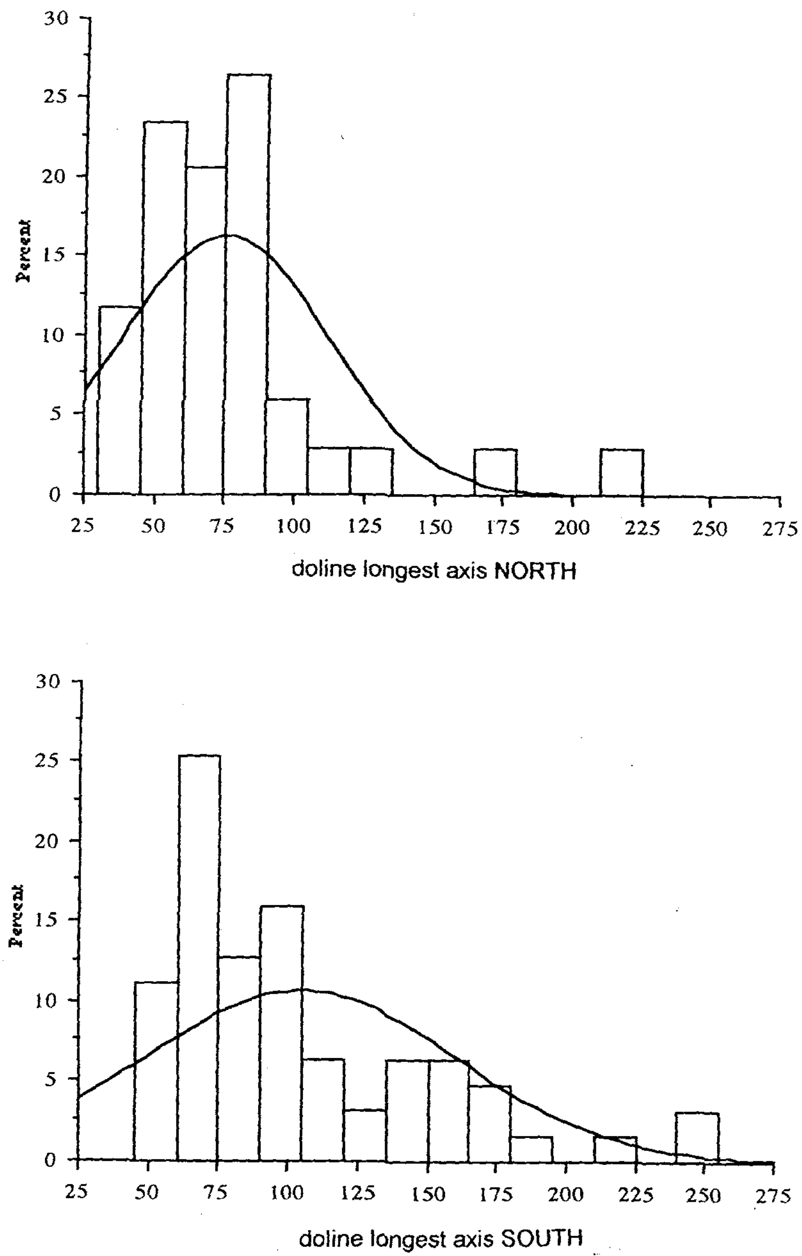

Fig. 3: Comparison between the two zones of the frequency distribution histograms for the variable "doline longest axis length"

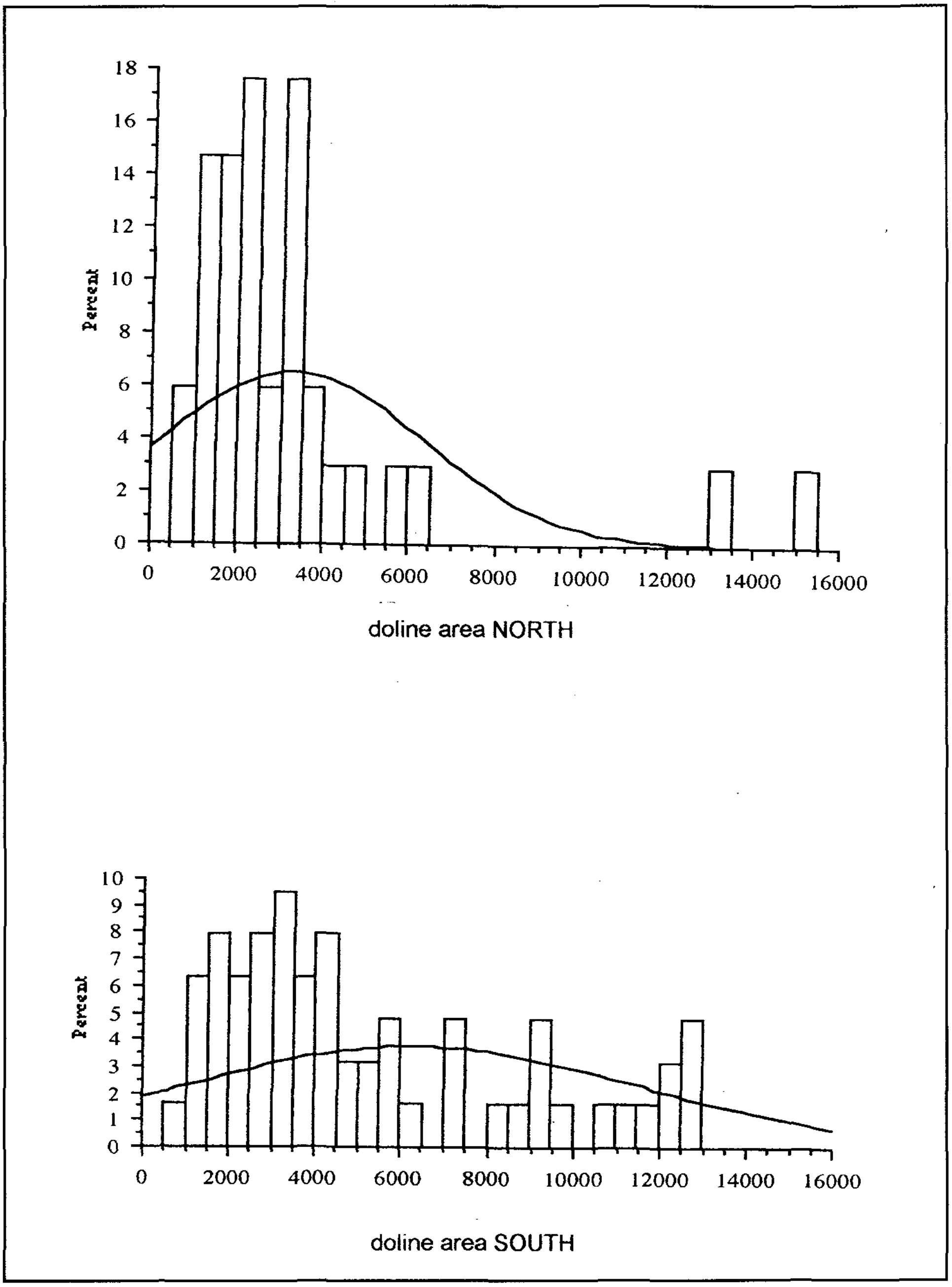

Fig. 4: Comparison between the two zones of the frequency distribution histograms for the variable "doline area"

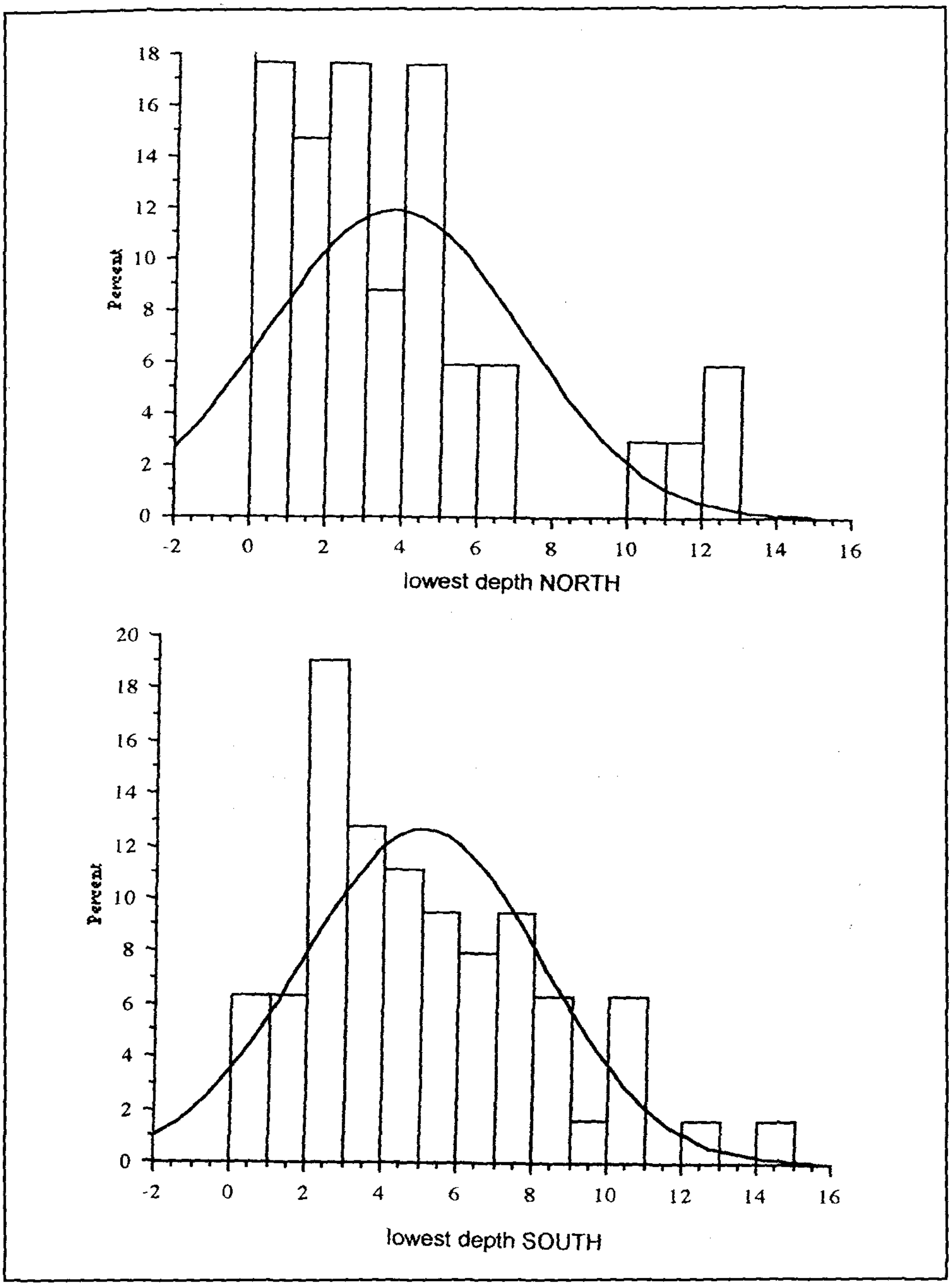

Fig. 5: Comparison between the two zones of the frequency distribution histograms for the variable "lowest depth"

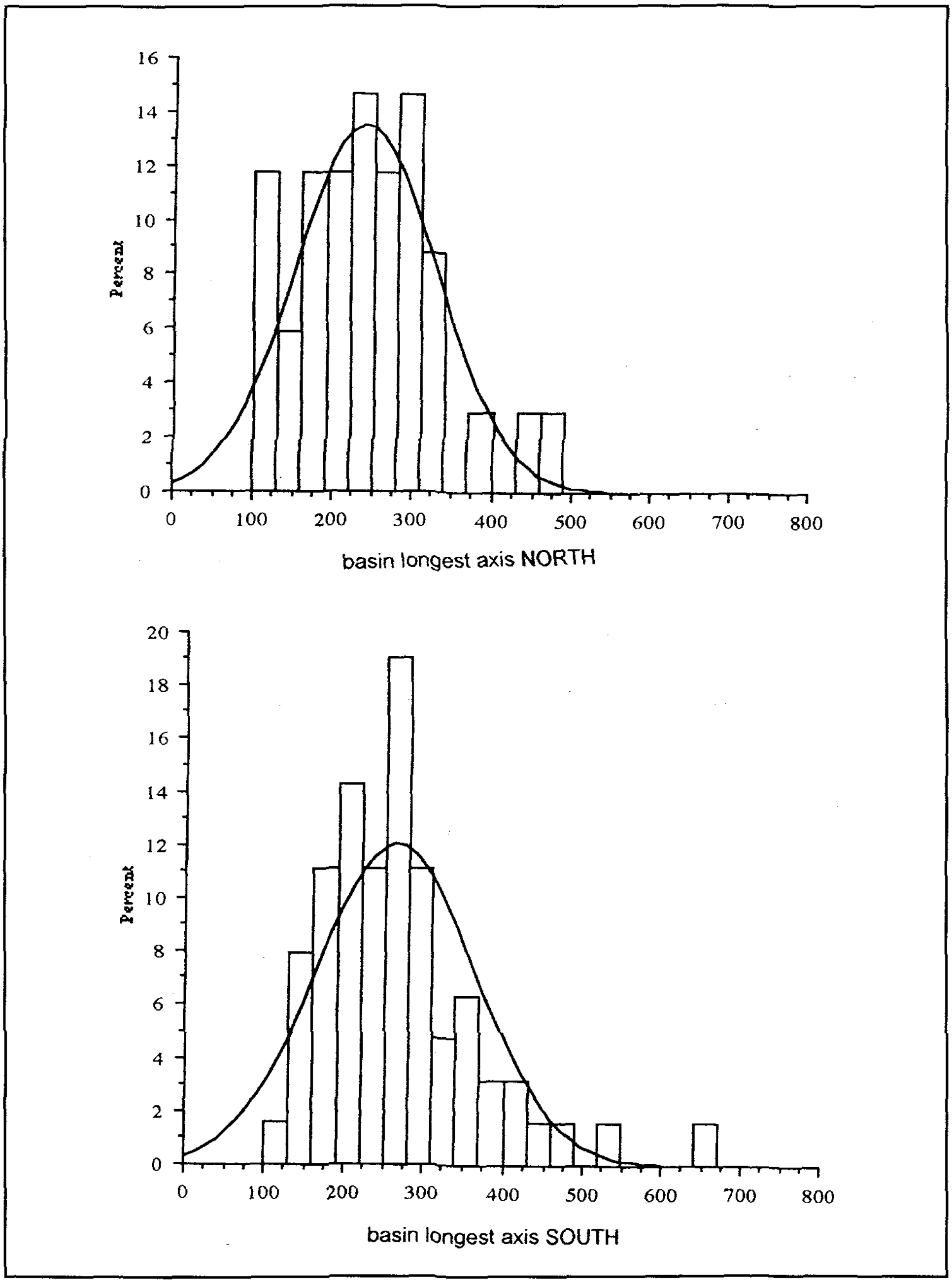

Fig. 6: Comparison between the two zones of the frequency distribution histograms for the variable "basin longest axis length"

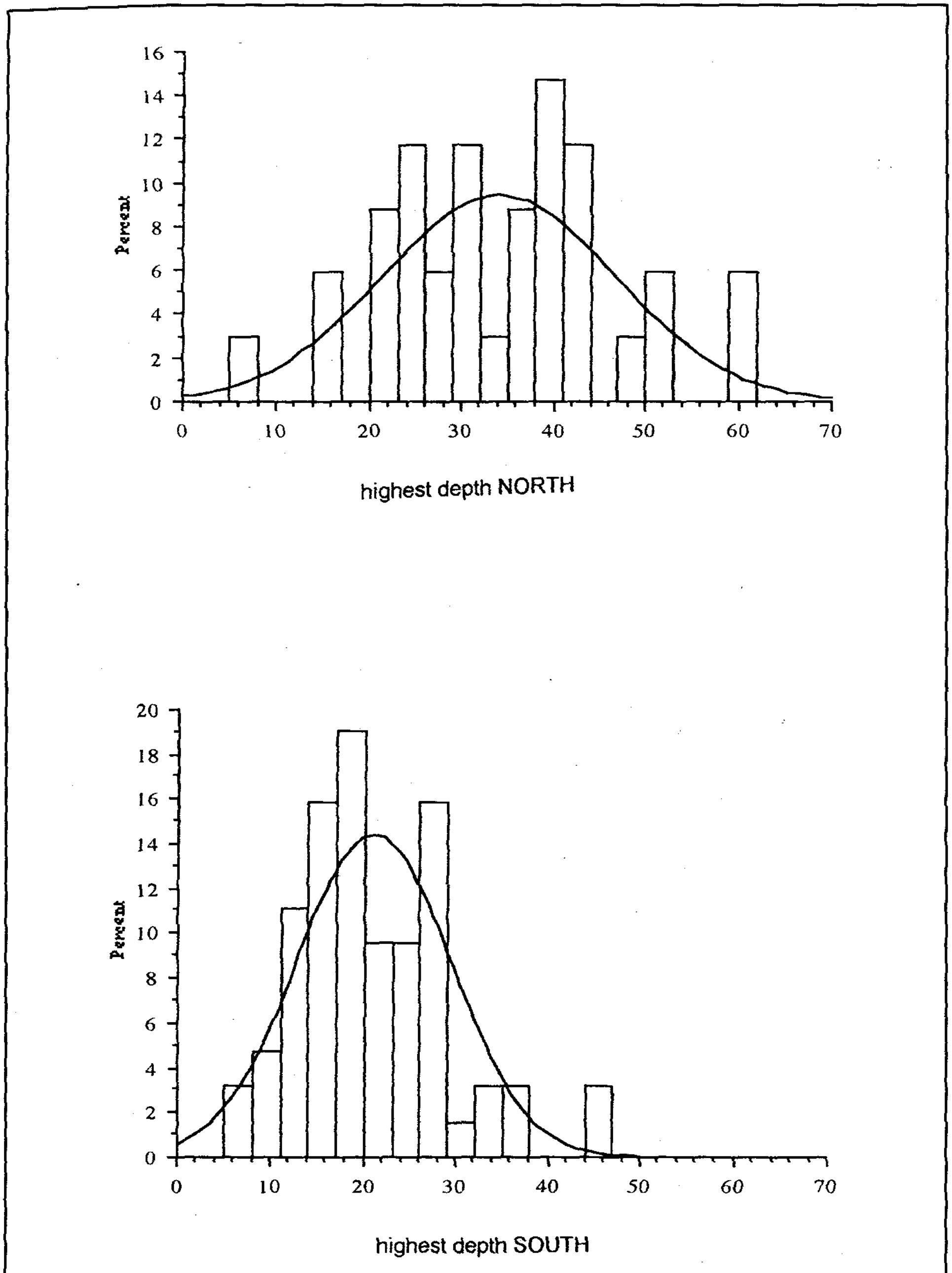

Fig. 7: Comparison between the two zones of the frequency distribution histograms for the variable "highest depth"

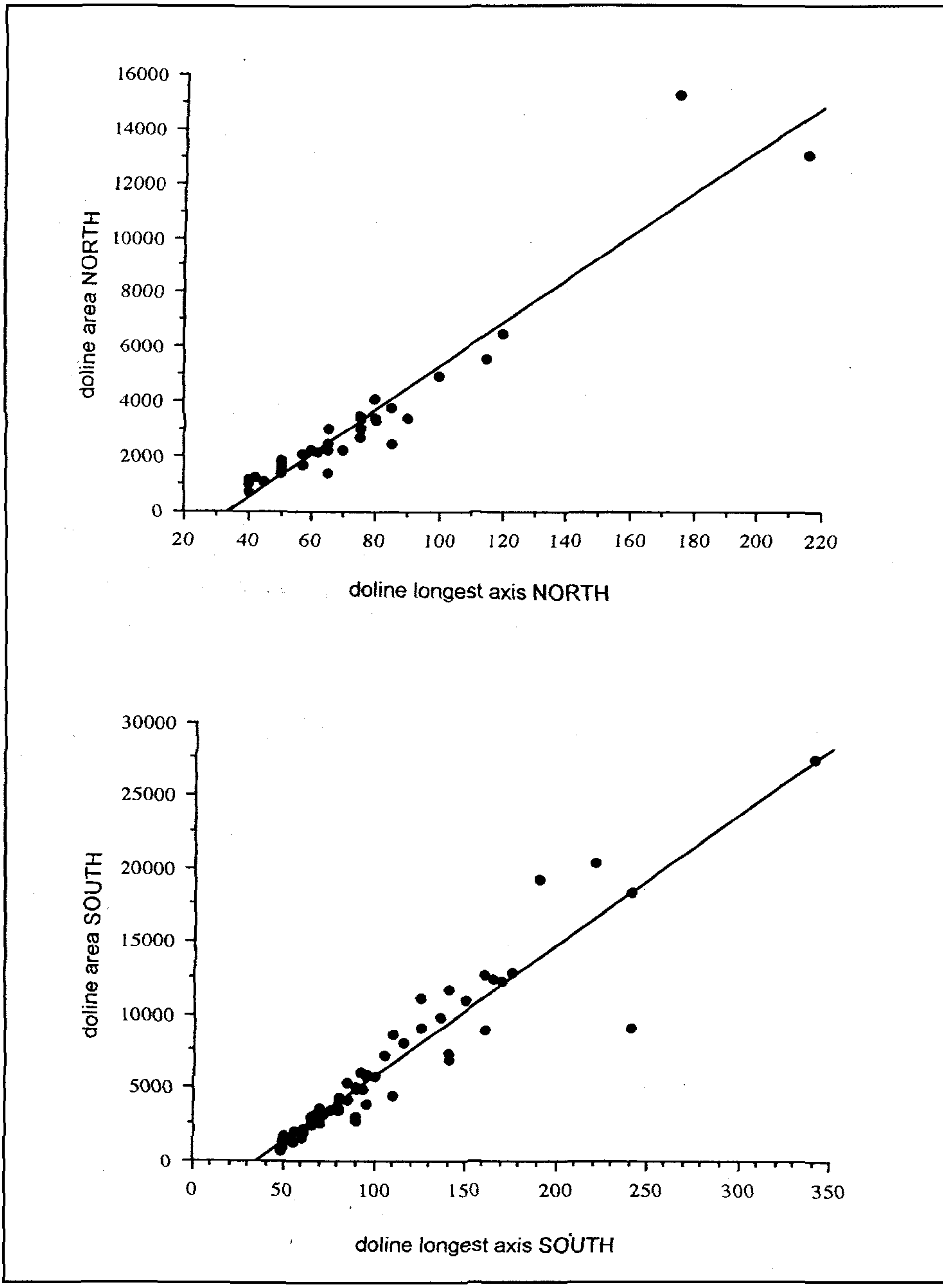

Fig. 8: Comparison between the two zones of the scattergrams concerning the variables "doline longest axis length" and "doline area"

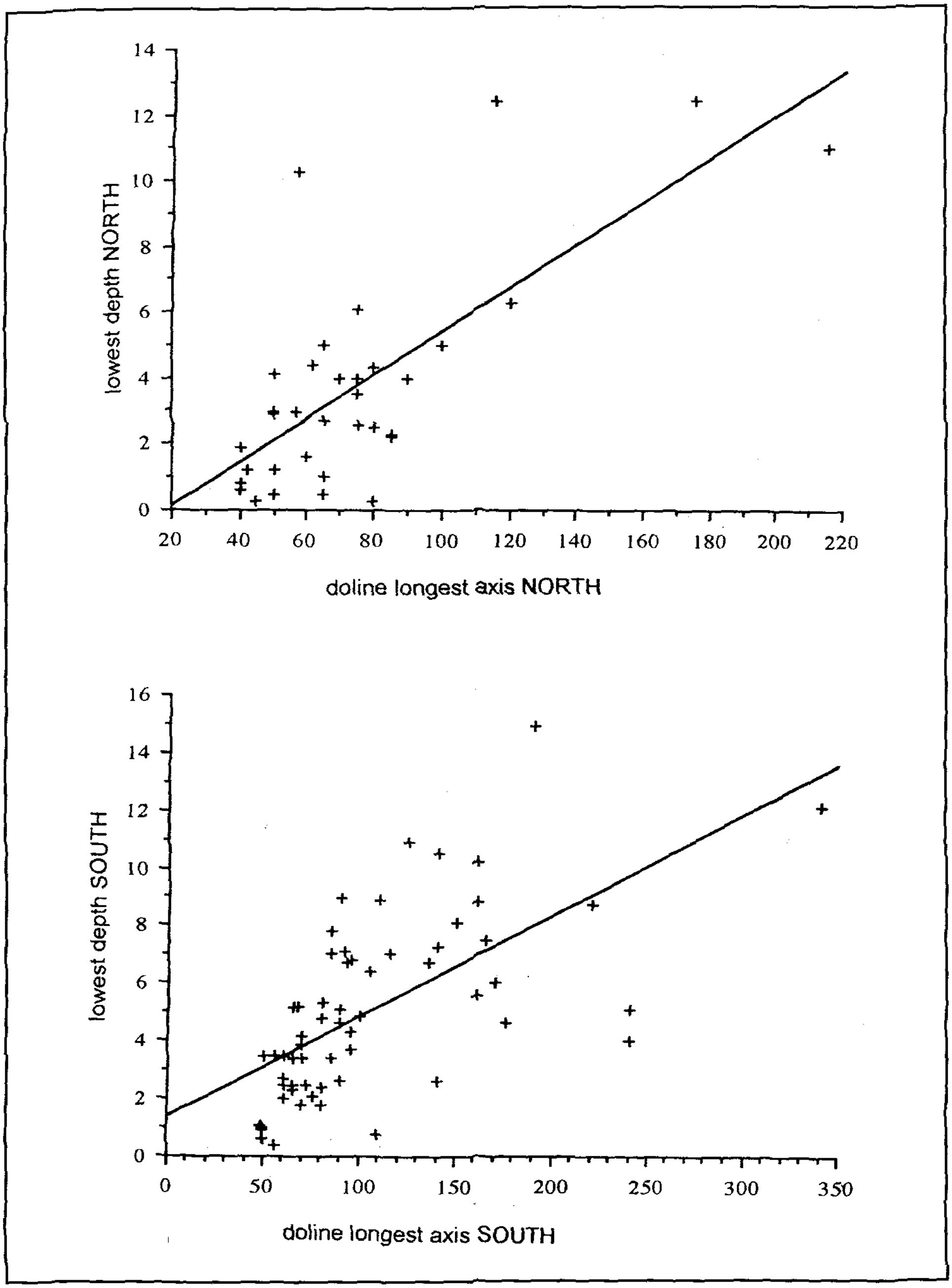

Fig. 9: Comparison between the two zones of the scattergrams concerning the variables "doline longest axis length" and "lowest depth"

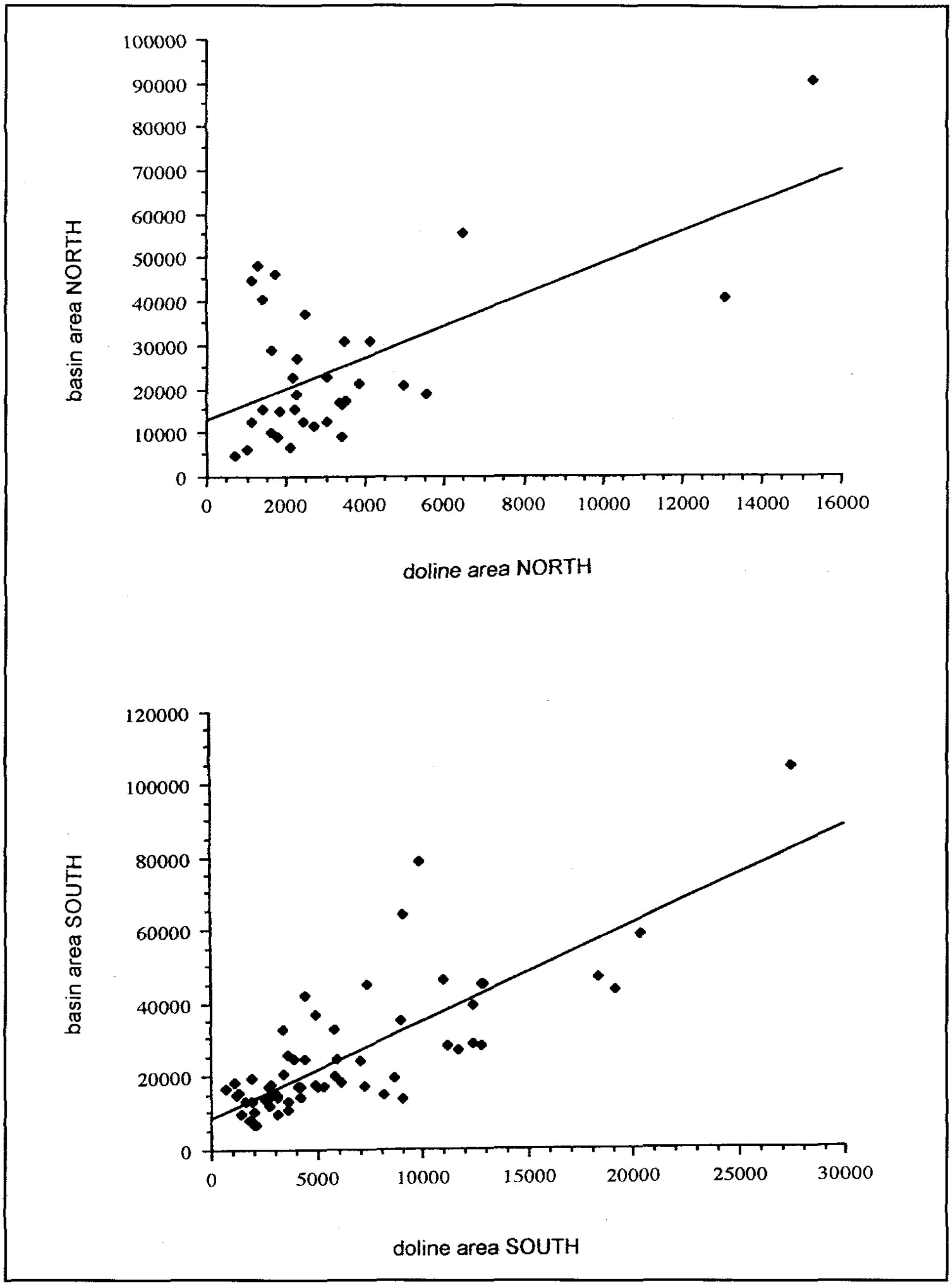

Fig. 10: Comparison between the two zones of the scattergrams concerning the variables "doline area" and "basin area"

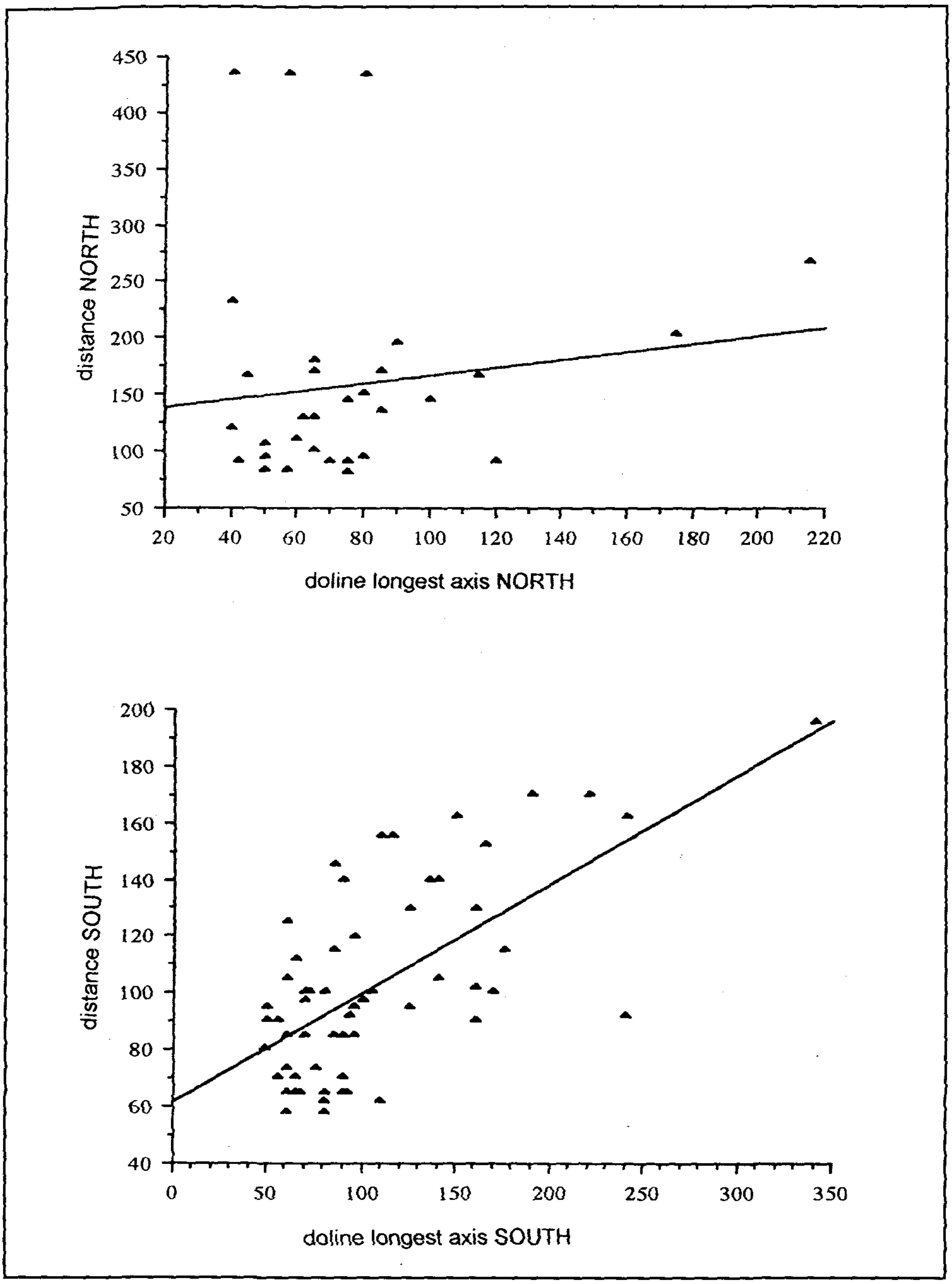

Fig. 11: Comparison between the two zones of the scattergrams concerning the variables "doline longest axis length" and "distance"

PRIMERJAVA MORFOLOGIJE VRTAČ IZ DVEH DELOV GRIČEVJA BERICI (VICENZA, ITALIJA)

Povzetek

Oblika vrtač kaže določene razlike med severnim in južnim delom gričevja Berici. Glavni vzrok je najbrž v različni litološki sestavi: lapornati apnenci na jugu, grebenski apnenci na severu. Razen tega so tudi različne reliefne oblike (planota ali sleme) tiste, ki so prispevale k različnemu značaju vrtač.

Rezultati meritev opravičujejo domnevo, da je severna cona bolj neugodna za nastanek vrtač, saj je na območju slemena več vrtač na robu planote odprtih proti pobočjem. Na slemenu je tako več manjših, a globokih vrtač, saj je tod večja reliefna energija, kot v južni coni. Dobro bi bilo poglobljeno preučiti medsebojni vpliv med razvojem pobočij in razvojem vrtač, med kraško in rečno morfogenezo v širšem smislu.

Več drugih okoliščin, pomembnih za razvoj krasa, je v obeh conah zelo podobnih (nadmorska višina, klimatske razmere, trajanje kraške morfogeneze), tako da ne morejo biti odločilni dejavniki za navedene razlike.

COMPUTER MODELLING OF CIRCULAR CAVE PASSAGE DEFORMATIONS DEPENDENT OF THE DEPTH

RAČUNALNIŠKO MODELIRANJE DEFORMACIJ OKROGLEGA JAMSKEGA ROVA V ODVISNOSTI OD GLOBINE

KARMEN FIFER-BIZJAK & FRANCE ŠUŠTERŠIČ

Izvleček UDK 624.121:681.3.01

Karmen Fifer-Bizjak & France Šušteršič: Računalniško modeliranje deformacij okroglega jamskega rova v odvisnosti od globine

S pomočjo računalniškega modela, ki temelji na metodi končnih razlik smo proučevali globino, na kateri se okrogel jamski kanal poruši zaradi geostatičnega tlaka. To se zgodi pri šibkih apnencih v globinah pod 750m, pri zelo trdnih pa pod 2500m.

Ključne besede: speleogeneza, mehanika hribin, računalniško modeliranje

Abstract UDC 624.121:681.3.01

Karmen Fifer-Bizjak & France Šušteršič: Computer modelling of circular cave passage deformations dependent of the depth

Using a computer model, based on the finite difference methoid we simulated the fail of circular cave channel, due to geostatic pressure. Poor limstone failed at the depth less than 750m, while very good limestone not until 2500m.

Key words: spelogenesis, rock mechanics, computer modelling

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INTRODUCTION

Present research of the early stages of the cave channel formation revealed the importance of a number controlling factors. Among them, the geomechanical properties of the rock play the key role, during the time between the inception, and the proper channel formation. In the further lines, we will discuss the control of the geomechanical properties of the rock.

The simplest and the most fundamental question is: At which depth the formation of the cave channels is impeded due to the large primary stress.

For this calculation we used program FLAC var. 3.03. It is installed at the PC computer at the Institute for Geology, Geotechnology and Geophysics in Ljubljana. As a modelling technique the program uses the finite difference method. According to this method, first, a finite different mesh is designed and in the second step the differential equation is transformed into a difference equation. The program uses Mohr-Coulomb criteria of failure. It is very effective to solve geomechanical problems because it considers the shear properties of the material, for example, angle of friction and cohesion.

Till now we have used this program for backanalyses of tunnels deformation on the motorways (for example Debeli hrib and Karavanke), for the research in Velenje coal mine and for feasibility study of underground garage in Piran.

THE MODEL

As the first step we acquired the grid of 20 elements in X direction and 20 elements in Y direction. The assumed diameter of the circular channel was set 1 mm. The calculation was simplified by considering only the upper right quarter of the channel.

In the next step we set the geomechanical properties of the limestone. The crucial problem in numerical modelling are the INPUT parameters, as the result of computations depends on the proper values of geomechanical data. At this stage we didn't use any measured field data. Rather than we made use of four general types of limestone, having taken the needed parameters from the literature, according to our previous experience with the numerical modelling. We processed the limestone of four basic groups, presented in the Table 1.

Table 1:

	label	E [MPa]	fi [°]	c[MPa]	T[MPa]
very good limestone	A1	20	42	3.0	1.5
good limestone	A2	15	35	1.0	1.0
fair limestone	A3	10	28	0.7	1.0
poor limestone	A4	7	28	0.7	0.2

In the next step we determined the primary stress field. We equalled the vertical primary stress with the geostatic pressure:

$\sigma_v = \gamma \times H$, where

σ_v ... vertical stress
γ ... specific weight

It was assumed that the horizontal and the vertical stresses are equal. In reality the relation between horizontal and vertical stress varies with depth.

We computed 18 models in total with various types of limestone at various depths. The results are summarised in

Table 2:

	DISPLACEMENT VECTORS (mm)			
	Label (type of limestone)			
DEPTH	A1	A2	A3	A4
500	5.60E-03	5.30E-03	1.00E-03	2.60E-04
600	9.60.E-03	-	-	-
750	FAIL	8.60E-03	2.40E-03	4.90E-04
1000		FAIL	4.50E-03	8.10E-04
1250			7.60E-03	1.10E-03
1500			FAIL	1.60E-03
2500				4.10E-03
3000				FAIL

As a result of our calculations we obtained for each model the maximal displacements around the channel. Our model failed for poor limestone at the depth 600 m, for the fair limestone after 750 m, for the good limestone after 1250 m and for the very good limestone after 2500 m. That means that at the listed depths formation of stable channels is not possible any more.

SOME DISCUSSION

Extremes are of our main interest because they display the limits of the results in various conditions.

In the figure of displacements showed that larger displacements appeared with the poor limestone. Displacementsare of the size order 10^{-6} m and for the good limestone 10^{-7} m. In both cases displacements have the same direction.

The largest vertical displacements occur in both cases at the top of the channel. Again, in different size orders. Displacements for the poor limestone presents Figure 1, and for very good limestone Figure 2.

In the pattern of maximum principal stresses the zone of weakness appears around the channel. After the zone of weakness, zone of higher stress occurs, which influences on the stabilisation of channel. The difference in both cases is in the dimension of the weakness zone. For the poor limestone (Fig. 3) zone of weakness is larger than for the good limestone (Fig. 4).

The zone of plasticity is larger for the poor limestone than for the very good limestone. Dimension of the plasticity zone has an influence on stabilisation of the channel. As expected, the channel in very good limestone is more stable that in poor limestone.

Though the model is rudimentary, the listed figures show the importance of the geomechanics properties of limestone for the final result of modelling.

CONCLUSIONS

According to the results of numerical modelling we can conclude that the limits of stability of circular voids in limestone are between depths of 600 to 2500 m. In the other words, in the limestones which have suffered complete diagenesis, karstification may reach approximatively four times deeper than in the nonconsolidated ones. The depth of the failure depends on geomechanical properties of the limestone. It must be pointed out that at this stage of research we didn't use any concrete field data of the geomechanical properties of the limestone, and we intended first to set the approximate limits of failure.

In the future we intend to investigate samples from selected location. With known properties of limestone and known stress field on the selected location we can make better model. Another issue that is intended to be investigated is the geometry of the primary channel, which will be approximated by ellipses of various a/b ratios.

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RAČUNALNIŠKO MODELIRANJE DEFORMACIJ OKROGLEGA JAMSKEGA ROVA V ODVISNOSTI OD GLOBINE

Povzetek

Eno pomebnih vprašnj speleogeneze je, do katere globine lahko sploh nastanejo jamski kanali, ne da bi jih sproti porušil geostatični tlak. Kot prvi korak k odgovoru smo s pomočjo računalniškega programa FLAC var. 3.03, ki temelji na metodi končnih diferenc, simulirali porušitev okroglega kanale pri štirih vrstah apnenecev. Njihovo mehansko trdnost smo definirali na osnovi podatkov z literature:

Tabela 1:

		E [MPa]	fi [°]	c [MPa]	T [MPa]
zelo trden apnenec	A1	20	42	3.0	1.5
trden apnenec	A2	15	35	1.0	1.0
primeren apnenec	A3	10	28	0.7	1.0
šibak apnenec	A4	7	28	0.7	0.2

Rezultate simulacije kaže

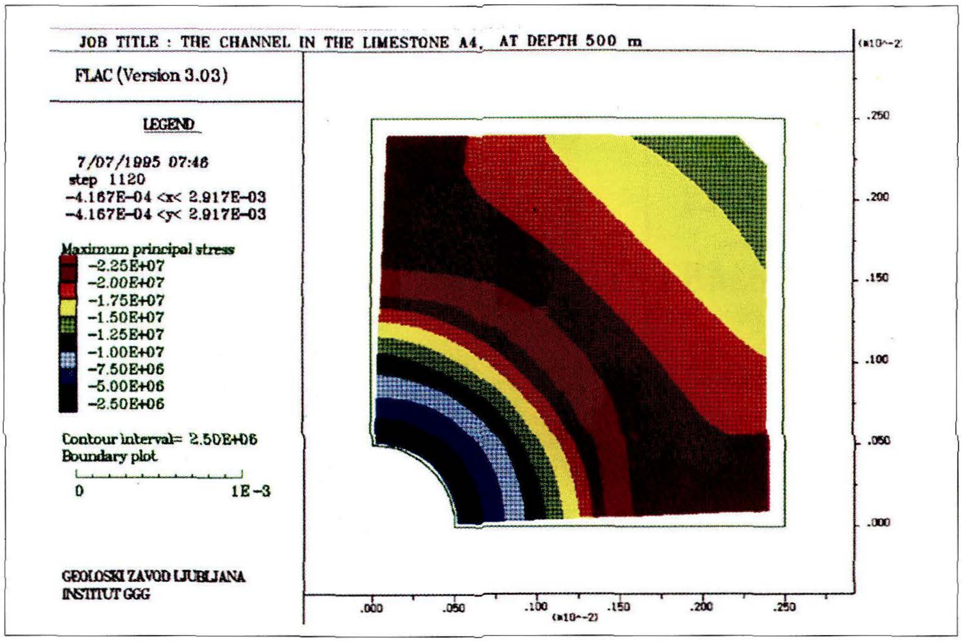
Tabela 2:

	VEKTORJI PREMIKA (mm)			
	Tip apnenca glede na Tabelo 1			
GLOBINA	A1	A2	A3	A4
500	5.60E-03	5.30E-03	1.00E-03	2.60E-04
600	9.60.E-03	-	-	-
750	PORUŠITEV	8.60E-03	2.40E-03	4.90E-04
1000		PORUŠITEV	4.50E-03	8.10E-04

1250			7.60E-03	1.10E-03
1500			PORUŠITEV	1.60E-03
2500				4.10E-03
3000				PORUŠITEV

Skupaj smo torej izračunali 18 modelov, pri čemer je za vsakega potrebnih več tisoč iteracij.

Na osnovi povedanega nastopi porušitev v globinah med 600 in 2500 metri. To pomeni, da lahko seže v trdnih apnencih, ki so prestali popolno diagenezo, zakrasevanje, štirikrat globlje, kot v tistih, kjer konsolidacija še ni končana.



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-4.167E-04 <y< 2.917E-03
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-2.00E+07
-1.75E+07
-1.50E+07
-1.25E+07
-1.00E+07
-7.50E+06
-5.00E+06
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Boundary plot
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1E-3
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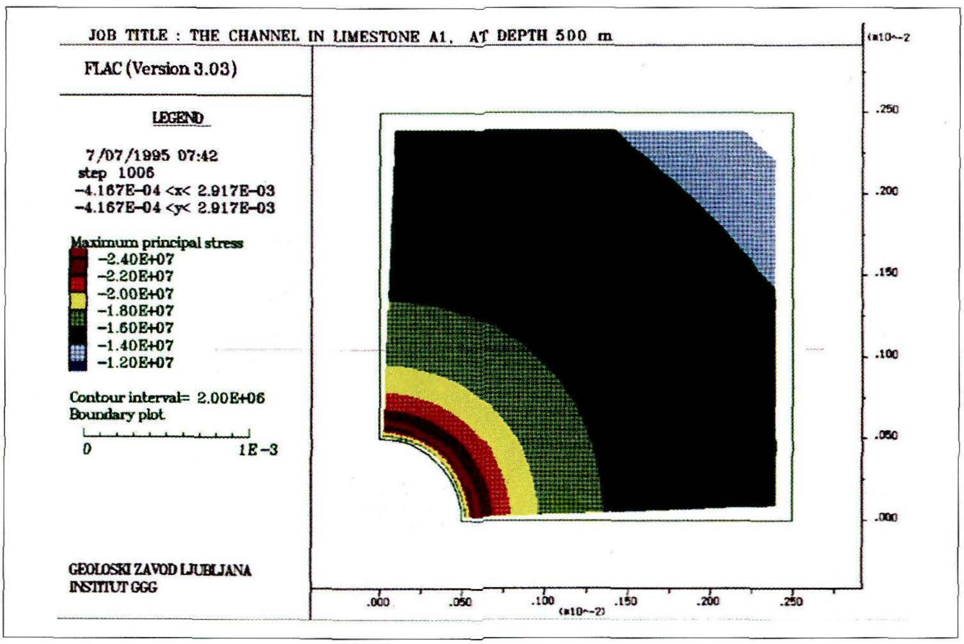
Fig. 1



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7/07/1995 07:42
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-4.167E-04 <y< 2.917E-03
Maximum principal stress
-2.40E+07
-2.20E+07
-2.00E+07
-1.80E+07
-1.60E+07
-1.40E+07
-1.20E+07
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Boundary plot
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1E-3
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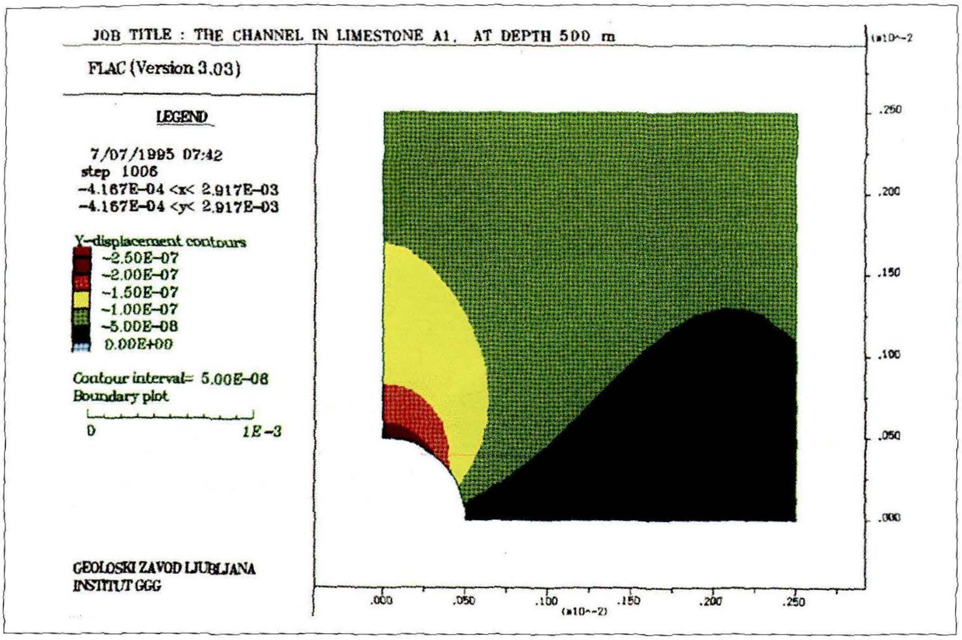
Fig. 2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-2.00E-07
-1.50E-07
-1.00E-07
-5.00E-08
0.00E+00
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Boundary plot
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1E-3
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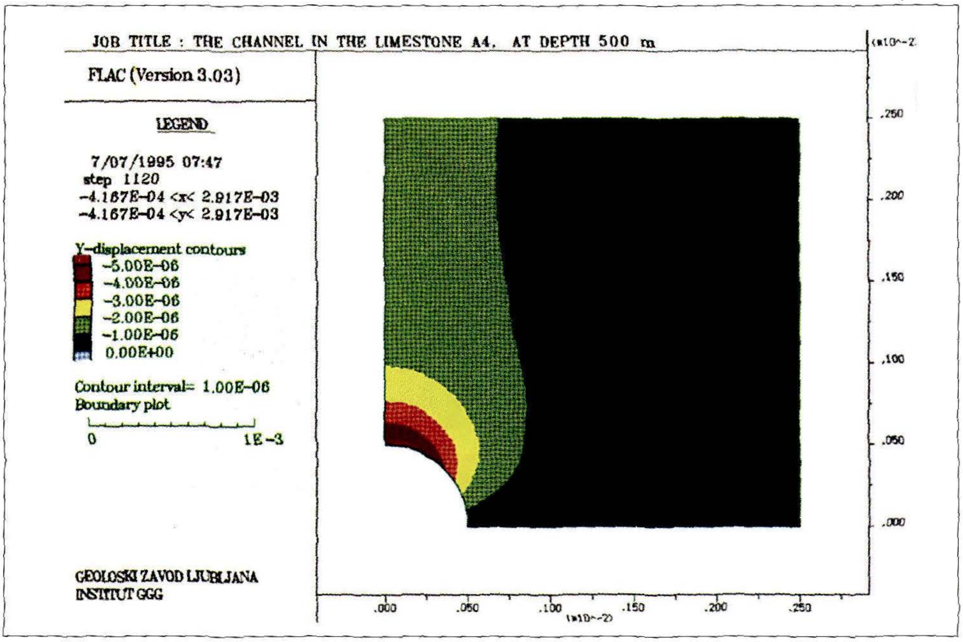
Fig. 3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Y-displacement contours
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-4.00E-06
-3.00E-06
-2.00E-06
-1.00E-06
0.00E+00
Contour interval= 1.00E-06
Boundary plot
0
1E-3
GEOLOSKI ZAVOD LJUBLJANA
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Fig. 4

THERMAL KARST SYSTEMS

TERMALNI KRAŠKI SISTEMI

PAOLO FORTI

Izvleček UDK 551.44:551.23
556.368

Paolo Forti: Termalni kraški sistemi

Hidrotermalni kraški sistemi predstavljajo pomemben gospodarski vir, tako z vidika hidrologije kot tudi rudnih ležišč. V mednarodni literaturi skoraj ni sintetičnih del o tej temi, pač pa jih mnogo obravnava posamične aspekte termalnih kraških vodonosnikov in tudi hidrotermalnih rudnih nahajališč. Zato je koristno predstaviti klasifikacijo termalnih jam in funkcije njihovega genetskega mehanizma in posebnosti morfologije skupaj s kemijskimi sedimenti. Do danes še ni bila izdelana primerjava med morfologijo in kemijskimi sedimenti v različnih termalnih sistemih in speleogenetskimi mehanizmi. Nekatere reakcije lahko razložimo samo v povezavi z določenimi deli vodonosnika. Pričujoči članek prvič poskuša shematizirati obstoječe odnose med speleogenetskimi mehanizmi, deli vodonosnika in morfologijo razvitih sedimentov.

Ključne besede: termalni kras, klasifikacija, speleogeneza

Abstract UDC 551.44:551.23
556.368

Paolo Forti: Thermal karst systems

Thermal karst systems represent an important economic resource from the point of view of hydrogeology and ore deposits. A general study has never been performed to relate morphologies and chemical deposits of the thermal karst with the speleogenetic mechanisms which may be active in the different zones of the aquifer. In reality, due to the complexity and the variability of the thermal fluids, there are plenty of different chemical-physical reactions which are possibly active in such an environment: anyway some of them may be regarded as the most important, because they are active singly or combined with some others, at least in part of most of the hydrothermal caves.

Key words: thermal karst, classification, speleogenesis

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INTRODUCTION

Thermal karst systems may represent an important economic resource with regards to the hydrogeology and to the hosted ore deposits. In many countries there are many thermal establishments which make a direct, or indirect exploitation of the hydrothermal caves. Furthermore, the great sulfide ore deposits, such as those of the Iglesiente in Sardinia which have represented one of the most important mineral resources in Europe, can for the most part be considered Mississippi Valley type ore deposits (MVTOD) and therefore related to thermal karst systems.

Notwithstanding the evident economic interest, generally very little is known about hydrothermal karst systems and their hydrogeological and speleogenetic behaviour: in fact, even on an international level few papers give an overview on this topic (FORD & WILLIAMS, 1989), while many papers exist on special aspects, in particular the hydrothermal ore deposits (DZULINSKIY & SASS - GUSTKIEWICZ, 1989).

In the past when a cave showed strange morphologies or contained uncommon chemical deposits it was normally considered of hydrothermal origin. (HILL & FORTI, 1986). In reality, the further knowledge on the ever increasingly complex speleogenetic mechanisms demonstrates that several previously supposed hydrothermal karst systems have in fact developed in a normal environment.

This would explain why even recently the number of thermal karst systems, calculated at more than 10% (FORD, 1988) of the global karst phenomenon, was surely greatly overestimated.

THERMAL KARST SYSTEMS

In theory a cave may be regarded as hydrothermal in origin (or part origin) only if thermal fluids (normally hot water) flowed inside at least during a period of its development. Though this definition is apparently simple, in practice it is difficult to have objective proof of this origin.

In reality the origin of thermal waters can be absolutely different: juvenile (i.e. volcanic in origin) waters, connate (tapped sedimentary) waters, deeply circulating meteoric (normal karst) waters or even mixtures of these three waters in any proportions (see fig 1). Moreover shallow karst water can mix with these when they approach the surface, so it is practically impossible to define the contents of a typical thermal water in any clear way, though it can be affirmed that these waters are almost always characterised by a sufficiently high content of CO_2 and H_2S. The evolution of the karst systems is different in morphologies and above all in chemical deposits which should be deposited depending on which of these two gases prevails. The complexity of chemical-physical parameters of the thermal waters makes it even more complex to establish acceptable criteria of identification for the hydrothermal caves.

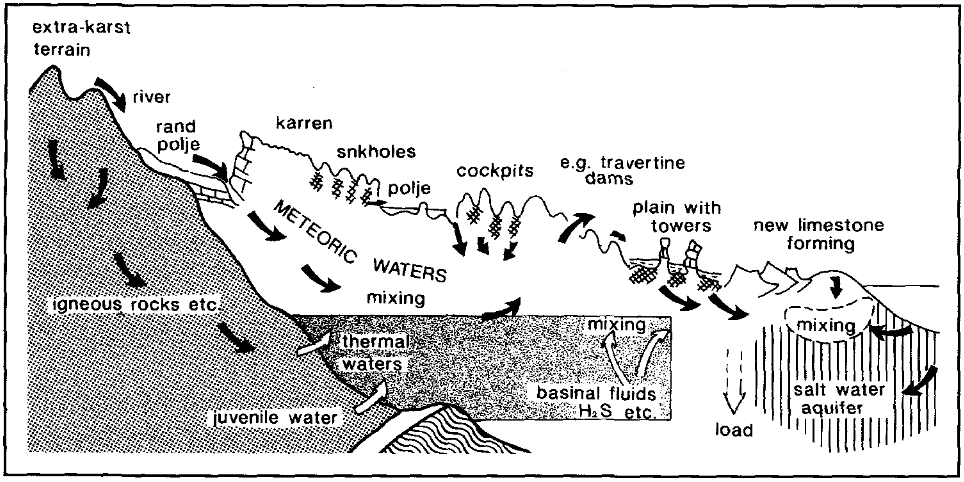

Fig. 1: The comprehensive karst system in which the area with possible active thermal phenomena is associated (FORD 1988, modified)

The identification critera may be divided in two categories: direct proof or indirect evidence (elements that suggest a former thermal activity).

There are essentially two kinds of certain proof; 1 - thermal waters flowing inside the karst system; 2 - stable isotope measurements of the chemical deposits in the system. Unfortunately it is not always possible to utilise either of these proofs.

In fact, it is unusual to find thermal waters in a cave due to the difficulty of entering inside a very hot system, therefore when we enter even a thermal cavity, the thermal flow has normally ceased long since. Moreover it does not always stand to reason that the presence of hot fluids automatically signifies a thermal evolution of the cavity: some cases are known where such fluids have penetrated a normal karst system (i.e. generated by meteoric waters), for example the Sciacca Cave, which has only recently become subject to the thermal effect and therefore at present the structure of the cavity has not been altered much by the hot fluids.

Thermal caves have often, though not always, internal chemical deposits (speleothems or cave minerals) which can be analysed to define their temperature of deposition (stable isotope analysis, fluids inclusion study, etc.). There are still problems in this case as these deposits are often found to be developed after the end of the thermal stage, or the geochemical system may result open and therefore altered in a more recent stage.

Therefore it is obvious that in the majority of cases we must use indirect evidence to define the thermal origin of a cave (either partial or total); these can be divided into two categories: the solution forms and the chemical deposits.

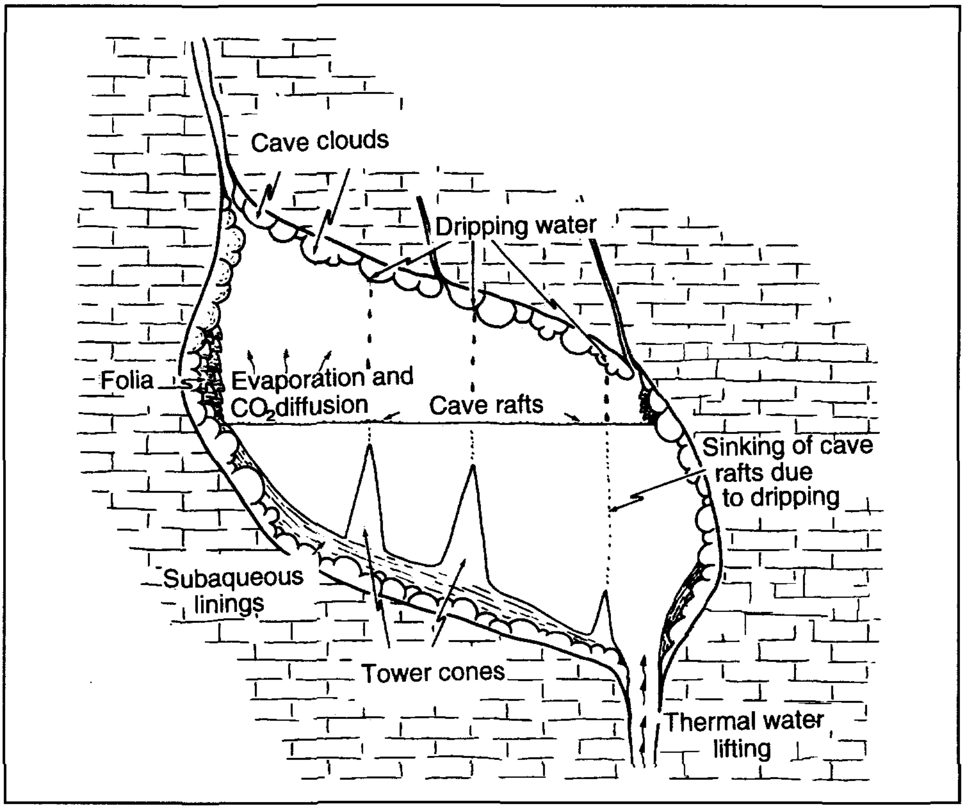

Fig. 2: Genetic scheme for the tower cones of the Giusti Cave (FORTI & UTILI, 1984): condensation water dripping from the ceiling causes the sinking of the cave rafts developing over the thermal water due to the CO_2 degassation. The underwater accumulation of the cave rafts allows the growth of cemented tight cones (tower cones)

Some solution forms are clear indicators of convective movements and therefore possible indicators of an upwelling of thermal waters. Among them the most characteristic are the rising structures of branching patterns of bell-shaped passages on top of a large basal chamber. Sometimes the presence of domed ceilings may also indicate thermal activity, though in most cases this morphology is evolved by completely different mechanisms (karst waters mixture, condensation corrosion etc.) The same can be said about the peculiar forms generated by gas bubbling in saturated environments, such as the bubble trials derived from gas diffusion from thermal waters in proximity to the piezometric surface (CHIESI & FORTI, 1987) but the same morphology can again derive from other phenomena, the principal one being biological oxidation of H_2S (FORTI, 1989).

The presence of a peculiar morphology is not the only indication of possible thermal water in a cave, but also the absence of other forms may be important as the lack of evidence for high to moderate water flow. The total absence of canyons and scallops or the lack of deposits of rounded cobble stones, are indirect proof of the water flow velocity from slow to very slow which is the normal hydrodynamic condition for hydrothermal fluids.

In the chemical deposit some speleothems tend, though not exclusively to be strictly confined to the hydrothermal environment: some to be remembered as thermal indicators are the Gaysermites from the Hungarian Czech and Slovak thermal caves (CHROMY, 1927; PANOŠ, 1960), the tower cones of the Monsummano cave (FORTI & UTILI, 1984: see Fig. 2) and the great development of cave clouds in the Carlsbad Cave (HILL, 1987).

Finally the presence of a large quantity and variety of cave minerals in a cave has always been attributed as proof of the "thermalness" (HILL & FORTI, 1986): in fact even if all of them may be found in a "normal" cave; what is distinctive in the hot water caves is their unusual abundance and their association together.

In conclusion we must always consider that even when all the indirect indicators of thermal origin are contemporaneously present in a cave, it is impossible to confirm for certain that hot fluids have gone through the cave; in fact, only direct proof can be conclusive.

MORPHO - GENETIC SUBDIVISION OF THE THERMAL KARST SYSTEM

The thermal karst systems can be morphologically divided in two principal categories:

1 - the thermal monogenic caves

2 - the maze caves

The subdivision remains consistent with the evolutive-genetic mechanisms which have developed the karst system into what we see today.

Monogenic caves: they are cavities created by the sole action of the hot water on the rock, hence the name monogenic: in effect the real "thermal caves" are quite rare also because it is unusual that the isolated action of hot water can produce wide karst voids. In fact an analysis of all the printed papers on this topic shows that the higher the development temperature, the fewer spaces generated (DUBLIANSKY, 1994).

A monogenic cave consists of a large basal chamber where the thermal waters accumulate (similar to the magmatic chambers in a volcano) from which a branching pattern of rising-bell shaped passages have grown; a typical "monogenic cave" is Statorkoputzka Cave in the Buda hills in Hungary (MULLER & SALVARY, 1977). These caves are generated by the dissolution and/or corrosion induced by the slow convective rising of thermal waters. The caves need a single point recharge at the base of the karst formation (where the basal chamber is formed) in order to develop. Though this condition is necessary it is not sufficient, because the karst rock needs to have a low fissure frequency and there must not be a point where the thermal waters have a direct discharge.

Only when all these "boundary conditions" are satisfied, thus allowing the establishing and subsequent maintenance of the upward convective motion of the hot water, then the evolution of the rising dendritical part that characterises these caves may develop. This is the reason the hydrothermal monogenic caves do not usually have a natural external outlet, and if they find one the development ceases, at least in this form.

It has been demonstrated (RUDNICKI J., 1978) that the form and dimensions of the bell-shaped passages forming the rising branches, as with the microforms eventually present on their surface, strictly depend on the convective motion installed in the bell itself. This in turn is controlled by the flow rate of the thermal water and by the temperature difference existing between this and the cave walls.

Thermal maze caves: the difference between a monogenic cave and this kind of cavity is that this is not a "pure" hydrothermal cave. More often than not its growth consists of different stages where not only thermal but also other different types of water take part in their evolution.

The possibility of evolution of these caves is where there is no defined input point and the recharge comes about in an aerial diffusion, moreover the karst rock must be heavily fractured and the discharge must be through one or more definite outlets (thermal springs).

The maze caves are subdivided in the following two categories;

2 - Dimensional maze caves

3 - Dimensional maze caves

which differentiate not only in structure but also in genetic mechanisms.

2-dimensional maze caves develop when hot rising water is tapped in the karst formation at a definite level. Thermal flow is then developed along horizontal lines thus creating a maze pattern of unclassed galleries. This always happens when the hydrothermal fluids are confined in the hosting carbonate formation by a watershed (fig. 3-A). But in reality, the biggest 2-D maze caves are observed in quite different conditions. In fact, even in this case the karst evolution still depends exclusively on the aggressive power of the thermal water and, as previously noted, it is not very strong.

There is another much more favourable condition that allows the evolution of the great 2-D maze caves: it is realised when a very stable thermal stratification is achieved inside the karst formation due to the presence of an overlying meteoric aquifer (fig. 3-B).

In these conditions the karst effect will be magnified by the cooling down effect (due to contact with a colder mass represented by the meteoric water) and above all by mixing corrosion (Bögli effect, Picknet effect, salt effect etc.) (FORTI, 1991).

In all cases, though the 2-D maze caves are more common than monogenic ones, they only represent a small minority in the range of hydrothermal caves, from being all points of view dominated by 3-D maze caves.

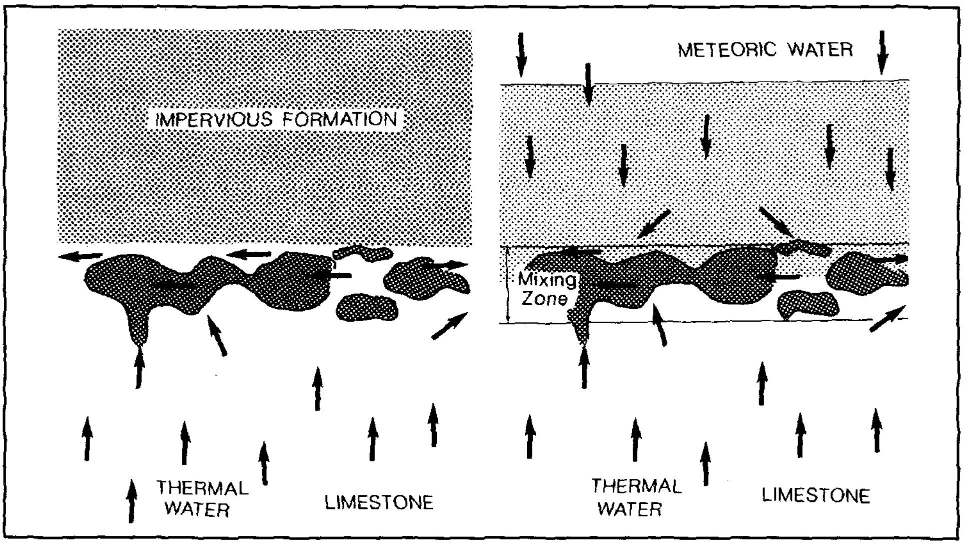

Fig. 3: Sketch for the evolution of 2-D maze caves; A - confined aquifer, B - unconfined aquifer with a very stable thermal - meteoric waters interface

3-D maze caves are by far the most common natural thermal karst phenomena, reaching over 100 km of passages (Jewel Cave in the USA, BAKALOWICS et al., 1987) and a depth of more than 600 m. (Stari Trg Mine in ex-Yugoslavia, PETROVIČ, 1969) This type of karst system can be generated by a homogeneous process when rapidly upwelling thermal fluids invade unconfined karst aquifers, even though this kind of genesis is not the most common. 3-D maze caves are more often the result of a heterogeneous process which corresponds to a progressive lowering of the thermal water and/ or episodes of infiltration of meteoric seeping water at different levels inside the thermal aquifer with consequent successive mixing.

SPELEOGENETICAL EFFECT OF THE THERMAL FLUIDS

Due to the complexity and variability in the composition of the thermal fluids, there are plenty of chemical-physical reactions that succeed in the aquifer between the hot fluids and the hosted rock and they are always very complex and in many cases unstudied. For example the effective role has yet to be stabilised (certainly of great importance) biological reactions have evolved in this context (AA., 1994).

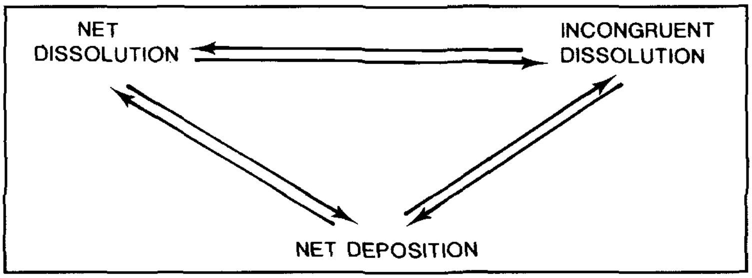

Fig. 4: Possible speleogenetic effects of the hydrothermal reactions: all three mechanisms may be active simultaneously in different zones of the same cave or the cave may be subjected to different effects at different periods

Generally, however, speleogenetic effects derived from these reactions can be put in three large groups (as schemed in fig. 4) practically corresponding to net dissolution which enlarge the voids, and to net deposition which corresponds to a reduction of the space available for the circulating water, but most of them are responsible for incongruent dissolution (deposition and dissolution in the mean time) (LOHMANN, 1987).

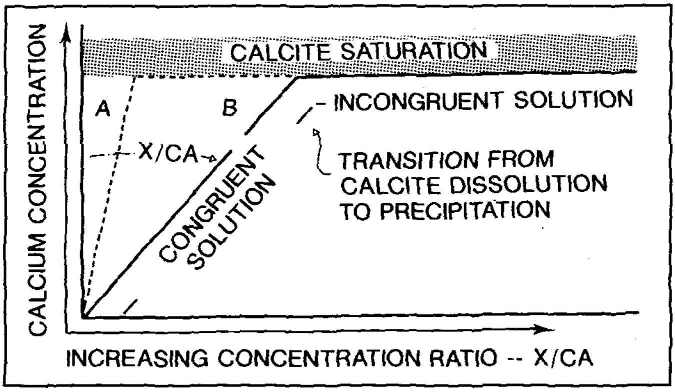

Fig. 5: The effect of solution of dolomite by water that already contained a certain amount of dissolved calcite. Initially the congruent solution of dolomites (net dissolution) is the active process and the resulting ions concentration is stochiometrically that obtained by the released ions from the solid stage. Once calcite saturation is achieved, whenever new dolomite is dissolved there will be a contemporaneous precipitation of calcium carbonate with a consequent variation of calcium/ magnesium content (incongruent dissolution) (LOHMANN, 1987, modified).

It is possible to have all three of these effects simultaneously active in different places of the same karst system, or the same zone may alternatively undergo different effects in later stages of the cavity development.

Incongruent dissolution is the most common of the three speleogenetic effects inside the hydrothermal karst systems; moreover it is responsible for all the ore deposits of the Mississippi Valley Type (MVT). The karst effect of incongruent dissolution on a thermal system can however vary from case to case depending on the type of chemical reaction involved, which determines the relative importance of the depositing process in comparison to the dissolution one. Some karst cavities are found which developed themselves through incongruent dissolution and have few chemical deposits inside, as the Pfaff Cave in the Iglesiente (see Fig. 6) , or more frequently it is possible to observe an hydrothermal karst system completely fossilised by mineral deposits (see Fig 7).

A wide bibliography exists on the ore deposits related with thermal karst systems (MTVOD) (DZULYNSKY & SASS-GUSTKIEWICZ, 1989) it is possible to find descriptions that go from one extreme to the other, from cavities overflowing with deposits to those completely without. All things considered, it is almost impossible in the present stage of our knowledge to explain the evolution of a particular karst system as its final morphology may derive from successive stages where not necessarily one only of the three speleogenetic mechanisms, and not always the same one was active.

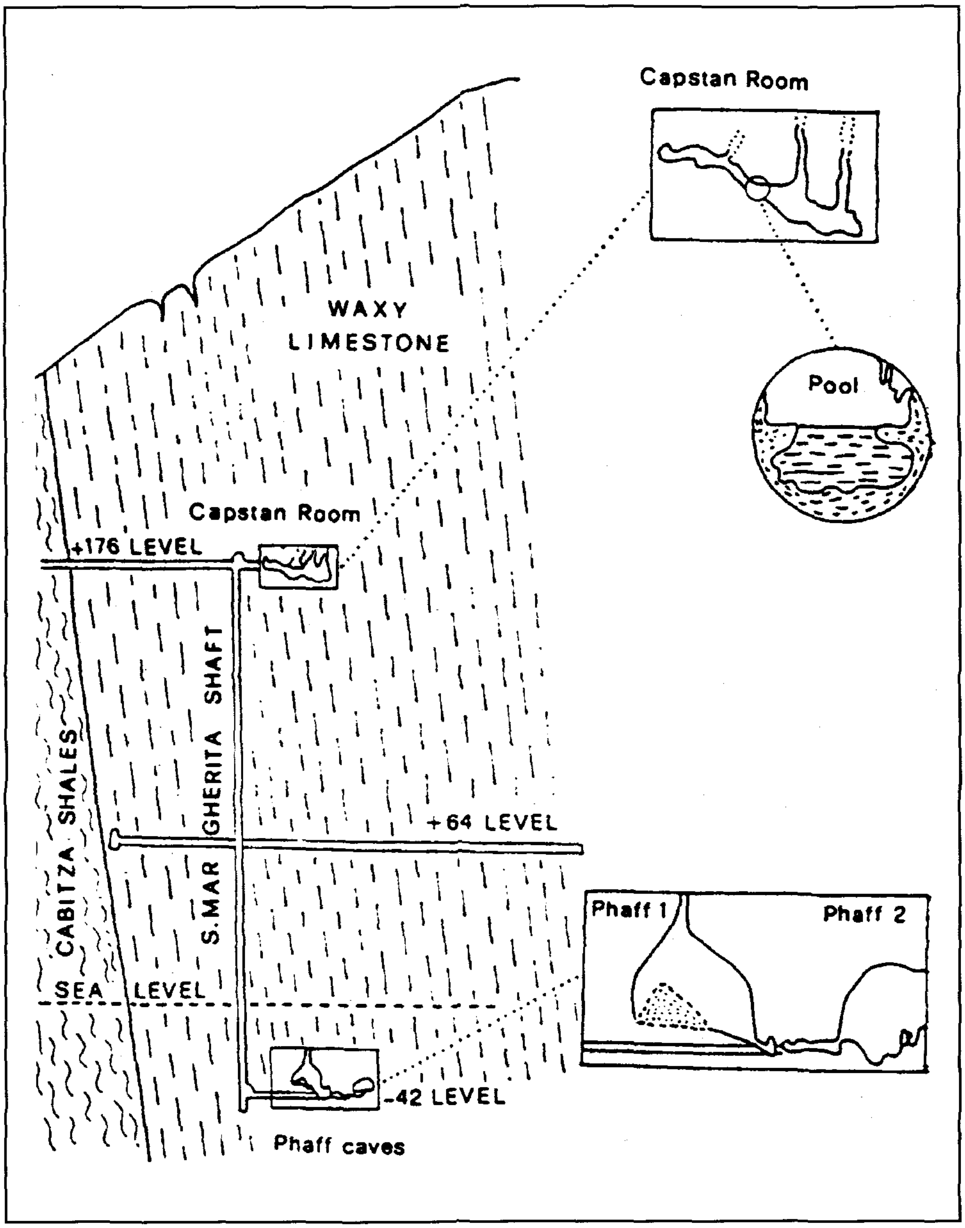

Fig. 6: Section on S.Margherita Shaft in the Masua Mine, where the position of the Pfaff Cave is in evidence, a large cavity partially thermal in origin, containing large thermal calcite crystals on the walls and a small quantity of Pb oxides and Zn sulphide (from DE VIVO et al., 1987, modified)

Even if this happened, the chemical reaction of the hot water or mixture can be greatly varied in time with consequent variation of the type of incongruent dissolution or the kind of deposition.

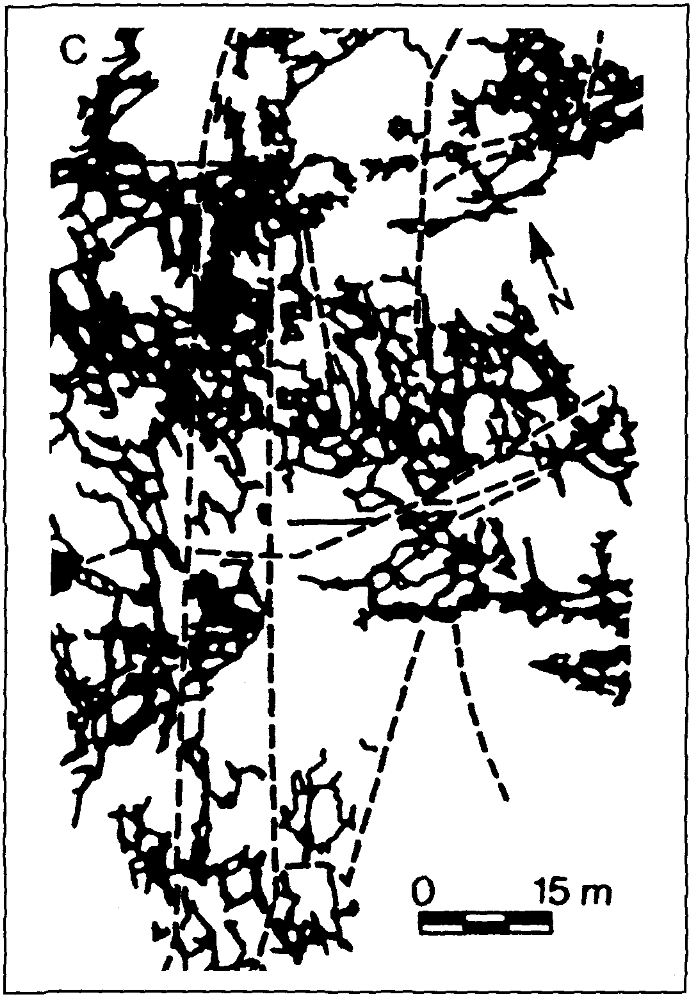

Fig. 7: Section of the Jefferson City Mine, Tennessee, where black is used to indicate galena deposits; it is evident how the mineralization has completely fossilised the 3-D maze karst system (from FORD & WILLIAMS, 1989, modified)

CHEMICAL DEPOSITS IN A THERMAL KARST SYSTEM

The ore deposits of MV type have been well documented and studied for their evident economical importance, but few specific papers have been written on particular hydrothermal karst deposits (HILL & FORTI, 1986)

The few existing papers reveal how the thermal caves are the shelter for peculiar concretions and a lot of cave minerals which are harder to find or totally absent in "normal" caves. In the paragraph dedicated to the thermal karst system we have already mentioned speleothems that can be directly referable to hydrothermal conditions (cave clouds, tower cones, gaysermites etc.) and therefore we will here only remark on the principal minerals which can be observed in thermal karst systems, as usual not taking into account those directly related to the ore deposit of MV type.

The secondary mineralization largely depends on the type of thermal fluid that circulates or has circulated in the cave: as it is not possible to list all the secondary minerals of thermal origin we will point out the more frequent, depending on the principal characteristics of the hot waters.

As previously said, thermal water always contains a great quantity of carbon dioxide and/or sulfidric acid; depending on the water chemistry, i.e. on the relative abundance of one or another of these two gases, the product of chemical deposition will vary enormously.

In the case when CO2 predominates, the most common deposit is calcite which is normally observed as an aggregate of large disphenoid crystals, often completely covering the cavity's walls and roof. Analysis has often indicated how these crystals have continued to develop from medium thermality up to meteoric waters, as in the Pfaff Cave in Sardinia (DE VIVO et al., 1987).

In the case when H2S predominates, gypsum is by far the most common deposit, under the form of more or less thick crusts of micro-crystals which may grow until reaching even total occlusion of great phreatic conduits; other much less common sulphates are barite, celestite etc.

Where H2S is dominant, a reasonably common deposit is sulphur which covers the walls of the aerate zone: its deposition is a direct consequence of the biological oxidation typical of the sulphur cycle in the vadose sections of the cave (FORTI, 1989).

Another common mineral in the hydrothermal caves is quartz: this mineral can be found in the systems characterised by dominating carbon dioxide and those with sulfidric acid even though it predominates in the last. It is generally observed under the form of great euhedral crystals: those deposited in the Jewel Cave in South Dakota (DEAL, 1962) are particularly famous. When, by chance, the thermal water temperature is not high enough, the silex is deposited as amorphous or cryptocrystalline speleothems, normally botryoidal opal.

Finally to give an example of the complexity of the thermal minerogenesis, we would like two small Italian cavities to be remembered which are united for the great interest in their secondary minerals: The Alum Cave at Volcano (Sicily) and the Cap Miseno Cave (Campania) (FORTI, 1992).

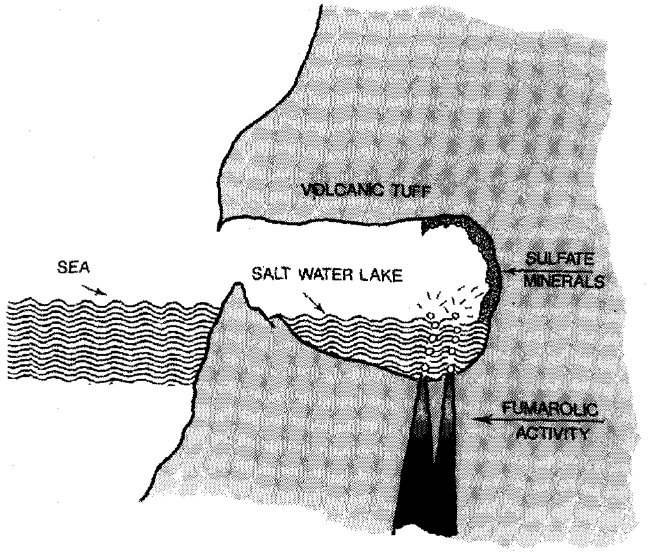

Fig. 8: The environmental conditions inside the Cap Miseno and Alum caves allow the mingling of sea water and thermal fluids and therefore cause the evolution of many rare secondary cave minerals (from FORTI, 1992)

They are two small tectonic cavities which open into volcanic tuff on sea level, therefore the saltwater in the cave comes in contact with fumarolic fluids, which react both with the salts in the sea water and with the tuff on the walls (see Fig. 8) giving place to an impressive series of minerals, some of which world-wide have only been observed inside these caves (see Tab. 1)

In the world, caves containing more than 4 or 5 different secondary minerals are extremely rare and merit absolute protection (HILL & FORTI, 1986), therefore it is understandable the exceptionality of these two small caves where the thermal fluids permit such an ample variety of peculiar deposits.

Table 1: The chemical deposits of Cap Miseno and the Alum Caves

MINERAL	Cave	Deposits morphological characteristics
Alunogen	M&A	small white to transparent crystals
Potash Alum	M	translucid lengthened fibres
Aragonite	A	coralloids
Coquimbite	A	small violet-pink hexagonal tablets
Hematite	M	translucent red - brown blades
Gypsum	A	acicular crystals
Halotrichite	M&A	white acicular fibres
Kalinite	A	acicular crystal tufts
Keramoalite	A	metallic silver coloured fibrous stalactite
Metavoltine	M&A	thin yellow hexagonal blades
Millosevichite	A	violet to green hygroscopic crusts
Misenite	M	pale grey soft fibre
Opal	A	small stalactite
Pickeringite	A	thin brilliant white crystals
Pisanite	A	green-blue crusts
Tamarugite	M	candid white elongated crystal figs
Voltaite	M&A	small pale green crusts
Sulphur	M	canary yellow crusts and single crystals

ACTIVE SPELEOGENETIC MECHANISMS AND THEIR MORPHOLOGIC AND DEPOSITIONAL EFFECT

At present, there are no general or specific papers in the international literature that relate morphologies and chemical deposits in thermal caves with the speleogenetic mechanisms which may be active in different zones of the aquifer.

Such analysis could be of extreme importance as it would permit, at least theoretically, recognition of the mechanisms which have affected the karst system maybe even in a remote age.

In fact, although there are at least ten different mechanisms which could make a thermal karst system evolve, each one has the possibility of being active only in a particular zone of the aquifer. The effect on the system varies from mechanism to mechanism and even internally of the same mechanism depending on the peculiar aquifer zone.

The biological oxidation of sulphur is an example: it can only be expressed in oxygen-rich zones, as in aerated places or at the most in the first meters down in the saturated area, but the results of such oxidation are far different. Gypsum flowers and elementary sulphur prevails in the aerate zones, while in the saturated one sulphur does not deposit and the gypsum is only of phreatic origin (thick deposits, undifferentiated or partially bladed, consisting of aggregates of micro crystals).

On the base of the few isolated and sporadic observations reported in the bibliography it was possible to schematise the existent relation between aquifer zones, the active speleogenetic mechanisms, the principal morphologies and/or evolved deposits (see Tab. 2).

This scheme is to be considered preliminary and essentially useful as a discussion base to reach a detailed relationship on the exististing relations between boundary conditions and evolved morphologies in a thermal karst system.

Table 2: Existent relations between aquifer zones, potentially active speleogenetic mechanisms, morphologies and/or chemical deposits developed in a hydrothermal karst system (modified from FORTI, 1994).

Zone	Mechanism	Morphologic or depositional effects
AE	Diffusion of CO_2 & H_2S	deposition of cave rafts, folia, tower cones, gaysermites
RE	Organic oxidation of H_2S	depositions of sulphur speleothems and crystals, large deposits of gypsum, opal crusts
ATE	Condensation corrosion	domed ceilings, accentuated forms of corrosion, gypsum deposits
INTER	Diffusion of CO_2 & H_2S	Megascallops, domed ceiling, bubble trials
FACE	Organic oxidation of H_2S	deposition of phreatic gypsum
S	Net dissolution	normal phreatic morphologies
A	Corrosion	normal phreatic morphologies
T	Mixing corrosion	domed shaped, branched, cavities via convective motions
U	Incongruent dissolution	large maze cave, deposit of MV type
R	Net disposition	large scalenoedric crystals of calcite
A	Pressure drop	deposition of large druse of calcite
T E	Temperature drop	deposition of various minerals in druses of large crystals

FINAL REMARKS

At the end of this short review on hydrothermal karst we can affirm that although the phenomenon is common in many parts of the globe it has been up to now certainly overestimated. This happened because our knowledge of the speleogenetic mechanisms was not sufficient to justify the evolution of complex morphologies and the great variability of chemical deposits in a normal karst environment, developed by meteoric seeping waters.

Apart from this, however, the hydrothermal karst systems maintain a great importance in the world and above all for the economic implications (mineral deposits of primary importance but not forgetting the hydrothermal exploitation). Notwithstanding this the thermal karst system is surely little known and less studied; the reason for this can be found in the complexity of the chemical-physical reactions which develop internally and which are often catalysed by living organisms (bacteria, nanobacteria, algae etc.), as recently demonstrated (AA. 1994).

Therefore an interdisciplinary approach is necessary fully to understand the thermal karst, in which scientists in hydrogeology, geology, karst and microbiology co-operate. It is auspicious that in the near future we are able to activate such multi-disciplinary research on this topic, maybe in Italy, a land especially rich in karst thermal phenomena.

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TERMALNI KRAŠKI SISTEMI

Povzetek

Termalni kraški sistemi so lahko pomemben hidrogeološki vir ali pomembna nahajališča rud. Kljub temu so zadevni prispevki zelo redki v mednarodni literaturi, v italijanski pa jih sploh ni.

V preteklosti se je za vsako jamo, ki je bila nenavadnih oblik ali je bila zapolnjena z eksotičnimi odkladninami, kot so nenavadni spelotemi ali različni minerali običajno menilo, da je nastala v hidrotermalnih razmerah.

V zadnjih desetih letih, ko se je naše znanje o različnih in od časa do časa bolj zamotanih speleogenetskih mehanizmih izboljšalo, se je večkrat pokazalo, da so številni, domnevno hidrotermalni kraški sistemi, nastali v normalnih okoliščinah.

Teoretično je neka jama hidrotermalnega nastanka (ali deloma takega) takrat, če so termalne tekočine (običajno vroča voda) tekle skoznjo (ali skozi njen del) vsaj v času njenega nastajanja.

Četudi je ta definicija zelo preprosta, so kriteriji, ki uvrščajo jamo med termalne relativno zamotani in često po njih ni mogoče napraviti zaključkov: najbolj gotov (čeprav najbolj redek) je tok vroče vode skozi jamo.

Iz literature poznamo več prispevkov, ki govore o posebnih termalnih sistemih, vendar zelo redki podajajo pregled preko te snovi (Ford & Williams 1989).

Večina raziskav se ukvarja z morfologijo takih jam. S tega vidika lahko hidrotermalne jame razdelimo v dve skupini (Müller & Salvary 1977); v monogene hidrotermalne jame, sestavljene iz velike osnovne votline, iz katere se širi navzgor razvejana mreža rovov v obliki zvonov; drugo skupino sestavljajo jame v obliki 2D in 3D labirintov. Možnosti za razvoj različnih tipov hidrotermalnih jam so dane z razpokanostjo kamnine, s prisotnostjo neprepustnih krovnih kamnin, z načinom napajanja in pretokom ter z drugimi dejavniki (Müller & Salvary 1977; Dubliansky 1980; Bakalowicz et al. 1987).

Le malo prispevkov govori o nenavadnih speleotemih iz hidrotermalnih jam in nobeden izmed njih s splošnega vidika (Hill & Forti 1986). Nasprotno pa je obilo literature o rudnih nahajališčih (tipa doline Mississippija) povezanih s termalnimi kraškimi sistemi (Dzulynsky & Sass-Gustkiewicz 1989).

Ni še bilo splošne raziskave, ki bi primerjala morfologijo in kemijske sedimente termalnega krasa s speleogenetskimi mehanizmi, ki lahko delujejo v raznih delih vodonosnika.

V resnici je, glede na kompleksnost in spremenljivost termalnih tekočin, mnogo raznih kemično-fizičnih reakcij, ki lahko delujejo v takem okolju. Vseeno pa lahko nekatere med njimi štejemo za najpomembnejše, glede na to, da same ali v kombinaciji z drugimi potekajo vsaj v delih večine izmed hidrotermalnih jam.

Nekatere od teh reakcij povzročajo ali samo raztapljanje ali samo odlaganje, toda večina med njimi povzroča "inkongruentno raztapljanje" (sočasno odlaganje in raztapljanje). Običajno ti mehanizmi lahko delujejo le v določenem delu vodonosnika in zato njihovi učinki kažejo na okolje, v katerem se je jama razvijala.

Zato bi bilo zelo pomembno, če bi lahko določili medsebojna razmerja med speleogenetskimi mehanizmi, deli vodonosnika in ustrezno morfologijo in/ali kemičnimi usedlinami. Ta prispevek daje v razpravo prvi poizkus take klasifikacije.

SHAPE OF FLUVIAL PEBBLES IN SURFACE AND SUBSURFACE KARST STREAM FROM MORAVIAN KARST, CZECH REPUBLIC

OBLIKA FLUVIALNI PRODNIKOV V POVRŠINSKIH IN PODZEMELJSKIH KRAŠKIH VODOTOKIH NA MORAVSKEM KRASU, ČEŠKA REPUBLIKA

JAROSLAV KADLEC

Izvleček UDK 556.34:553.628

Jaroslav Kadlec: Oblika fluvialnih prodnikov v površinskih in podzemeljskih kraških vodotokih na Moravskem krasu, Češka republika

Voda s kraških področij pogosto teče skozi jame, kjer se hidravlične razmere močno razlikujejo od površinskih. Na Moravskem krasu je avtor primerjal različne stopnje zaobljenosti prodnikov, ki jih prenašajo tokovi na površju in v podzemlju. Za študijo so bili izbrani recentni prodniki v Bili vodi in Punkvi. Dolžina površinskega teka je 18.5 km, podzemni tek pa je dolg 6 km. Skupno je bilo izmerjenih 960 prodnikov iz greywacke (velikost od 16 do 31.5 mm). Spremembe v obliki in zaobljenosti prodnikov v sedanjem vodotoku zanesljivo kažejo odvisnost fluvialnega drobirja od hidravličnih lastnosti okolja.

Ključne besede: kraški vodotok, fluvialni prodniki, oblika, zaobljenost

Abstract UDC 556.34:553.628

Jaroslav Kadlec: Shape of Fluvial Pebbles in Surface and Subsurface Karst Stream from Moravian Karst, Czech Republic

Streams draining karst areas often flow through caves which have significantly different hydraulic parameters than surface channels. The Moravian Karst yields a possibility of comparing different degrees of reworking of pebbles transported by streams in surface and subsurface environments. For the study of the reworking of fluvially deposited pebbles, modern sediments of the Bila Voda and Punkva Rivers were chosen. The length of the surface stream is 18.5 km; the subsurface stream is 6 km long. 960 pebbles of greywacke (size interval 16-31.5 mm) were measured in total. The changes in shape and roundness of pebbles in the modern stream channel persuasively demonstrated the dependence of reworking of clasts of fluvial sediments on the hydraulic conditions of the environment.

Key words: karst stream, fluvial pebbles, shape, roundness

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The karst environment is characterised by its unique hydrologic conditions. Streams draining karst areas often flow through caves which have significantly different hydraulic parameters than surface channels. The hydraulic conditions of the environment have a dominant influence on the means of transport and reworking of pebbles of fluvial sediments. The length of transportation and the degree of reworking of fluvial clasts depend on the kinetic energy of the flow. The energy of water increases either due to higher flow velocity or due to the increase in water amount. These processes are caused by higher water levels during spring thaw. Flood stages may also be occasionally caused by high rainfall in different periods of the year.

Several authors have studied the shape of pebbles in superficial streams and the level of their reworking (e.g. Sneed and Folk, 1958; Mills, 1979). Pebbles deposited by underground karstic streams were also investigated (e.g. Bull, 1978; Kranjc, 1981). Kranjc (1989, pp. 51- 54) published a data set characterizing reworking of pebbles in a subterranean river flowing through the Škocjanske Jame and Kačna Jama Caves. The set is complemented by three samples of a psephite collected from a surface stream at different distances in front of the caves. However, significant differences between reworking of pebbles in the surface stream and the underground stream are not apparent.

Moravian Karst yields a possibility of comparing different degrees of reworking of pebbles transported by streams in surface and subsurface environments. The common feature of rivers flowing through the Moravian Karst is the fact that the larger part of their catchment area is formed by non-karstic rocks of Lower Carboniferous age. On the boundary with the Devonian limestones of the Moravian Karst, the flows sink underground and continue through caves.

For the study of the reworking of fluvially deposited pebbles, modern sediments of the Bila Voda River were chosen. This stream originates in the Drahanska Vrchovina Upland 2 km southwest of Protivanov village. It flows through the Lower Carboniferous greywackes, siltstones and shales of the Protivanov and Rozstáni formations. Most of the pebbles transported by the Bila Voda River consist of fine - to medium-grained greywackes (83-98%), siltstones and shales are present in a much smaller scale (9-17%) and quartz can be found exceptionally in the psephitic fraction. The Bila Voda River originates 640 m a.s.l. and the length of its surface stream to the northern margin of the Moravian Karst is 18.5 km. South of the village of Holstejn, the stream sinks underground to the Rasovna Cave. It drops 30 m vertically and continues through the cave systems (Fig. 1.). In the Amaterska Jeskyne cave, the Bila Voda merges with a stream which sinks underground in the Sloupsko-Sosuvske caves. It is the Luha Creek and its tributaries. Waters of these two streams continue as the Punkva River through the Amaterska Cave towards the Macocha Chasm and Punkevni Caves. The subterranean river resurges on the bottom of the Pusty Žleb valley. Punkva continues 13 km on the surface and meets the Svitava River on the southern margin of the town of Blansko.

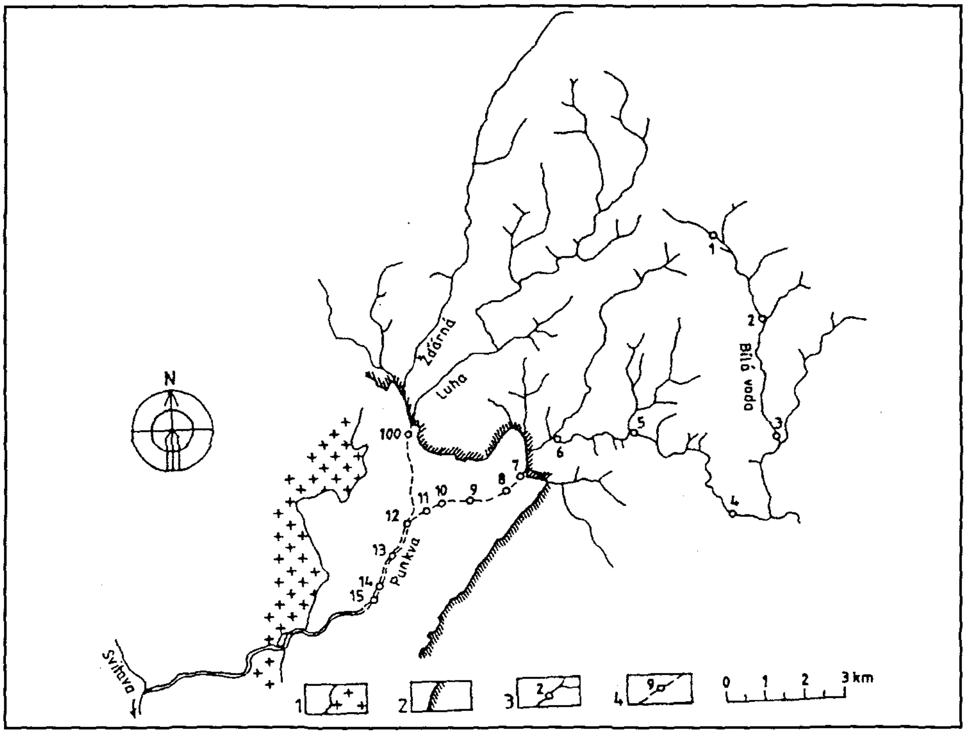

Fig. 1: The northern part of the Moravian Karst; 1 - boundary between Devonian limestones and Proterozoic Brno massiv, 2 - boundary between Devonian limestones and Lower Carboniferous non-karstic sediments, 3 - surface stream with a sampling point, 4 - subsurface stream with a sampling point

Sl. 1: Severni del Moravskega krasa; 1 - meja med devonskimi apnenci in proterozojskim masivom Brna, 2 - meja med devonskimi apnenci in spodnje karbonskimi nekraškimi sedimenti, 3 - površinski tok in mesto vzorčevanja, 4 - podzemeljski tok in mesto vzorčevanja

Reworking of the clasts during transportation both in the surface and underground channels of the Bila Voda and Punkva Rivers is expressed by the roundness and shape of the pebbles. Each sample consisted of 60 pebbles of greywacke from the size interval 16-31.5 mm (Ø = -4 to -5). Eight samples were collected in the surface channel and another eight in the caves. 960 pebbles were measured in total.

Roundness is determined by the ratio of the diameters of the largest and smallest circle drawn into the plane of the pebbles' largest projection (Dobkins and Folk, 1970). The resultant roundness of the suite of 60 pebbles is calculated as a weighted average. Weights are determined by the above average abundance in each bin of the roundness distribution. Figure 2-B shows that roundness in the surface flow gently rises downstream (samples 1-7). In places where short tributaries carrying less reworked pebbles enter the Bila Voda River, the roundness drops (samples 2, 4, 7). The profile of the flow rapidly changes its character at the ponor of the Bila Voda (Fig. 2-A). The hydrodynamic potential of the river increases and so does the rate of reworking of the pebbles. This is also caused by the specific hydraulic conditions of an underground environment. The stream flows through narrow places, often without open air surface, at an increased velocity. Another increase in the pebble roundness occurs after the confluence with the Luha Creek which transports more reworked clasts. The pebbles in a sample of fluvial sandy gravels collected in front of the ponor at Sloup (sample 100) are more rounded than those found in front of the sink of the Bila Voda River near Holstejn (Fig. 2-B). The steeper profile of the Luha increases the hydrodynamic potential of the flow causing higher roundness of clasts.

It is not possible reliably to determine the roundness of pebbles in the surface flow of the Punkva from its resurgence in the Pusty Žleb valley to its confluence with the Svitava River. Limestone and granitoid clasts dominate in the channel and it is not possible to collect a psephitic sample with the necessary amount of greywacke pebbles. This part of the Punkva surface stream is graded with the same slope as that of the Bila Voda from its spring to the sink in the Rasovna Cave (Fig. 2-A). One can thus assume that the roundness of pebbles in the surface flow of Punkva gently rises in the same manner as in the Bila Voda in the part represented by samples 1 to 7.

The shape of pebbles is determined by the ratio of all three axes and calculated by a formula used by Dobkins and Folk (1970). The resultant value is once again a weighted average of 60 values. Weights are determined from the above average abundance in each bin of the distribution. Positive values represent a rodlike pebble shape, negative values an oblate shape. An obvious trend in flattening of pebbles can be seen from the source of the Bila Voda downstream (Fig. 2-C, samples 1-7). In places where short tributaries bring less reworked clasts, rodlike pebbles are more abundant (samples 2,4,7). Continuous flattening downstream results from shortening of the shortest axes

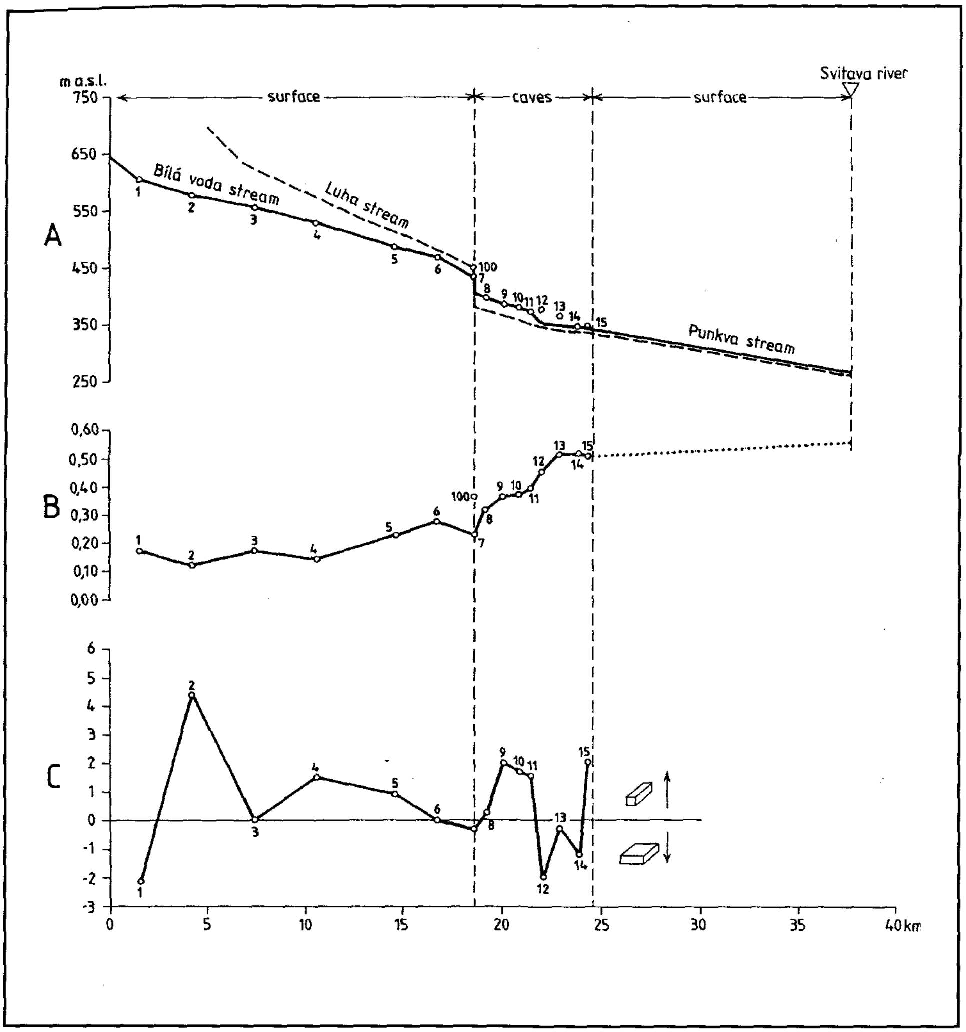

Fig. 2: A - gradient curves of the Luha, Bila Voda and Punkva rivers with sampling points, B - roundness of the pebbles, C - shape of the pebbles

Sl. 2: A - strmec rek Luha, Bila voda in Punkva z vzorčevalnimi mesti, B - zaobljenost prodnikov, C - oblika prodnikov

(S). This is caused by sliding of pebbles along the bottom of the channel. The flux pushes the clasts to the bottom by a force opposite to hydraulic lift (Blatt et al., 1972, p. 108). The same force causes imbrication of pebbles.

On the margin of the Moravian Karst where the Bila Voda sinks underground, hydraulic conditions change. In the karstic caverns which often form narrow channels, water flows with increased velocity often without a free air surface. The fluvial greywacke pebbles from the initial part of subterranean stream have significantly rodlike shapes (samples 9,10). The Bila Voda flows through several long narrow siphons connecting the caves. The increased velocity in the underground channels lowers the pressure (Dreybrodt, 1988, Kranjc, 1989). The clasts are not being forced to the bottom of the channel, they rotate around their long axes (L) and obtain a rodlike shape. The next segment of the active stream channel is mostly unknown as it is situated 10-20 m below the Amaterska Jeskyne cave which consists of vast flood passages probably active still in the Holocene. In some of the extremely spacious passages, the hydraulic conditions were similar to those of a surface channel. In such segments of the underground stream, the pebbles of greywacke were rapidly flattened due to decrease in water velocity and increase in pressure (samples 11,12,13). The last part of the underground flow of the Punkva River is formed by narrow channels and a 400 m long siphon between the Amaterska and Punkevni Caves. The pebbles become rodlike again due to the previously described mechanism (samples 14,15).

The changes in shape and roundness of pebbles in the modern stream channels of the Bila Voda and Punkva Rivers persuasively demonstrate the dependence of reworking of clasts of the fluvial sediments on the hydraulic conditions of the environment.

ACKNOWLEDGEMENT

The study of the shape of fluvial pebbles is a part of the project "Research of the Quaternary sediments of the Moravian Karst" supported by the Grant Agency of the Czech Republic (grant No. 205/93/0726).

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OBLIKA FLUVIALNIH PRODNIKOV V POVRŠINSKIH IN PODZEMELJSKIH KRAŠKIH VODOTOKIH NA MORAVSKEM KRASU, ČEŠKA REPUBLIKA

Povzetek

Voda s kraških področij pogosto teče skozi jame, kjer se hidravlične razmere močno razlikujejo od površinskih. Dolžina transporta in stopnja preoblikovanja fluvialnega kamninskega drobirja sta odvisni od kinetične energije vode, ta pa od hitrosti toka in od pretoka. Na Moravskem krasu so bile v okviru študije primerjane različne stopnje zaobljenosti prodnikov, ki jih prenašajo tokovi na površju in v podzemlju. Za študijo so bili izbrani recentni prodniki v Bili vodi in Punkvi. Njuna glavna značilnost je velik delež porečja na normalnem svetu, ob prehodu na devonske apnence pa reki ponikata in tečeta dalje pod zemljo. Dolžina površinskega teka je 18.5 km, podzemni tek pa je dolg 6 km. Skupno je bilo izmerjenih 960 prodnikov iz greywacke (velikost od 16 do 31.5 mm). Spremembe v obliki in zaobljenosti prodnikov v sedanjem vodotoku zanesljivo kažejo odvisnost fluvialnega drobirja od hidravličnih lastnosti okolja. Tako v zaobljenosti kot v obliki se pokažejo bistvene razlike med prodniki iz površinske in tistimi iz podzemeljske struge. Ponorna cona je tisti del rečne struge, kjer se lastnosti prodnikov najhitreje spremene.

HARACEAS IN THE TRNJE PROFILE

HARACEJE V PROFILU TRNJE

MARTIN KNEZ

Izvleček UDK 56.02(118)(497.4)
552.5(497.4)

Martin Knez: Haraceje v profilu Trnje

V kozinskih plasteh profila Trnje se, poleg različnih tipov haracejskih horizontov, pojavljajo le horizonti tipa "B: horizonti z oogoniji" - haraceje kažejo znake transporta. Predpostavlja se, da so oogonije prenašali vodni tokovi proti relativno globljim delom sedimentacijskega bazena. Na prehodu iz apnencev brez oogonijev v sedimente s številnimi oogoniji haracej ni sedimentoloških sprememb.

Ključne besede: geologija, paleoekologija, biostratigrafija, kozinske plasti, haraceje, Škocjanske jame, Slovenija

Abstract UDC 56.02(118)(497.4)
552.5(497.4)

Martin Knez: Haraceas in the Trnje Profile

Within the Kozina beds of the Trnje profile there appear horizons of "Type B: oogonia horizons" among the various types of Haracea horizons; Haraceas evidence characteristics of transport. It is presumed that oogonia were carried along by water currents towards relatively deeper parts of the sedimentary basin. Within the limestone beds, at the transition from the parts with no oogonia into the sediments containing numerous oogonia of Haracea, there are no sedimentological changes.

Key words: geology, paleoecology, biostratigraphy, Kozina beds, Haraceae, Škocjanske jame Caves, Slovenia

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INTRODUCTION

This work was written during sedimentological research of the beds in the close vicinity of the Škocjanske jame Caves. With regard to lithology, petrology and biostratigraphy, the area of Cretaceous and Palaeogene beds within the classical Karst territory has not yet been completely researched. Beside the above-mentioned, the results of palaeoecological research of sedimentation conditions in the Cretaceous and Tertiary sedimentary basin could be an additional aid to speleogenetical interpretations. The research is not of classical karstological or speleological significance, but it is a positive contribution to knowledge of the best represented rocks in the Karst area.

The study was carried out within the project Karst in Slovenia I, financed by the Ministry of Science and Technology of Republic of Slovenia.

PREVIOUS RESEARCH IN THE AREA OF THE TRNJE PROFILE

LOCATION OF THE TRNJE PROFILE WITH REGARD TO BROADER GEOLOGICAL STRUCTURE

The Trnje profile is located in the south-western section of the Postojna Basic Geological Map (S. Buser, K. Grad & M. Pleničar, 1967), in the vicinity of Divača (Fig. 1).

The profile is located on the Trieste-Komen plateau (the Trieste-Komen anticline), which is a tectonic unit of lower grade (S. Buser, 1973) and is part of the Adriatic-Ionian folded zone (M. Pleničar, 1970). On the south-western edge, the tectonic unit of the Trieste-Komen plateau borders on the Brkini Tertiary (D. Šikić & M. Pleničar, 1975; M. Pleničar, A. Polšak & D. Šikić, 1973). The territory is part of the former Dinaric Carboniferous platform (K. Drobne et al., 1988; S. Buser, 1989). According to S. Buser (1988) this territory belongs to the range of Zunanji Dinaridi.

BRIEF CHARACTERIZATION OF THE LIBURNIAN FORMATION

In south-western Slovenia and Istria, predominantly the Carboniferous sediments which appear within the rudist limestones and limestones containing alveolines and nummulites were named the Liburnian stage or protocene by G. Stache in 1872. This succession of beds was given detailed research by G. Stache, who in 1889 divided it into three parts: lower foraminiferous (imperforative)

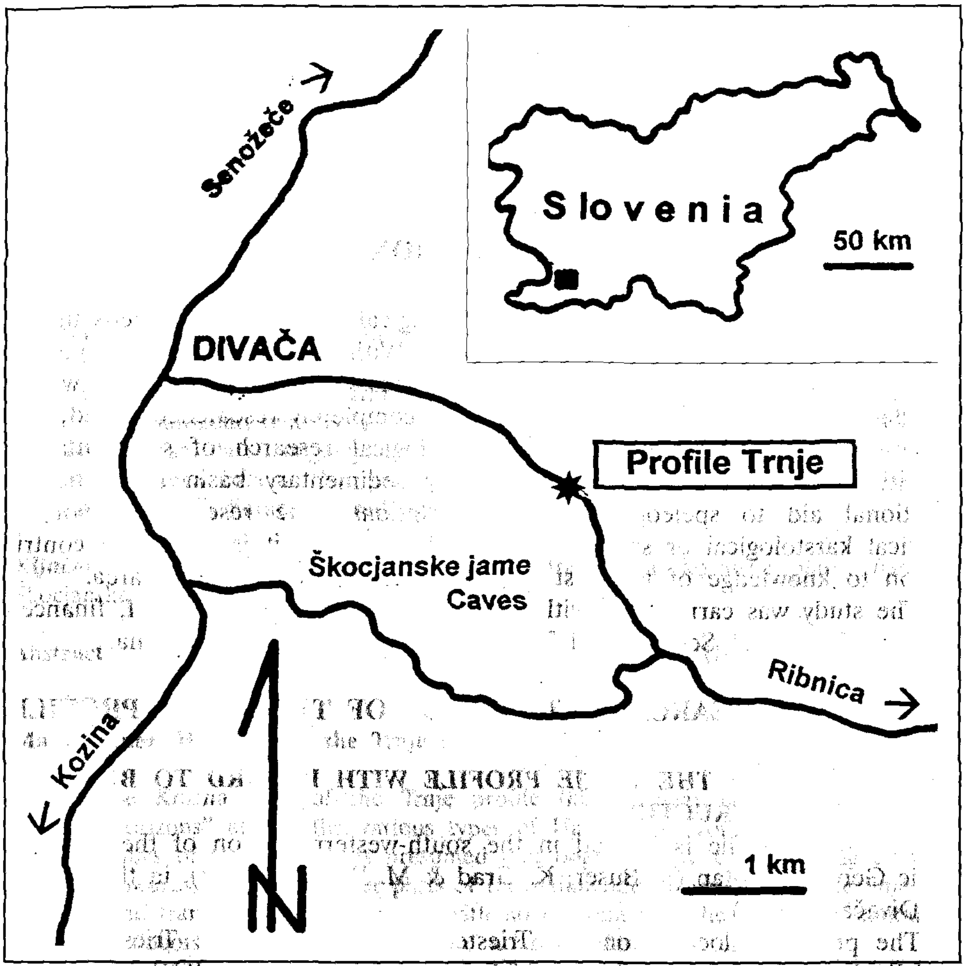

Fig. 1: Location of the profile Trnje
Sl. 1: Položaj profila Trnje

limestones, the Kozina beds with inliers of the major Haracea, limestone, and upper imperforative (milliolidic) limestone. The Liburnian formation (R. Pavlovec & M. Pleničar, 1979, 1981) is a chronolithological conception, which means that also lithologically and facially similar beds from the same development stage (from the Maastrichtian up to the Thanetian) are included into the Liburnian formation.

THE KOZINA BEDS

At present, the succession of beds is known as the Liburnian formation, which in its lower part is composed of the Vreme beds of Upper Maastrichtian age, in the middle part of the Kozina beds of Danian age and in its upper part of milliolidic limestones of Thanetian age (R. Pavlovec, 1963; K. Drobne, 1979; G. Bignot, 1972; M. Hötzl & R. Pavlovec, 1981; R. Pavlovec & M. Pleničar, 1983; R. Pavlovec & K. Drobne, 1991; M. Knez, 1994). G. Stache (1859) primarily knew only the middle part (the Kozina beds) of the succession of beds, although he distinguished between the lower and upper foraminiferous limestones.

The lower and the upper levels of the Kozina beds were divided by G. Stache (1859) into stomatopsis limestones and Haracea limestones respectively. Subsequently, the middle part of the beds was named by G. Stache (1889) the Kozina beds after the settlement of Kozina. This name has been retained up to the present time (K. Drobne & R. Pavlovec, 1991).

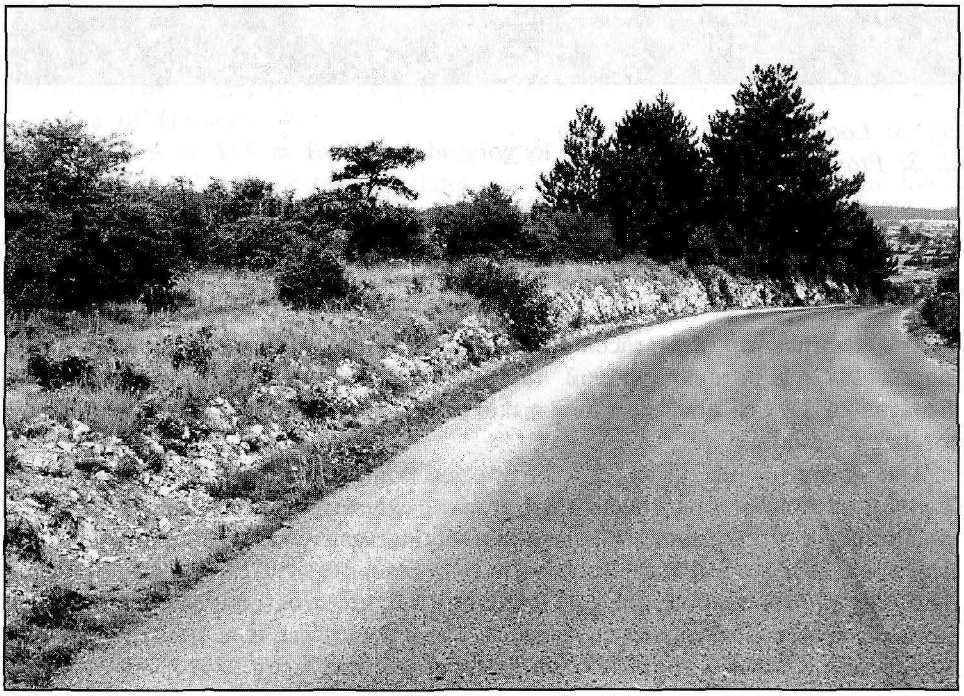

Fig. 2: The Trnje profile
Sl. 2: Profil Trnje

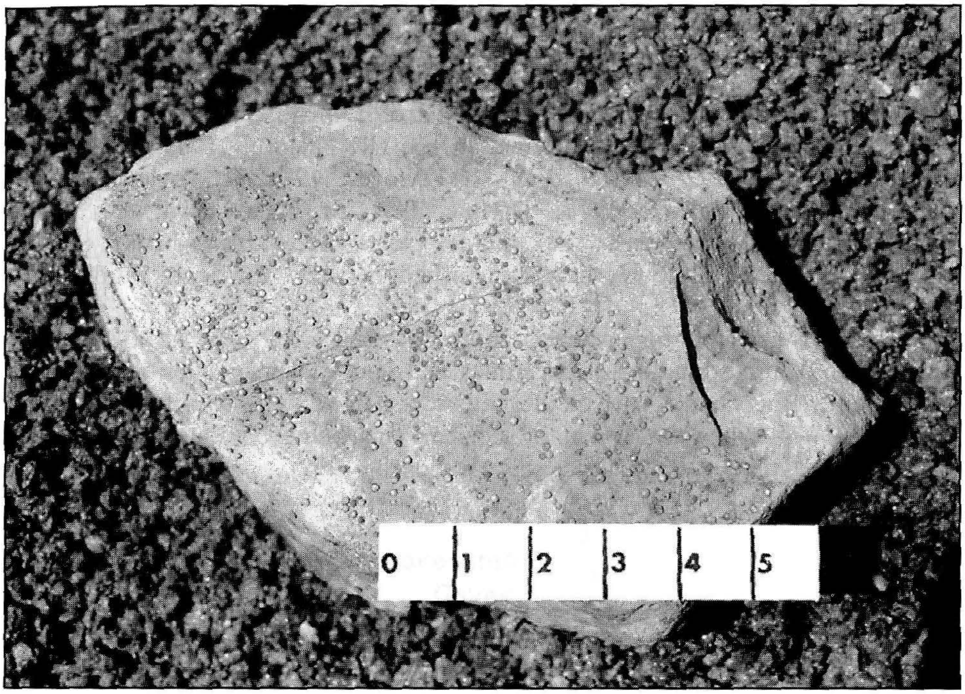

Fig. 3: Loose oogonia of Haracea
Sl. 3: Prosti oogoniji haracej

THE TRNJE PROFILE

The significance of Haracea has been discussed by numerous authors (G. Bignot, 1972; L. Grambast, 1962, 1965 and others) who did some research in the area of Divača and the Škocjanske jame Caves, but the Trnje profile has not been described yet.

The Trnje profile (Fig. 2) consists predominantly of Haracea oogonia (Fig. 3), except for one 10 cm thick horizon where beside oogonia also thalli of Haracea can be found. The oogonia of Haracea which appear within the Trnje profile were called Porochara by G. Stache (1889). G. Bignot and L. Grambast (1969) suppose that all oogonia of Haracea within the older part of the Kozina beds belong to the species Porochara stacheana. As this species can be found also in the youngest Palaeocene parts, they are of the opinion that this species was preserved particularly due to the fact that it was probably dependent and related to specific local ecological conditions or particularities of the genera Porochara.

The Trnje profile is located within a cutting of the road connecting the settlements of Famlje and Divača, about 550 m before the crossroads of the road already mentioned and another road leading to the settlement of Brežec. The profile is located in the close vicinity of a topographical feature called Trnje; for that reason I named it the Trnje profile.

DESCRIPTION OF THE TRNJE PROFILE

Due to a gentle dip of beds (mostly about 10 degrees, in places even less), better connection of individual parts of the profile, and due to very thin layers which occur only occasionally, I decided to describe the profile in nine interconnecting sections (Fig. 4). The dip of beds is mostly 180/10.

Section 1 at 68 m from the begging of the profile

In the lower half of the 180 cm thick section there are 10 to 20 cm thick limestone beds; in the upper half the beds are 40 cm thick.

In the lower part of the profile up to a thickness of 90 cm there is dark-brown slightly bituminous limestone without oogonia of Haracea. At 90 cm thickness, the first individual oogonia can be found. A similar density of Haracea oogonia (approx. 5 per 100 cm^2) can be followed to a thickness of 180 cm.

Section 2 at 88 m from the begging of the profile

The thickness of limestone beds within the 220 cm thick second section is 20 to 60 cm. This part of the profile consists of dark-grey limestone without oogonia of Haracea.

Section 3 at 113 m from the begging of the profile

Within the 2 m thick section, there are 30 to 40 cm thick beds in the lower third of the section; in the upper two thirds the beds are 10 to 50 cm thick.

The lower part consists of black dense limestone which contains individual oogonia of Haracea 30 cm above the margin of the section, in a some-centimetre-thick horizon. Upwards there follows dark-brown limestone without Haracea. Individual Haracea reappear at 120 cm. Between 120 cm and 190 cm there appears dark-brown limestone without oogonia. At 200 cm, oogonia of Haracea and their fragments appear much more frequently and make up a horizon.

Section 4 at 140 m from the begging of the profile

The thickness of beds in this section is 140 cm. Within the lower 50 cm part, light-grey compact and nonbituminous limestone appears without any fossils. At 50 cm it turns into dark-brown to black bituminous limestone interwoven with numerous stylolite stitches. Oogonia of Haracea, partly whole and partly fragmented, appear in the same limestone at 120 cm.

Section 5 at 148 m from the begging of the profile

In the lower part, the beds are 5 to 40 cm thick, and in the upper 70 cm. The total thickness of the section is 150 cm. At 20 cm, numerous oogonia particles appear in dark-brown limestone. Stylolite stitches are distributed in various directions.

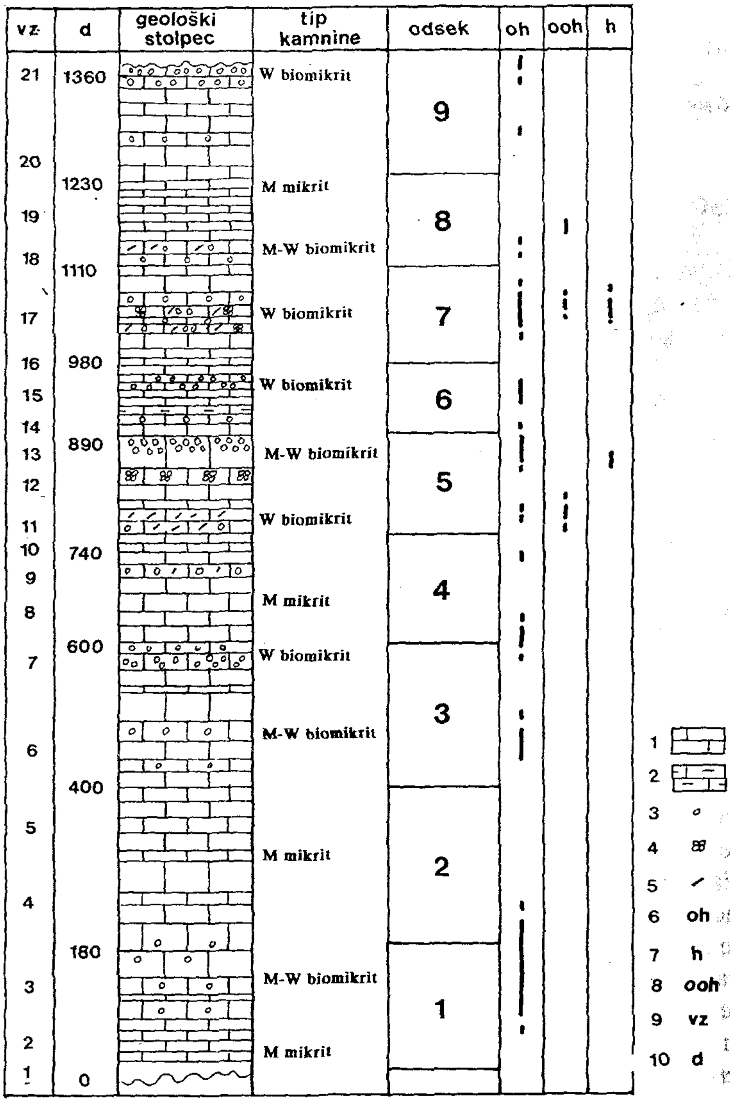

Fig. 4: Geological column of the Trnje profile. 1 - limestone, 2 - marly limestone, 3 - oogonia, 4 - oogonia with algae parts, 5 - oogonia fragments, 6 - oogonia of Haracea, 7 - oogonia and other parts of Haracea, 8 - fragments of Haracea oogonia, 9 - sample, 10 - thickness (in cm)

Sl. 4: Geološki stolpec profila Trnje. 1 - apnenec, 2 - laporni apnenec, 3 - oogoniji, 4 - oogoniji z deli steljke, 5 - odlomki oogonijev, 6 - oogoniji haracej, 7 - oogoniji in drugi deli haracej, 8 - odlomki oogonijev haracej, 9 - vzorec, 10 - debelina (cm)

Fragmented and broken oogonia particles prevail between 20 cm and 40 cm. The majority of oogonia lack one half and some up to three fourths of the whole size. Within this horizon there are almost no undamaged oogonia of Haracea. At 40 cm, limestone turns lighter. Here no oogonia fragments can be found. The last individual whole oogonia within this horizon appear at 50 cm. In dark-brown dense limestone at 90 cm and 140 cm, there appear two thinner, about 10 cm thick horizons with well preserved oogonia.

At 148 cm there is the 15 cm thick first horizon, which besides two other horizons is the richest in oogonia of Haracea. The limestone instantly contains numerous oogonia. Parts of the horizon containing distributed oogonia of Haracea can be well seen. These parts of the horizon are parallel to each other and to the limestone beds (Fig. 5).

Section 6 at 154 m from the begging of the profile

In the lower part of the sixth segment the thickness of beds is about 30 cm; the profile between 30 cm and 90 cm consists of 3 to 10 cm thick beds.

Within the lower 20 cm part of a highly bituminous dark-brown and compact limestone, whole oogonia of Haracea and their fragments can rarely

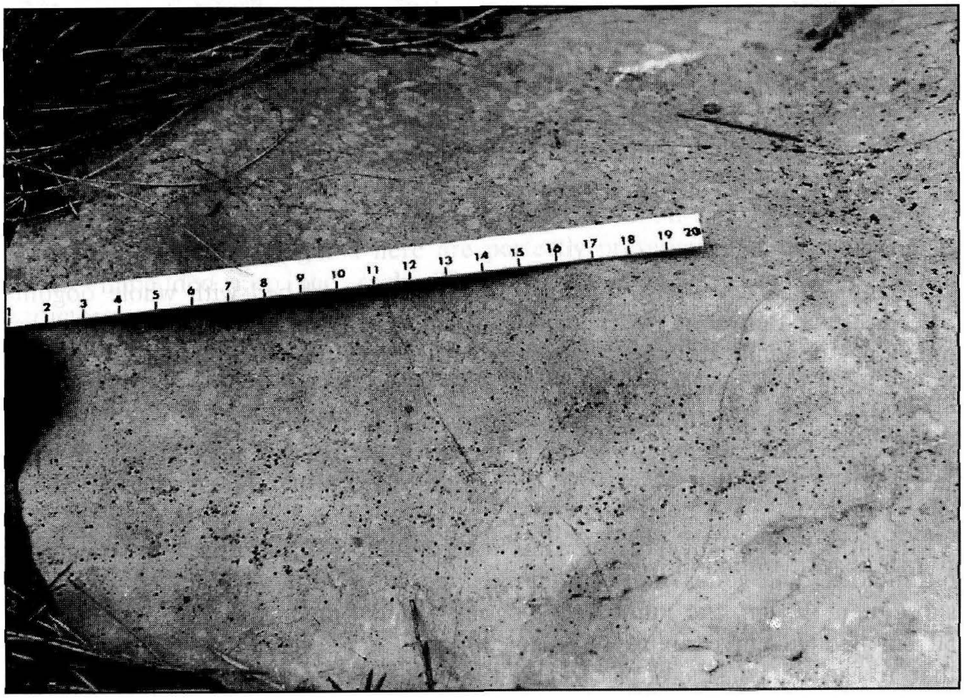

Fig. 5: The first horizon containing Haracea. It is parallel to the succession of beds.
Sl. 5: Prvi horizont s haracejami. Horizont je vzporeden s plastnatostjo.

Fig. 6: Thin-bedded limestone within Section 7
Sl. 6: Drobnoplastnat apnenec v sedmem odseku

be found. At 30 cm there appears a 3 cm thick marl bed with whole oogonia of Haracea. Between 30 cm and 70 cm of the limestone, there appear individual oogonia and their fragments. At 70 cm there is a horizon of light-brown limestone which contains whole oogonia of Haracea.

Section 7 at 165 m from the begging of the profile

The thickness of limestone beds in the lower 70 cm part of the seventh section is 3 to 8 cm; between 70 cm and 130 cm the thickness is 10 to 20 cm (Fig. 6).

In the lower 40 cm part, the limestone is almost black, dense, solid, slightly bituminous and does not contain Haracea or other fossils. Within the subsequent 10 cm, the number of oogonia rapidly increases. The part between 50 cm and 70 cm contains so many oogonia and some other parts of plants that it can be considered as a Haracea horizon.

Among the oogonia fragments which can be found in this horizon there are also broken particles of Haracea thalli. At 100 cm thickness, only oogonia of Haracea can be seen.

Section 8 at 171 m from the begging of the profile

The thickness of the beds within the lower 40 cm is 10 cm to 20 cm, and upwards to the top of the section the thickness is 1 cm to 5 cm. In the profile, bedding planes between individual beds are often undulating, but in general they are parallel to the succession of beds.

In the lower 30 cm of dark-brown, highly bituminous limestone there are individual oogonia of Haracea and their numerous fragments. At 30, cm the oogonia fragments gradually disappear. Ten centimetres upwards in the profile there are only individual oogonia to be found in brown bituminous limestone. The thin-bedded limestone contains numerous stylolites.

Between 30 cm and 40 cm there is a thin-bedded, slightly marly limestone containing individual oogonia of Haracea. Due to weathering, the beds of the 3 cm to 7 cm thick bedded limestone contain a lighter upper and lower margin, the middle part of the beds is darker.

Individual oogonia of Haracea and their occasional fragments can again be found at 80 cm of the 5 cm thick horizon. There follows a highly marly limestone, which at 100 cm thickness turns into a black, bituminous, dense and compact limestone without oogonia of Haracea or other fossils.

Section 9 at 179 m from the begging of the profile

The thickness of the ninth section is 130 cm. The thickness of beds in the lower half is about 30 cm and in the upper half between 5 cm and 30 cm.

The lower 30 cm of the last section within the Trnje profile is composed of dense, dark-brown to black micrite limestone without any fossils. At 30 cm, the limestone is exceptionally bituminous. Numerous Haracea which appear instantly can be seen between 30 cm and 40 cm. Here the oogonia of Haracea are so numerous that they make up a horizon. At 50 cm, the Haracea gradually disappear. Oogonia here are perfectly preserved, but they are mostly firmly imbedded into the rock. Their surface consists of a typical spiral structure.

At 50 cm, a lighter brown micrite limestone without any Haracea is covered with numerous stylolites which run in various directions; approximately one half of them is parallel to the beds, the other half is perpendicular to the beds.

At 70 cm there is a 10 cm thick bed of recrystallized limestone. Above the bed there is a 10 cm thick horizon containing less numerous, well-preserved oogonia of Haracea. Between 70 cm and 80 cm, the grey limestone contains also rare oogonia fragments. Light-grey limestone without any fossils can be found upwards up to the 120 cm of the profile.

The last horizon containing oogonia of Haraces is at 120 cm above the bottom of the section. The number of Haracea increases with the darkness of the limestone. A slightly marly limestone is dark - to grey-brown.

PALAEOECOLOGICAL OBSERVATIONS

PALAEOGEOGRAPHICAL AND PALAEOECOLOGICAL PROPERTIES OF THE LIBURNIAN FORMATION

The beds of the Liburnian formation were formed in the period from the Maastrichtian to the Thanetian (R. Pavlovec & K. Drobne, 1991). M. Pleničar, A. Polšak and D. Šikić (1973) say that the region of the Slovenian Littoral was influenced by the Laramian folding at the end of the Cretaceous. During the Danian and the Palaeocene, the sea transgraded into the already formed synclines. According to D. Šikić and M. Pleničar (1975), this part of the territory is characteristized by general rising at the end of the Cretaceous. In the transitional period between the Cretateous and the Tertiary, the sea bed oscillated many times.

After sedimentation of beds with rudists there followed regression, due to which the Vreme beds started to form in Slovenia (R. Pavlovec, 1981).

According to the latest research, the beds of the Liburnian formation are neither completely marine nor completely of fresh-water origin. Above the Vreme beds there are limestones containing numerous Haracea. These limestones evidence the proximity of freshwater or brackish environments (R. Pavlovec, 1981).

THE KOZINA BEDS

Types of horizons containing haracea

Individual horizons containing Haracea have not been separately dealt with by most of the authors. Haracea do not appear within one or more beds, they appear in horizons which represent one or more beds.

Within the Kozina beds of the Trnje profile there appear only horizons of "Type B: oogonia horizons" among the various types of Haracea horizons (M. Knez, 1996). With Type B, I characterize the Haracea horizons which evidence characteristics of transport. Of the whole plant only oogonia are preserved (Fig. 7).

Interpretation of the haracea horizons

When speaking of Haracea, it is necessary to take into account that they are quite easily carried along by water streams and waves. For this reason only resedimented Haracea of Type B can be found within most of the limestones of the Kozina beds. Due to fragility, parts of algae are broken during the transport and integrate into the sediment. Mostly only their oogonia are preserved at secondary sites. A. Carozzi (1953) is of the opinion that only those horizons can be considered as autochthonous which beside oogonia contain also parts of whole algae. This opinion is shared also by R. Pavlovec (1963), saying that most of the Haracea remains within the Liburnian sediments can be found at secondary sites. The remains of Haracea meadows are only those Haracea horizons which beside oogonia contain also many other preserved parts of plants.

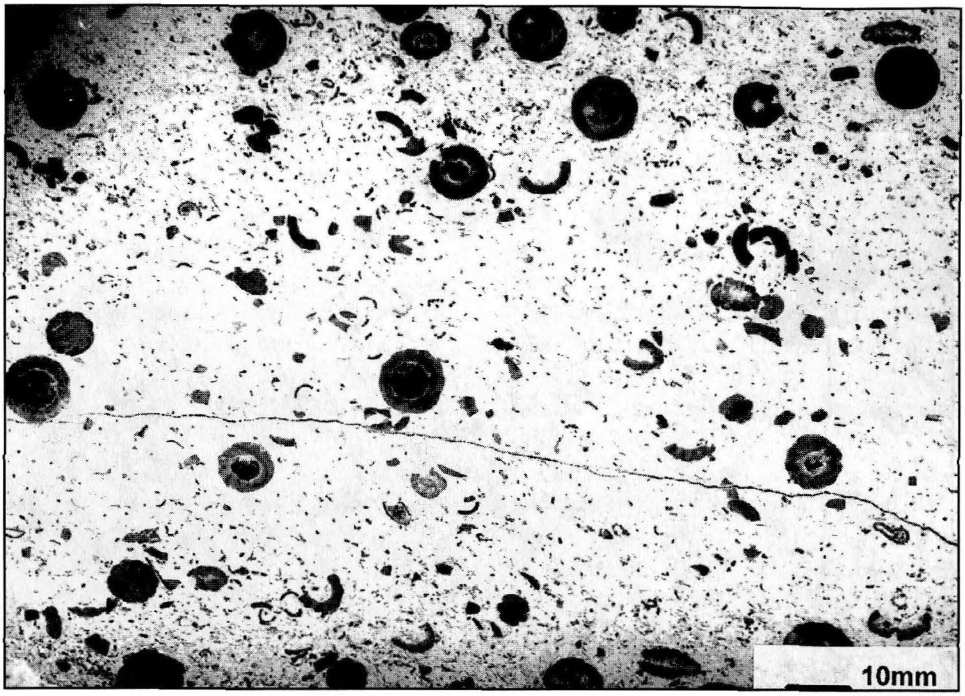

Fig. 7: Haracea indicating the signs of transport. Of the whole plant only oogonia are preserved
Sl. 7: Haraceje kažejo znake transporta. Od celotne rastline so ohranjeni samo oogoniji

Within the Trnje profile, only oogonia of Haracea can be found. There are no major sedimentological changes within the beds of limestones and slightly marly limestones containing no oogonia, as well as in the sediments with numerous oogonia of Haracea (Fig. 8), which means that during deposition of the material there were no major changes in sedimentation. The micrite basis evidences that the environment of sedimentation was relatively calm and shallow, but not calm and shallow enough for oogonia to be preserved in the environment, which on the contrary is the case within the Divača profile. Presumably, the dead remains of Haracea suffered a short transport towards a relatively deeper (with regard to the environment of sedimentation in the Divača profile) part of the sedimentary basin. Here only the most resistant parts of Haracea - oogonia - were preserved. Within the Trnje profile, the other parts of thalli can only exceptionally be found.

Within the Trnje profile, I have discovered only three horizons containing an extreme number of Haracea oogonia. In these horizons, in places also a

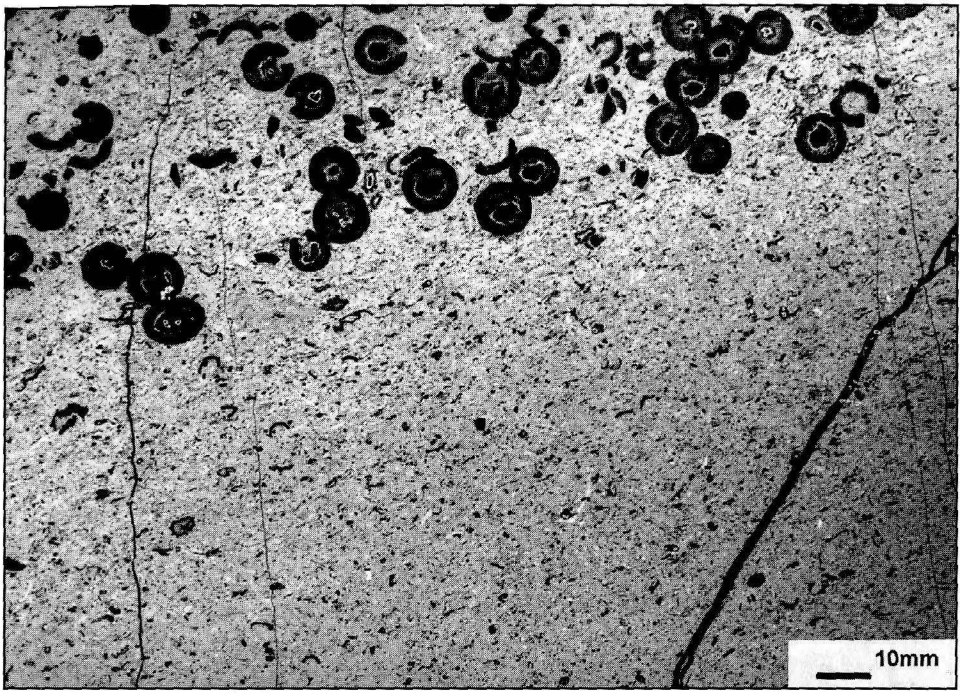

Fig. 8: Transition from the beds with no oogonia remains into the sediments containing numerous oogonia of Haracea - here no lithological and sedimentological changes occur
Sl. 8: Na prehodu iz plasti, v katerih ni oogonijev v sedimente s številnimi oogoniji haracej, ni litoloških in sedimentoloških sprememb

great number of oogonia fragments can be found among well preserved whole oogonia. As conditions within the sediment are almost the same as those in the sediment with horizons containing Gyropleura (M. Knez, 1994), I presume that numerous Haracea were brought to the site of sedimentation by stormy waves and water currents.

CONCLUSION

The basic aim of my research work was to study the environment of bed sedimentation in that part of the Kozina beds which contains Haracea. I have come to the following conclusions:

1. In the Kozina beds of the Trnje profile, I discovered exclusively only the specimens of resedimented Haracea particles (oogonia).

2. I presume that oogonia were carried along by water currents towards relatively deeper parts of the sedimentary basin.
3. Within the limestone beds, at the transition from the parts with no oogonia into the sediments containing numerous oogonia of Haracea, there are no sedimentological changes.

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HARACEJE V PROFILU TRNJE*

Povzetek

Profil Trnje leži v vseku ceste, ki povezuje vas Famlje z Divačo, približno 550 m pred križiščem s potjo, ki vodi v vas Brežec. Ker je profil v neposredni bližini topografskega imena Trnje, sem ga tako tudi imenoval. Profil je na jugozahodnem robu Osnovne geološke karte, list Postojna (Buser, S., Grad, K. & Pleničar, M. 1967).

Zaradi položnega vpada plasti (večinoma okrog 10 stopinj, ponekod tudi manj), zaradi boljše povezave posameznih delov profila in zaradi ponekod zelo drobne plastnatosti, sem profil opisal v devetih odsekih, ki so med seboj povezani. Vpad plasti je večinoma 180/10.

V profilu Trnje najdemo le oogonije haracej. V apnencih in rahlo lapornatih apnencih na prehodu iz plasti, v katerih ni oogonijev v sedimente s številnimi oogoniji haracej ni večjih litoloških in sedimentoloških sprememb. To pomeni, da med odlaganjem materiala ni bilo večjih sprememb v sedimentaciji. Mikritna osnova kaže, da je bilo okolje sedimentacije relativno mirno in plitvo (energijski indeks 1 do 2). Kljub temu pa ne toliko, da bi se oogoniji obdržali v svojem življenjskem položaju, kot je to primer v profilu Divača. Predvidevam, da so odmrli ostanki rastlin haracej pretrpeli krajši transport proti relativno globljemu (glede na okolje sedimentcije v profilu Divača) delu sedimentacijskega bazena. Pri tem so se ohranili le najodpornejši deli haracej - oogoniji. Ostale dele talusov najdemo v profilu Trnje le izjemoma.

V profilu Trnje sem našel tri horizonte, kjer so oogoniji haracej izredno številni. Med dobro ohranjenimi celimi oogoniji je v teh horizontih ponekod tudi veliko njihovih odlomkov. Ker so razmere v sedimentu skoraj enake s sedimentom, ki sem ga opisal v horizontih z giroplevrami, predvidevam, da so številne haraceje na mesto sedimentacije prav tako prinesli navihtni valovi in tokovi.

V kozinskih plasteh profila Trnje se, poleg različnih tipov haracejskih horizontov, pojavljajo le horizonti tipa “B: horizonti z oogoniji” - haraceje kažejo znake transporta. Predpostavlja se, da so oogonije prenašali vodni tokovi proti relativno globljim delom sedimentacijskega bazena. Na prehodu iz apnencev brez oogonijev v sedimente s številnimi oogoniji haracej ni sedimentoloških sprememb.

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SINKING RIVERS QUALITY - THE PIVKA CASE STUDY

KVALITETA PONIKALNIC - PRIMER REKE PIVKE

JANJA KOGOVŠEK

Izvleček UDK 551.448(497.4)

Janja Kogovšek: Kvaliteta ponikalnic - primer reke Pivke

Prispevek obravnava kvaliteto ponikalnice Pivke na ponoru v Postojnsko jamo. Pivka sprejema odpadne komunalne in industrijske vode naselij, od katerih čistijo le odpadne vode Postojne. Z različnimi pristopi pri vzorčevanju so skušali zajeti čim več značilnosti Pivke. Občasna opazovanja so podala nihanja posameznih parametrov in opozorila na kritične situacije, ki nastopajo v zimski in poletni suši zaradi nizkega vodostaja Pivke že v zgornjem delu struge. Kritičnost se odraža v nizki vsebnosti raztopljenega kisika ter prisotnosti organskega onesnaženja. Podrobnejša sistematična opazovanja tekom 24 ur so podala značilnosti kvalitete ob nizkih zimskih in poletnih vodah ter ob naraščanju in upadanju pretoka.

Ključne besede: krasoslovje, ponikalnice, kvaliteta vode, hidrološki dogodki, reka Pivka, Slovenija

Abstract UDC 551.448(497.4)

Janja Kogovšek: Sinking rivers quality - The Pivka case study

The paper deals with the quality of the Pivka sinking stream at the Postojnska jama swallow-hole. In its superficial flow the Pivka receives waste communal and industrial waters from the villages; only the waste waters of Postojna itself are treated. By various methods of sampling the author tried to estimate properties of the Pivka quality. Periodical observations provided the variations of single parameters during the observations and pointed out critical situations occurring during winter and summer drought. During drought the water level is low and the Pivka sinks in upstream parts of the riverbed already. Specially critical is the low level of dissolved oxygen and the presence of organic pollution. Detailed systematic observations during 24 hours provided properties of water quality at low winter and summer levels and also at increase, or decrease of discharge.

Key words: karstology, sinking stream, water quality, hydrological events, the Pivka river, Slovenia

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INTRODUCTION

Sinking rivers are exposed during their superficial flow to pollution by waste municipal and industrial waters and also due to agriculture and various waste disposal sites. When sinking in the poljes they transport this pollution underground and it reappears at the resurgences. It means that "the same water" and "the same pollution" reappears again at the resurgences; in the case of the Ljubljanica this repeats five times. Thus pollution of the upstream part of a sinking flow means the pollution of the entire flow and of all the resurgences. This fact dictates the need for care for quality at the first swallow-hole already, the treatment of waste waters flowing underground and control over its quality.

PIVKA SINKING RIVER

The Pivka sinking river flows 15 km on the surface before disappearing into Postojnska jama. Along its flow there are several settlements where people are engaged in agriculture or employed in the wood industry (Fig. 1). More or less untreated waste waters flow into the Pivka. Since 1987 only the town of Postojna has had treatment for the major part of the municipal waters. After sinking into Postojnska jama the Pivka receives tributaries: we are aware of the polluted Črni potok but it is possible that the stream and waste waters of Studeno village flow into it too. The Pivka reappears in Planinska jama where, underground, it is joined by the Rak river; the water flowing out of the cave is called the Unica.

In the past the sinking Pivka river has been studied several times. In 1974 hydrologists from Sarajevo studied the processes of self-purification capacity in its underground flow (Preka & Preka-Lipold 1976). The Pivka pollution problem was studied by Sket and Velkavrh (1981). In the years 1984 and 1985 analyses of the Pivka quality along its flow and the quality of its tributaries were carried out (Gospodarič 1989). At the same time detailed observations of the Pivka quality were made at the swallow-hole to Postojnska jama, along its underground flow in Pivka jama and in Planinska jama (Kogovšek 1991).

During dry periods in summer and autumn the Pivka low waters disappear in the riverbed upstream; this means that the water at the swallow-hole is mainly that of its tributary - the Nanoščica. During high water level the Pivka is diluted by springs at Žeje and Trnje and by the superficial stream of the

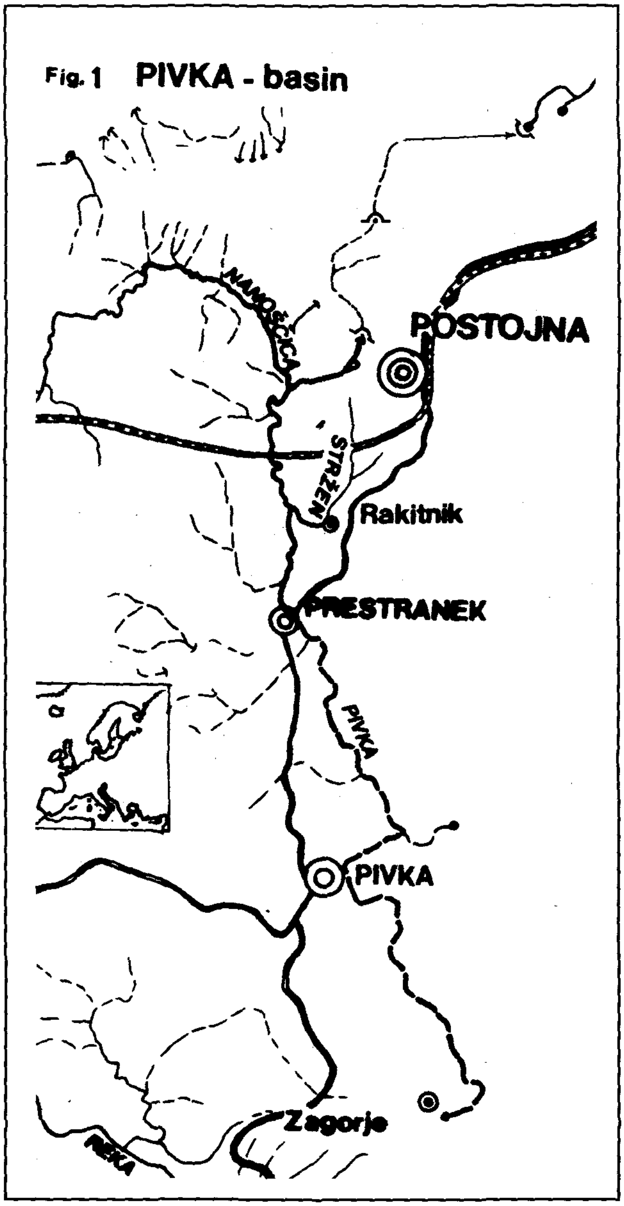

Fig. 1: The Pivka sinking river appears near Zagorje and in its superficial flow up to the swallow-hole at the entrance to Postojnska Jama receives waste communal and industrial waters from the villages
Sl. 1: Ponikalnica Pivka izvira pri Zagorju in na poti do ponora v Postojnsko jamo sprejema vodo pritokov kot tudi odpadne vode naselij

Slavenski potok (Gospodarič & Habič, 1985). Thus the waters of Pivka are of various discharges and quality at the Postojnska jama swallow-hole where the river starts its underground way towards Planinska jama (air distance 7.3 km); at low waters it requires 5 days and at high water 7 hours only (Sket & Velkavrh 1981).

PIVKA QUALITY - SEASONAL OBSERVATIONS IN THE YEARS 1984-1985

The Pivka quality at its ponor into Postojnska jama was observed at first seasonally and later in more detail. The increased concentrations of all the studied parameters, except for dissolved oxygen, indicated the deterioration of the quality.

Seasonal observations mostly assessed critical situations of the Pivka quality connected with low water level in summer and autumn months, August, September and October. In that time the level of o-phosphate and chloride, the level of chemical (COD) and biochemical (BOD) oxygen demand and specific electric conductivity (SEC) increase were observed and at the same time the decrease of dissolved oxygen concentrations (Kogovšek 1991).

Due to efficient Postojna waste water treatment at the water works which started in 1987, the concentrations of the above-mentioned parameters decreased considerably. COD decreased by one third, BOD_5 by 3 times, chlorides by 2 times and o-phosphates by 5 times.

Poor Pivka quality occurs during winter drought at low discharges and temperatures. A part of water freezes and the pollution concentrates in the remaining water. We have measured even bigger COD values than in summer drought due to slower decomposition, and lower self-purification effect at low temperatures.

During rains the waste waters are joined by meteoric waters and the quantity augments so much that the water treatment plant is able to treat one part only, the remaining water flows into Pivka directly. But, the dilution is so effective that the water quality is even better than during the efficient treatment of all the waste waters when the water level is low.

DETAILED OBSERVATIONS OF PIVKA QUALITY WERE MADE DURING LOW STABLE WATER LEVEL IN AUGUST 1985, JULY 1991 AND FEBRUARY 1993.

The observations show that the levels of chloride and o-phosphate variations are small, yet COD, BOD, nitrate and oxygen levels vary much more.

In February 1993 at temperatures below 2°C the COD during 24 hours did not change essentially. In August 1985 at temperatures between 18 and 20°C the first maximum was noted about noon and a little lower second maximum about 8 p.m. In July 1991 at approximately the same conditions we measured a compatible increase of COD at midday. But at that time the water treatment plant was already in action; thus the COD increase probably reflects the general pollution increase in the last years.

Comparing the nitrate levels of February 1993 with August 1985, the first were considerably higher (Fig. 2). Even during periodical measurements after the water treatment plant started to operate, the nitrates, unlike other parameters, increased.

O-phosphates were considerably lower in winter 1993 and summer 1991 than in August 1985, reflecting the efficient phosphate treatment by the water treatment plant (Fig. 3).

In July 1991 the chlorides were substantially lower than in August 1985, but in February 1993 they were high again, probably due to road salting during the winter (Fig. 4).

These detailed observations have shown that it is very important at which time of the day the sinking stream is sampled because COD, BOD_5 and dissolved oxygen levels vary substantially during a day.

DETAILED OBSERVATIONS OF THE PIVKA QUALITY AT INCREASE AND DECREASE OF DISCHARGE

In March 1992 we observed a water pulse at water temperatures between 6 and 8°C when the Pivka discharge greatly increased, and later decreased

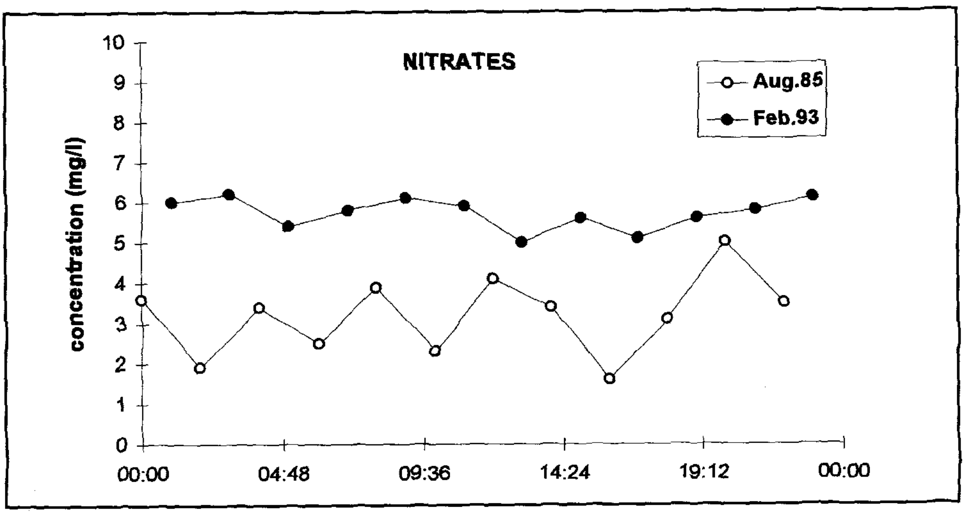

Fig. 2: A detailed study of nitrate levels in the Pivka at the swallow-hole to Postojnska Jama at low water level in winter, February 1993 and in summer, August 1985

Sl. 2: Podrobno spremljanje nitratov Pivke na ponoru v Postojnsko jamo ob nizkem vodostaju pozimi februarja 1993 in poleti avgusta 1985

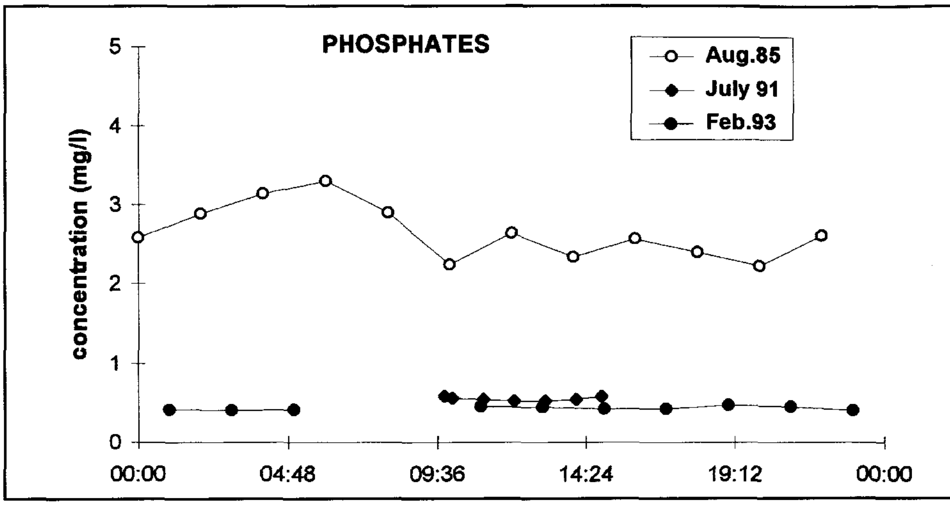

Fig. 3: A detailed study of phosphate levels in the Pivka at the swallow-hole to Postojnska Jama at low water level in winter, February 1993 and in summer, August 1985 and July 1991

Sl. 3: Podrobno spremljanje vsebnosti fosfatov Pivke na ponoru v Postojnsko jamo ob nizkem vodostaju pozimi (februarja 1993) in poleti (avgusta 1985 in julija 1991)

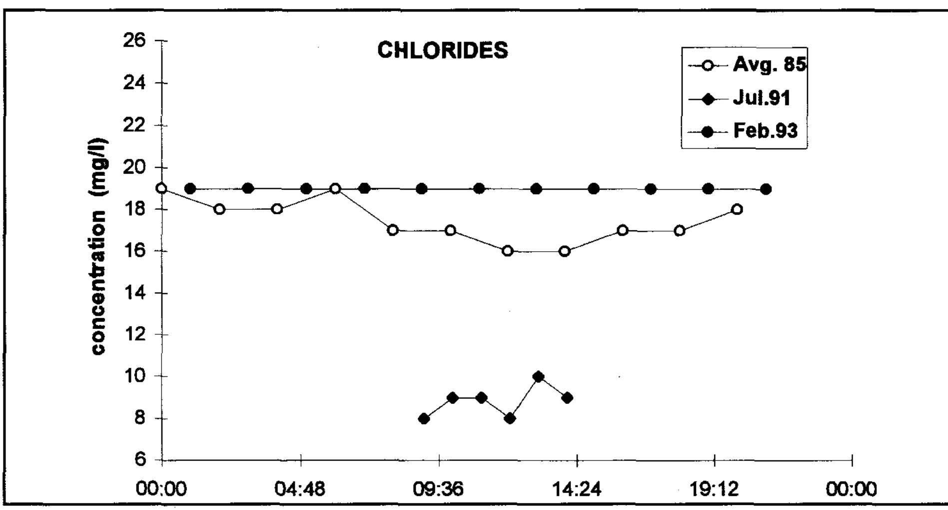

Fig. 4: A detailed study of chloride levels in the Pivka at the swallow-hole to Postojnska Jama at low water level in winter, February 1993 and in summer, August 1985 and July 1991

Sl. 4: Podrobno spremljanje vsebnosti kloridov Pivke na ponoru v Postojnsko jamo ob nizkem vodostaju pozimi (februarja 1993) in poleti (avgusta 1985 in julija 1991)

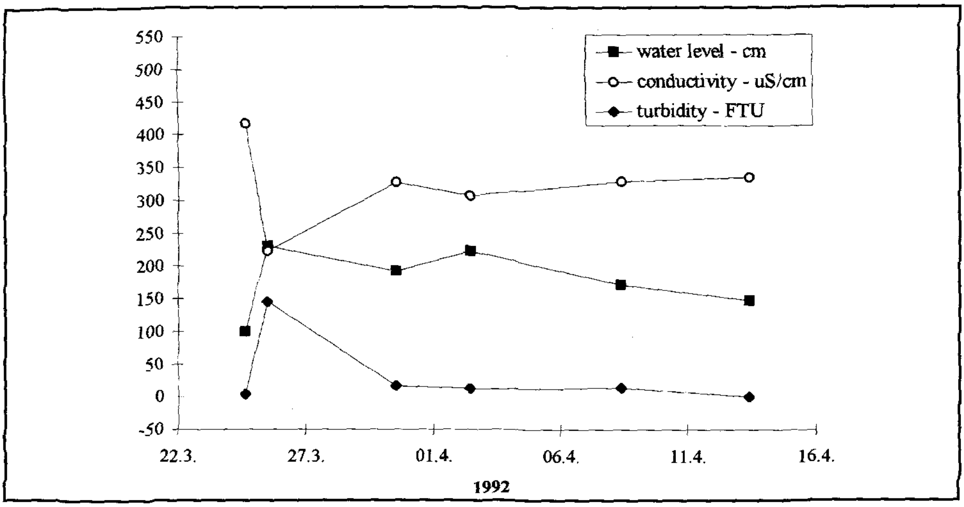

Fig. 5: Water pulse of the Pivka at the swallow-hole in Postojnska Jama in March 1992: measurements of water level, specific electric conductivity and turbidity
Sl. 5: Vodni val Pivke na ponoru v Postojnsko jamo marca 1992: meritve vodostaja, specifične električne prevodnosti in kalnosti

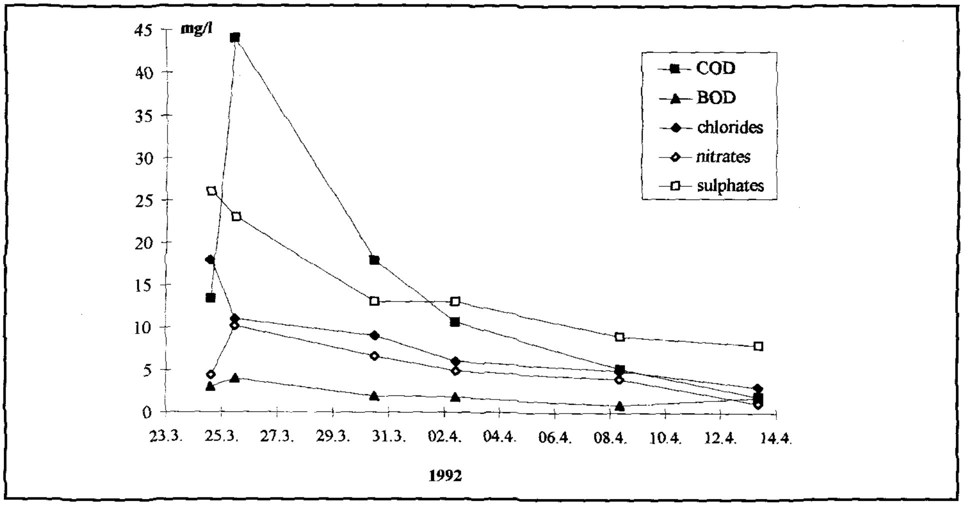

Fig. 6: Water pulse of the Pivka at the swallow-hole in Postojnska Jama in March 1992: measurements of chemical (COD) and biochemical (BOD) oxygen demand and chloride, sulphate and nitrate levels
Sl. 6: Vodni val Pivke na ponoru v Postojnsko jamo marca 1992: meritve kemijske (COD) in biokemijske (BOD) potrebe po kisiku, vsebnosti kloridov, sulfatov in nitratov

slowly. When the discharge increased, the turbidity increased also yet SEC decreased (Fig. 5). Referring to other measured parameters, COD increased the most (maximum level 44 mg O_2 l^{-1}) while BOD_5 and nitrate much less due to riverbed outwash after a long dry period. At maximum discharge maximum values of COD, BOD, and nitrate levels were registered. Regarding chloride and sulphate levels the dilution effect was noticed and continuous steady decrease of their concentrations (Fig. 6). High output of chloride levels is due to winter road salting.

A similar water pulse or increase of the Pivka discharge was observed during May 1994 (Fig. 7). By sampling we mostly got the initial part of the discharge increase. We sampled in Pivka jama. At first the water level increased slowly and on May 22 much more.

Slow discharge increase after the first days was followed by contemporaneous slow increase in concentrations of the chloride and nitrate levels and conspicuous increase in COD which reached its maximum value of 28 mg O_2 l^{-1} even before the discharge of the Pivka level considerably increased. This high increase in discharge caused higher dilution and thus COD started to decrease in the same manner as it increased previously. The decrease of the sulphate and chloride level was less dramatic.

Nitrates were relatively low and gradually increasing even when higher dilution occurred due to discharge increase.

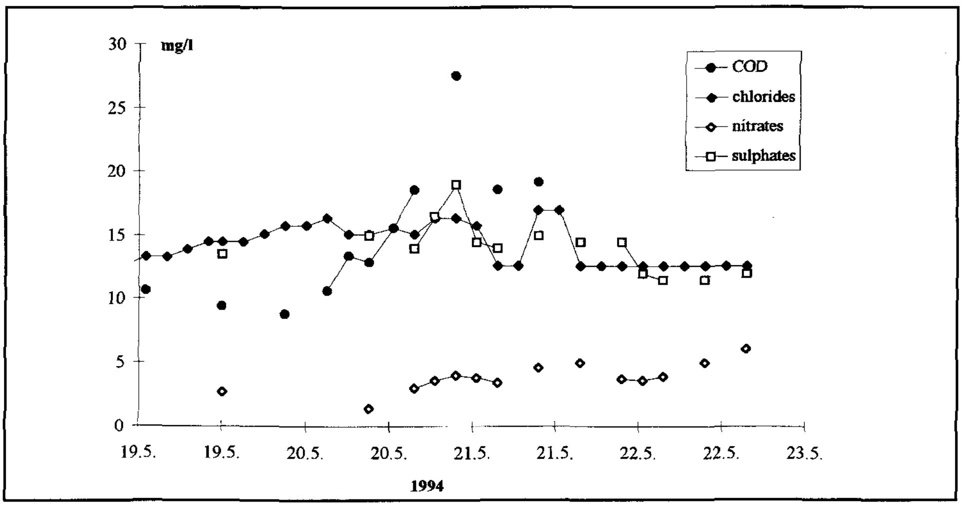

Fig. 7: Measurements of chemical oxygen demand (COD) and levels of chloride, sulphate and nitrate during the Pivka level increase at the swallow-hole to Postojnska Jama in May 1994
Sl. 7: Meritve kemijske potrebe po kisiku (COD), vsebnosti kloridov, sulfatov in nitratov ob naraščanju Pivke na ponoru v Postojnsko jamo maja 1994

THE COMPARISON OF BOTH WATER PULSES OF THE PIVKA

Almost four months before the observed water pulse in March 1992 there was no serious rainfall (altogether slightly less than 100 mm had fallen as gentle rain). Abundant rainfall occurring in March 23 and 25 and slightly less intensive at the beginning of April caused a high water pulse of the Pivka; we observed it at the swallow-hole to Postojnska jama where the water level increased for 1.30 m and decreased very slowly. Intensive showers washed the riverbeds of the tributaries and of the Pivka and in spite of high dilution effect a very high turbidity and increased organic pollution and increased nitrate level occurred. The initial state of the measured parameters existing before this water pulse were not restored in less than a week; considering the quantity of water this indicates that serious pollution was washed underground. High dilution was reflected in a conspicuous decrease of SEC due to dilution of most of the dissolved components, in particular chloride, sulphate and phosphate levels.

The water pulse in May 1994 occurred after a relatively wet April and after the rainfall at the beginning of May when the pollution was every time washed away. The amount of rainfall in May 18 and 20 was smaller than that of March 1992 and created a less distinctive water pulse. Again a prominent increase in organic pollution was recorded yet it was considerably smaller than in the observed water pulse in March 1992; the pollution appeared in the initial part of the water pulse, it lasted for two days but later discharge increase already exhibited a dilution effect.

CONCLUSION

We inferred that critical situations of the Pivka quality at the swallow-hole occur at low waters in summer and in autumn, and also in winter. The Pivka pollution varies over a day, the worsening of its quality in the last years means that water treatment for the villages which now drain directly into the Pivka and treatment of all the waste waters of Postojna, is urgent. The water treatment plant in Postojna now treats only a part of Postojna waste waters.

Water pulses, the increase of the stream discharge after a longer time without rainfall results in flushing of the riverbeds and other tributaries and the transport of this pollution underground. When the water quantity increases this pollution pulse is followed by strong dilution and a better situation is restored.

The quality in Planinska jama depends on the quality at the swallow-hole. Until 1989 good quality of the Pivka was registered in Planinska jama due to favourable self-purification processes in the underground. The deterioration was registered in 1990 and 1991. Later, in 1993 and 1995 we did not record the deterioration of the Pivka quality in Planinska jama at low water level. We infer that it was a case of periodic, short-lasting major pollutions; however, a true state of the Pivka quality at its resurgence might be shown by regular monitoring of its waters only.

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KVALITETA PONIKALNIC - PRIMER REKE PIVKE

Povzetek

Ponikalnica Pivka na svoji 15 km dolgi poti po površju do ponora teče ob naseljih, kjer se ljudje ukvarjajo s kmetijstvom ali pa so zaposleni v lesni industriji. Odpadne vode boj ali manj direktno odtekajo neočiščene v Pivko, saj ima čiščenje odpadnih voda od leta 1987 le Postojna. Po ponikanju v Postojnsko jamo dobi še pritoke, onesnažen Črni potok, zelo verjetno tudi potok pri Studenem, v katerega se izlivajo odpadne vode tega naselja, verjetno pa tudi nam neznane pritoke. Pivka se nato ponovno pojavi v Planinski jami. Za svojo 7.3 km dolgo podzemno pot (zračna razdalja) potrebuje ob visokih vodah 7 ur (B. Sket & F. Velkavrh 1981), ob nizki vodi pa pet dni.

Z različnimi pristopi pri raziskovanju kvalitete Pivke, predvsem pri vzorčevanju smo skušali zajeti čim več značilnosti njene kvalitete. Občasna opazovanja Pivke smo dopolnili s podrobnejšimi sistematičnimi opazovanji ob nizkih vodah v poletni in zimski suši tekom 24 ur, ter s pogostimi opazovanji ob naraščanju in upadanju njenega pretoka po izdatnejših padavinah.

Ugotovili smo, da kritične situacije kvalitete Pivke na ponoru v Postojnsko jamo nastopajo ob njenem nizkem vodostaju kasno poleti in jeseni, pa tudi pozimi. Onesnaženje Pivke niha že preko dneva, občasna poslabšanja njene kvalitete v zadnjih letih pa kažejo, da je nujno čiščenje odpadnih voda naselij ob Pivki, kot tudi celotnih odpadnih voda Postojne.

Vodni valovi, naraščanje pretoka Pivke po izdatnejših padavinah, ko dalj časa ni bilo dežja, pomenijo spiranje odloženega onesnaženja iz struge Pivke

in njenih pritokov ter prenos tega onesnaženja v kraško podzemlje. Temu povečanju onesnaženosti v začetku vodnega vala sledi močna razredčitev in tako vzpostavitev boljše kvalitete Pivke.

Kvaliteta Pivke v Planinski jami zavisi od njene kvalitete na ponoru v Postojnsko jamo, od razredčevalnih ali onesnaževalnih učinkov pritokov ter od poteka samočistilnih procesov v podzemlju. Do leta 1989 je bila zabeležena dobra kvaliteta Pivke v Planinski jami. Kasnejše občasne meritve pa so pokazale na njeno poslabšanje. Sklepamo, da gre le za krajša poslabšanja, ki nastopajo po daljših sušnih obdobjih, ko prve padavine dobro sperejo akumulirano onesnaženje iz strug Pivke in pritokov in jih v vodnem valu hitro prenesejo do ponovnega izvira v Planinski jami. Pri krajšem zadrževalnem času potečejo samočistilni procesi v podzemlju v znatno manjši meri, kar rezultira v slabši kvaliteti Pivke v Planinski jami. Podrobno sliko kvalitete Pivke bi dala le redna opazovanja njene kvalitete.

THE VERTICAL RUN-OFF OF RAINFALL THROUGH DOLINES
The examples of dolines above Planinska Jama and Pivka Jama

VERTIKALNI ODTOK PADAVIN SKOZI VRTAČE
Primer vrtač nad Planinsko in Pivko jamo

JANJA KOGOVŠEK

Izvleček UDK 556.12:551.442(497.4)

Janja Kogovšek: Vertikalni odtok padavin skozi vrtače. Primer vrtač nad Planinsko in Pivko jamo

Za izdatnejše curke se predvideva, da se napajajo iz območij vrtač. To so ugotavljali s sledilnimi poskusi na območju Planinske in Pivke jame. Vrtača nad Planinsko jamo, ki jo ločijo od jame 100 m debeli apnenci, odvaja hitro in večje količine padavinske vode po glavnem, prepustnejšem prevodniku. Po spletu slabše prepustnih prevodnikov, ki so povezani z glavnim prevodnikom, pa se pretakajo počasneje manjše količine. Iz vrtače nad Pivko jamo vodita skozi 40 m debele kamnine dva prepustnejša prevodnika, ki odvajata večje količine vode. Spremlja ju večje število manjših prevodnikov. Zaledja curkov so med seboj prepletena, vendar so njihove medsebojne povezave zelo različno prepustne.

Ključne besede: krasoslovje, kraška hidrologija, prenikajoča voda, sledilni poskusi, vertikalna prepustnost, Planinska jama, Pivka jama, Slovenija

Abstract UDC 556.12:551.442(497.4)

Janja Kogovšek: The vertical run-off of rainfall through dolines. The examples of dolines above Planinska Jama and Pivka Jama

It was presumed that the abundant trickles are fed from the areas covered by dolines. Later we confirmed this by water tracing tests above Planinska Jama and Pivka Jama. The dolines above Planinska Jama, separated from the cave by a 100 m thick layer of limestones, drain the rainfall water fast through the main, more permeable conduit. By a system of less permeable conduits which are associated with the main one, smaller quantities drain much more slowly. From a doline above Pivka jama two highly permeable conduits lead through 40 m thick rocks draining a significant amount of water. Around them several smaller conduits exist. The recharge area of the trickles is connected but their mutual links are of various permeabilities.

Key words: karstology, karst hydrology, percolation water, water tracing test, vertical permeability, Planinska Jama, Pivka Jama, Slovenia

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INTRODUCTION

The difference between particular caves or their parts is evident by an attentive view of the underground spaces at equal or similar rainfall and hydrological conditions. In some places abundant trickles prevail, elsewhere only moderate drops, in some parts no infiltrated water may be seen. These facts aroused the question what is the reason that the rainwater from the surface gathers into abundant trickles in the cave. One of the reasons are dolines. Ford and Williams (1989) discuss the water discharge from the dolines where solution creates more and more significant vertical water permeability.

THE WATER RUN-OFF FROM THE DOLINE ABOVE PLANINSKA JAMA

For several years the solvent capacity of the abundant trickle 1 was monitored in Planinska Jama. Its discharge seasonally varied from 30 ml min^{-1} to 200 l min^{-1}, the annual quantity of infiltrated water amounted to 2000 m^3 and the quantity of carbonates, dissolved by the water in the cave roof and transported into the cave, exceeded 400 kg. We presumed that the trickle is fed by the area of doline on the surface. We tried to prove it by water tracing from the doline (Kogovšek & Habič 1981).

According to the known geological structure (Gospodarič 1976) we chose the most probable doline for draining the water into the observed trickle. It is about 15 m in diameter; in the bottom 3,5 m of soil was measured suggesting the possibility of accumulation and retention of the rainfall, and the prolongation of its discharge. Into a bore-hole, directly in the rock 100 m above the cave, we poured a solution of Uranin and within 90 minutes we flushed it by two cisterns of water (14 m^3). Three weeks before and after the injection there was no rainfall worth mentioning. Thus only the added water with tracer drained into the underground.

Positive result was obtained at trickle 3 (increase of discharge and appearance of tracer) some meters only distant from the trickle 1, where less distinctive appearance of tracer without discharge reaction was noticed. There were no other significant trickles near; the tracer did not occur in the drops. However the major quantity of tracer and added water drained through the spring X that lies about 60 m west from the bottom of a doline in the Unica riverbed which was previously unknown to us; obviously it appeared seasonally after heavy rain and was active only during the time when the water level of the Unica increased and was hence it submerged by the flood water (Fig. 1).

Monitoring of the discharge showed the most intensive drainage of almost half of added water during the first ten hours; later the discharge decreased sharply and fluctuated about the value 2 l min^{-1} showing the connection of a main, very permeable conduit with a system of less permeable conduits. Spring X drained in the first ten hours after the injection more than 6000 l, and in following 20 hours additional 2000 l, altogether more than 60% of all the water and more than 20% of Uranin that were added. Relatively slow discharge of the remained tracer through spring X and secondary impulses of tracer and appearance of tracer in the trickles show that the recharge from the doline is done by numerous, interrelated conduits; however, the most permeable conduit is the one towards the spring X.

The knowledge was completed by the tracing result during naturally wet conditions when a six-times smaller amount of tracer was used. Tracer was dissolved in 30 l of water and poured into a borehole without additional water. At spring X the tracer appeared after 9 hours, although the first heavy rainfall occured after 2 days only. In that time the tracer appeared in trickle 3 as well, but it was not recorded in trickle 1. It shows that the recharge under the natural conditions is much slower than under intensive artificial watering. In trickle 1 we did not detect the tracer due to the small quantity that was injected, and due to big dilution.

Thus we concluded that trickles 1 and 3 are fed substantially out of the doline area, maybe from the nearby doline. From the doline where the tracing test was done the water flows through a system of conduits which are connected with the main X highly permeable conduit that recharges a significant amount of rainwater into the underground.

However, only parallel double tracing under exactly the same conditions from a doline and from a nearby area out of doline would record the differences in rainfall drainage from the karst surface. Till now only one tracing was achieved and at that time tracer was not injected into doline. This was tracing through 100 m thick cave roof above Kristalni Rov when tracer was injected into a cess-pit of waste waters, it means, directly in the rocky base of a roof (Kogovšek 1995). During 16 days the most abundant trickle drained only 3% of total 5 m^3 of water that was added to tracer. Compared to this statement the drainage from the doline above Planinska Jama into spring X is extremely fast. The flushing of Uranin out of a cave roof was intensified after each abundant rainfall and lasted for one year and a half. Unfortunately we did not possess appropriate equipment for continuous monitoring of discharge which would enable us to calculate the returned amount of tracer and would give us many concrete answers useful for future researches.

WATER RUN-OFF FROM THE DOLINE ABOVE PIVKA JAMA

A similar case of water run-off from the doline underground was observed in the area of Pivka Jama where we identified, on a basis of pollution, the trickles that receive the water within a doline area (Fig. 2).

The lavatories were built in the doline on the surface at Pivka Jama Camp and the waste water drained by a cess-pit without bottom directly to a rocky bottom through the 40 m thick cave roof into the trickles. The trickle area covers about 10 m in radius. In order to prove that conection and to get detailed picture about the permeability of particular trickles we carried out a tracing test with added water. From the water taps 4,7 m^3 of water were injected. The most intensive reaction was at the trickle on the pathway (8); other smaller trickles and droppings showed various smaller reactions (Kogovšek 1987). Obviously this was the reason that the cave managers built the roof at this place to protect the cave visitors.

During the summer season, when up to 400 people overnighted in the campsite above, we observed the recharge oscillations and the composition of the infiltrated water. There was no rainfall. The peaks in discharge appeared in the morning and in the evening, this is the time when the most of water is used in the campsite. For comparison we observed the droppings away from the polluted area where no discharge occurred.

We observed also how the trickle from this area reacts to rainfall, the so-called water pulse. The discharge of the less permeable trickle 3 reacted after 1 hour, but reached its maximum 4 hours after the rain began. The near droppings reacted immediately. The abundant trickle on the pathway (8) did not react before the other trickles reached the maximum and it decreased faster. Obviously the water from the doline is drained by differently permeable conduits.

In 1985 the campsite was renewed and the doline was deepened, the upper layer of rock was removed, and later modern lavatories and toilets were built. Due to construction work, blasting included, the waste water used the previous conduits out of the doline; when the works were done we assessed increased pollution of the infiltrated water but we explained it by intensive flushing of accumulated pollution from the cave roof because of building work.

The waste waters from the new lavatories were directed into treatment plant. But our analyses in the cave showed that the sewage system was not tight enough and in the cave polluted water still occured. The manager was not persuaded and by his order several tracing tests were carried out.

TRACER EXPERIMENTS IN PIVKA JAMA

In the years from 1992 to 1994 several tracing tests were carried out in the doline area. In all the cases when we injected the tracer directly into the sewage system some percents of water and tracer appeared in the cave. Hence it is obvious that the sewage system is not completely tight, however the majority of waste water drains into water treatment plant.

On June 19, 1992 we injected 31 g of Uranin into an external channel close to the wall and watered the tracer by 9 m^3. After one hour the tracer and increased discharge were noticed at the trickles 2, 4, 5 and 15*, being the most at the last. The trickle 15* lies about 10 m northwards from the bottom of a doline. The trickles 7 and 9 were slightly late with considerably poorer response of tracer and its concentration.

In May 1994, during low level of the cave infiltrated water, a combined tracing test from three different points into the sewage system was carried out (Kogovšek 1994). We used Uranin, Rhodamin and NaCl (into sinks of showers, toilets and washbasins). The tracers were diluted by 4,7 m^3 of water.

Only about one percent of the injected water appeared in the cave. A small recharge pulse was recorded at the most permeable trickle 15* while the trickles 4 (Tik levo) and 7 (Na stalagmit) did not react. At the points 2 (A ciklus), 5 (Na poševno skalo) and 9 (Na kopo) the discharge increased after 2 days only due to rainfall. Thus the injected water almost entirely flowed into the water treatment plant, one part remained in the very dry catchment area and only a smaller part appeared at the trickles. Uranin and Rhodamin appeared the most distinctly at trickles 4 and 15* immediately after the increased discharge and less distinctly with some delay at point 9 and after some days at points 2 and 5. At point 7, low concentrations of Rhodamin were recorded. Figure 3 shows the different permeability of trickles 4 and 15* and Figure 4 the occurrence of Uranin in both trickles.

In one case of tracing we injected the tracer solution in the soil at the bottom of doline. Thus the tracer had to overcome the layers of soil and later continued its way through the conduits within the carbonate massif. The thickness of soil is presumably less than 1 m as it was artifically deposited. This is why it is difficult to compare with dolines where several m thick layers of soil are found at the bottom. The tracer was recorded in all the observed trickles, even in trickle 2. As expected the highest concentration was recorded in trickle 15*, substantially lower at other trickles; only trickle 7, which is slow permanent dripping, reacted with long delay. Long lasting washing of the tracer followed but it was intensified after each heavy rain. After one year trickles 2 and 9 did not contain any tracer while the other trickles continued to flush small quantities of tracer after each rain. It shows an important retention capacity within the soil, with the slowed down washing and the retention respectively.

Later another tracing test was carried out from the outer channel. The most distinct appearance was at point 15* and less distinctive at points 4, 7 and 9, and none at all at 2.

The tracing when we injected 10 m^3 of water only (outer channel) considerably increased the discharge at the trickle on the pathway (8) and the trickle 15*, while trickle 2 did not react at all.

All the studies show that two very permeable conduits lead from the doline through 40 m thick limestones, draining significant amounts of water. The most permeable appears at the trickle on the pathway (8) where the water appears after heavy rain when the recharge area is filled. The discharge increases fast and then it decreases the first. Trickle 15* reacts faster but is less distinctive. Both trickles dry up during periods without rainfall, due to the high permeability. At several other smaller trickles or droppings retention occurs. The catchment area of the trickles is interconnected, but their connections are very different.

CONCLUSIONS

The described researches indicate that the rainwater thus drains differently through the dolines through very permeable or less permeable conduits which are interconnected. The main conduit drains significant amount of rainwater into the karst underground. The discharge of the most permeable trickle increases just after the catchment area is filled and later decreases very fast. Due to such run-off these conduits or trickles in the caves are seasonally active only. The parallel system of less permeable conduits drains smaller amount of water with big retention. The catchment area of the trickles is interconnected, but their connections are very different.

However these statements open a question about a drainage from the surface away from the doline area; the question may be answered only by simultaneous checking of both cases under equal conditions.

Water tracing tests proved to be very useful at studying the run-off water from the dolines into the underground. If they are done by adding water the conduits and their permeability from the surface to the interior are shown. This provides bases for understanding the drainage of eventual harmful substances spilt into karst; this happens frequently at the road accidents where the transportation of liquids is involved (Knez et al., 1994; Kogovšek 1995a). Water tracing tests under naturally wet conditions show the drainage dynamics which is essential for the corrosion processes.

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VERTIKALNI ODTOK PADAVIN SKOZI VRTAČE
Primer vrtač nad Planinsko in Pivko jamo

Povzetek

Različno izdatni curki prenikle vode, ki jih srečujemo v podzemeljskih jamah, in ki so stalni ali pa se pojavljajo le občasno po izdatnejših padavinah, so dali slutiti, da imajo zelo različna zbirna območja. Predvidevali smo, da se preko vrtač odvajajo v podzemlje večje količine padavin.

Večletna podrobna opazovanja pretakanja skozi curke v Planinski in Pivki jami so podala letne količine pretekle vode, dinamiko pretakanja glede na padavine ter obseg in dinamiko korozijskega raztapljanja pri vertikalnem prenikanju, kar je pokazalo na hitrost večanja prepustnosti curkov. Za ugotavljanje povezav curkov s površjem smo uporabili sledilne poskuse, najprej z vlitjem sledil nad Planinsko jamo ter kasneje nad Pivko jamo.

Sledilni poskusi z dodatno vodo in fluorescentnimi sledili so se izkazali kot zelo uporabni pri ugotavljanju povezav vrtač na površju s podzemljem kot tudi pri študiju odtoka vode iz vrtač. V primerih, ko se vlito sledilo zalijemo z večjo količino vode, dobimo informacijo o prepustnosti prevodnikov. To pa je tudi osnova za sklepanje kako odtečejo morebitne razlite nevarne snovi v kras, če pride do takega izlitja. V zadnjem času se kar pogosto dogaja, da pride ob prometnih nesrečah, kjer so udeleženi prevozniki raznih tekočin (mineralna olja, nafta...) do izlitja in ogrožanja kraške vode. Sledenja, ki jih izvedemo ob naravnih pogojih, kjer sledilo spirajo le padavine, pa nam dajo informacijo o dinamiki prenikanja, ki je pomembna za korozijsko raztapljanje karbonatnih kamnin oz. večanje prepustnosti prevodnikov.

Vse omenjene raziskave so pokazale, da odvajajo vodo iz vrtač različno prepustni prevodniki. Osrednji prevodnik odvaja v kraško podzemlje znatne količine padavin. Pretok takih curkov po padavinah ali vlitjih vode močno naraste, nato pa hitro upade in kasneje presahne prav zaradi velike prepustnosti svojega prevodnika. Vzporedno pretakanje po spletu manj prepustnih prevodnikov je dušeno. Pretok teh curkov manj izrazito narašča in kasneje le počasi upada, kar pa jim zagotavlja njihovo stalnost. Ob ugotavljanju pretakanja skozi vrtače pa se postavlja vprašanje, kakšno pa je pretakanje izven njih, kar pa bi pokazala le testiranja obeh primerov ob enakih pogojih.

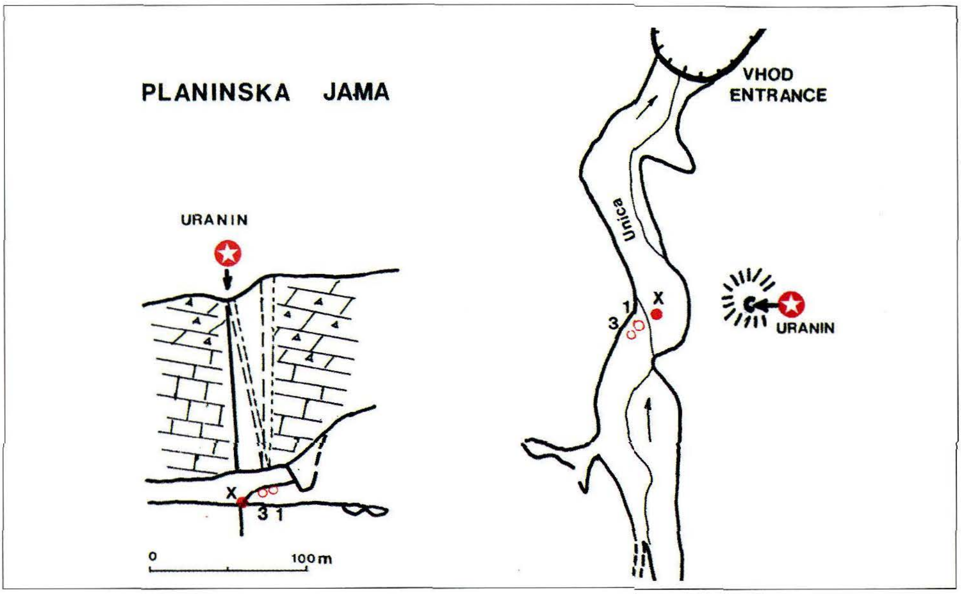

Fig. 1: Situation of the observed trickles in Planina cave
Sl. 1: Položaj opazovanih curkov v Planinski jami

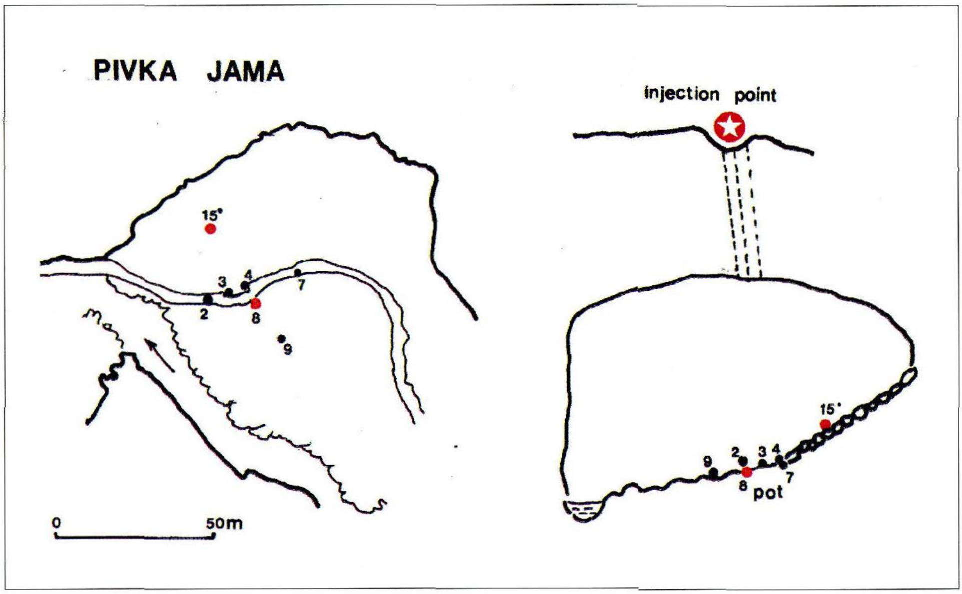

Fig. 2: Situation of the observed trickles in Pivka cave
Sl. 2: Položaj opazovanih curkov v Pivki jami

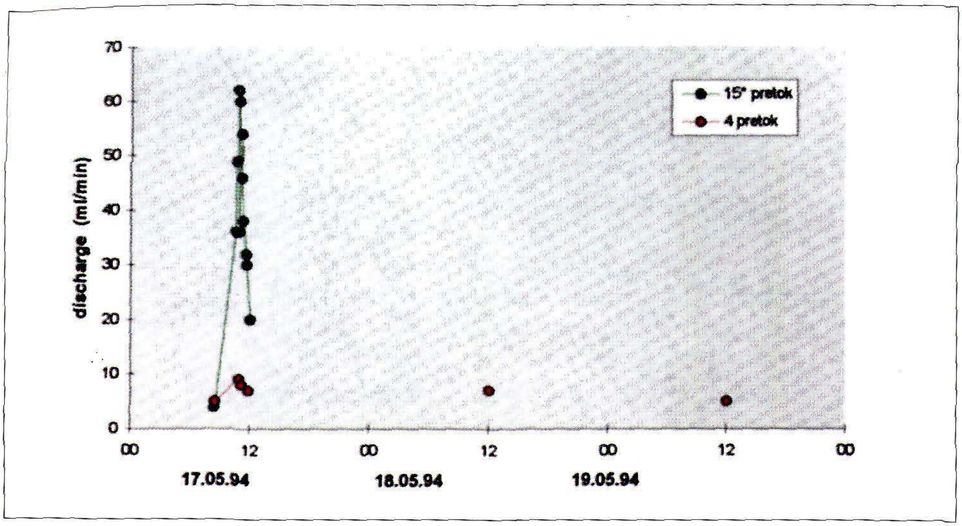

Fig. 3: Combined water tracing test in May 17,1994: After the water was added a smaller water pulse was recorded at trickle 15 while trickle 4 did not react*
Sl. 3: Kombiniran sledilni poskus 17. maja 1994: po vliti vodi smo zaznali manjši vodni val pri curku 15, medtem ko pretok curka 4 ni reagiral*

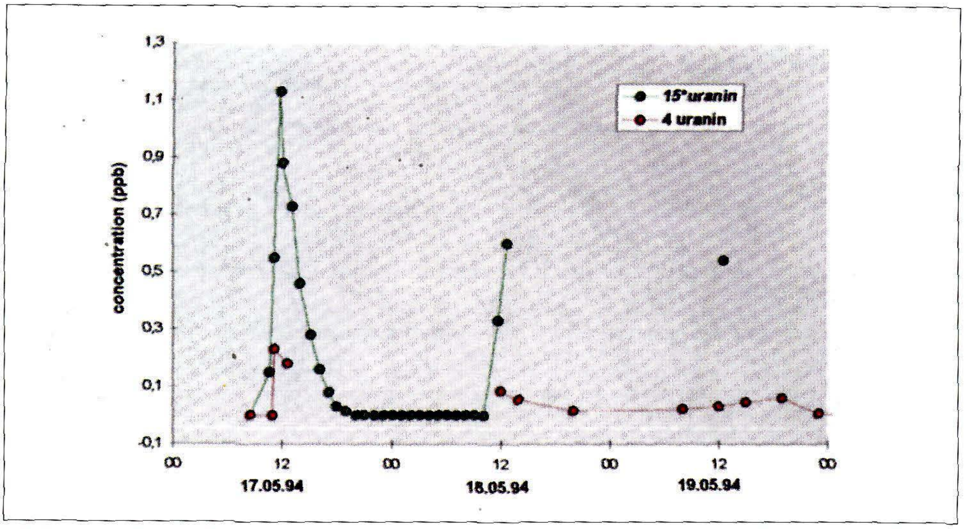

Fig. 4: Combined water tracing test in May 17, 1994: a distinctive occurrence of Uranin in permeable trickle 15 compared to poorly permeable trickle 4, is seen*
Sl. 4: Kombiniran sledilni poskus 17. maja 1994: viden je izrazit pojav uranina v dobro prepustnem curku 15 v primerjavi s slabo prepustnim curkom 4*

CLASTIC SEDIMENTS FROM DOLINES AND CAVES FOUND DURING THE CONSTRUCTION OF THE MOTORWAY NEAR DIVAČA, ON THE CLASSICAL KARST

KLASTIČNI SEDIMENTI IZ VRTAČ IN JAM NA TRASI AVTOCESTE PRI DIVAČI, KLASIČNI KRAS

ANDREJ MIHEVC & NADJA ZUPAN HAJNA

Izvleček UDK 551.435.83(497.4)
551.44:552.517(497.4)

Andrej Mihevc & Nadja Zupan Hajna: Klastični sedimenti iz vrtač in jam na trasi avtoceste pri Divači, klasični Kras

Vrtače se ločijo po obliki, velikosti in po vsebini oziroma sedimentih. V številnih vrtačah so bili najdeni alohtoni nekarbonatni prodi, peski ter ilovnati sedimenti. Pri gradnji avtoceste na Krasu je bilo pri gradbenih delih odprtih večje število vrtač in z mehanskimi sedimenti zapolnjenih jam. Analiza sedimentov je pokazala, da so nekatere depresije stare jame zapolnjene s fluvialnimi alohtonimi sedimenti, kasneje odprte na površje zaradi zniževanja površja in spremenjene v površinske depresije.

Ključne besede: jame, vrtače, jamski alohtoni klastični sedimenti, mineralna sestava, zniževanje površja, speleogeneza, Kras, Divača, Slovenija

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Andrej Mihevc & Nadja Zupan Hajna: Clastic sediments from dolines and caves found during the construction of the motorway near Divača, on the classical Karst

Dolines differ in form and size and also by the sediments in them. In numerous dolines allochthonous non-carbonate pebbles, sands and loam sediments were found. During the construction of the motorway across the Karst the works uncovered a vast number of dolines, and crossed several caves filled up by mechanical sediments. Sediment analyses showed that some depressions were actually fossil caves filled up by fluvial allochthonous sediments and later opened to the surface due to its lowering and so changed into superficial depressions.

Key words: caves, dolines, cave allochthonous clastic sediments, mineral composition, lowering of the surface, speleogenesis, Karst, Divača, Slovenia

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INTRODUCTION

The classical Karst is a vast carbonate plateau gently sloping towards the north-west. At its upper border the Reka river sinks into Škocjanske jame and its underground flow may be traced in some other caves. In the upper part of the Karst, around Divača, the underground Reka flows about 250 m below the surface. Thus one may presume that an equally thick karst vadose zone exists there. Dolines are the most common relief forms. They developed on places where larger amount of rock had been dissolved and transported through the karst giving rise to circular depressions. They vary in shape, size, depth and density; genetically they may form by dissolution, collapse or a combination of these. Solution dolines, their density up to 70 per square kilometer, are usually small. In general they are up to 10 m in depth and 50 m across. Larger dolines are usually attributed to collapse origin. During the motorway construction over the Karst the works uncovered a large number of dolines or similar depression forms and also fossil, unactive cave passages (Knez & Šebela 1994; Mihevc & Šebela 1995) that are filled by allochthonous fluvial sediments. Helped by these sediments we succeeded in distinguishing some dolines from eroded cave passages near Divača. Cave sediments found on the surface of the Karst differ from other superficial sediments and may provide an important diagnostic trace to distinguish between solution dolines and underground caverns similar to dolines. Similar sediments that we found during the laying-out of the motorway had been already perceived and described in the Karst. They were usually attributed to superficial deposits, to the remains of a once much wider dam of the former Reka when it, supposedly, had still flowed over the Karst (D'Ambrosi 1965; Melik 1961; Radinja 1964). These sediments would be preserved in resedimented form at the lowest parts of the Karst surface, in the bottoms of dolines. Less frequently and in particular in a narrow area some authors attributed them to cave sedimentation (Pleničar 1954; Habič 1992). A distinctive character of described sediments can undoubtedly be attributed to cave sedimentation environment, with large distribution and voluminous quantity of these sedi-

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The cave explorations, in particular the analyses of the sediments, were made feasible by the financial support of DARS within the project of speleological control over the motorway construction.

ments. It offers a possibility explain the origin of numerous sediments, now found at the surface, as being the remains of the cave sediments which had appeared due to the surface lowering. Not only the possibility of genetically defining single forms, but also their quantity and the location of fluvial sediments indicate that probably most of the allochthonous sediments up to now found on the surface of the Karst have a cave origin and that they are not a deposit from superficially flowing streams, the Reka for instance.

THE FINDING SITES AND DESCRIPTION OF ALLOCHTHONOUS CLASTIC SEDIMENTS IN THE SURFACE DEPRESSIONS

During the motorway construction over the Karst the works revealed a large number of dolines and caves, filled up by mechanical sediments. The clastic sediments from some of them were studied more in detail (Fig. 1).

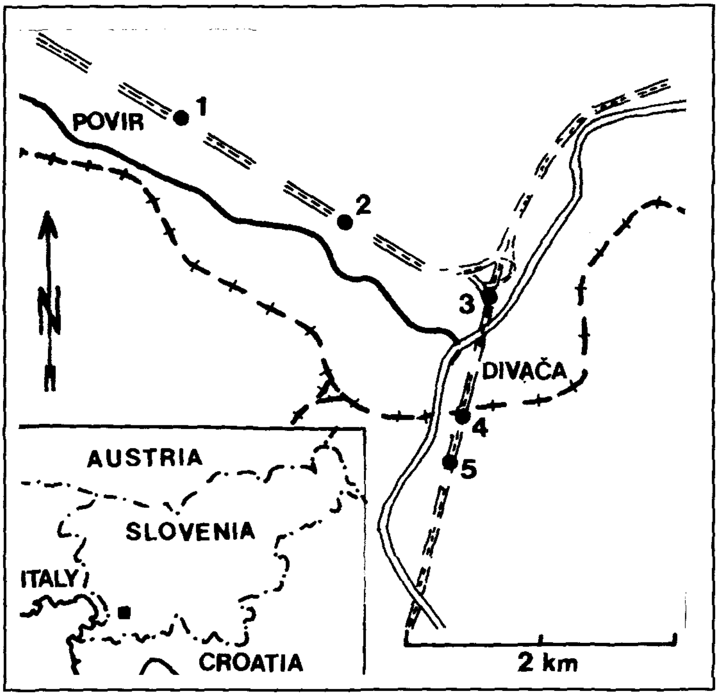


Fig. 1: Location of described sediments
Legend: 1. The Cave without Roof, 2. Profile 650+10, 3. Divaški Hrib, 4. Bojni Dol, 5. Grintavca

Sl. 1: Lokacija opisanih sedimentov
Legenda: 1. Brezstropa jama, 2. Profil 650+10, 3. Divaški hrib, 4. Bojni dol, 5. Grintavca

The samples of loam, sand and gravel were analysed by x-ray diffraction technique and some by thin sections. Within the loam the single particles are silt- and clay-sized.

Samples were analysed by x-ray diffraction method in such a way that less represented minerals were more visible. The quantity of the minerals is given in respect to the height of the main reflection of a single mineral in the x-ray record. Thin sections of some samples were made also. Plagioclases are not defined in the samples; their main peaks were not clear enough due to too low level. All the minerals that are defined in traces were not expressed very well because a lot of different minerals occur in one sample and some of them are even not crystallised well, so the background was very high.

BREZSTROPA JAMA - THE CAVE WITHOUT ROOF

North of Divača in the axis of the motorway under construction there was an elongated place displaying poor geomechanical properties. The bore-holes (Dular 1993) recorded a depression filled up by mechanically unstable sediments. When the workers had removed the sod and upper layer of soil, red loam and other sediments, it became clear that below was a fossil cave passage intersected in the midle by a shallow doline. Flowstone, speleothems, flutes and scallops are preserved within this passage. Before the motorway construction started the passage was barely visible in the surface relief. On aerial photographs of infrared spectrum in white and black technique (cyclic filming of SRS 1980) it is well seen as a belt of lighter, hence warmer soil. Nearby, away from the laying-out of the road, we saw traces of other similar caves. The whole passage, included 320 m in length and 5 m in depth, or 6900 cubic metres in all, was filled up by allochthonous fluvial cave sediments. In the passage were found yellow brown loams, quartz sand and gravel, up to 25 cm in size. The depth of the excavation mostly did not exceed 3 to 4 m and nowhere touched bedrock (Fig. 2). Cave features are preserved in several places on the walls. In the northern part of the cave the scallops had been covered by a layer of flowstone and thus their features are perfectly preserved. The average size of the scallops is from 2 to 3 cm. In some places in the passage the rock is covered by flowstone and thus it is perfectly preserved, yet elsewhere, close by, corrosion has worn away a more or less thick layer of a rock. At such places we might assess the extent of subcutaneous corrosion since the cave was filled up by sediments. Subcutaneous dissolution removed at the utmost from 5 to 20 mm of the superficial veneer of the rock. At several places in the passage there are points of more intensive vertical percolation and associated transport-controlled reactions indicated by a breakthrough of brown superficial soil into the cave sediment. Vertical, shallow flutes occurred on the rock. In the sediment filling the passage there are no traces of breakdown. Among the excavated sediments there were a few rocks floating on the sediment but it was impossible to establish whether these are

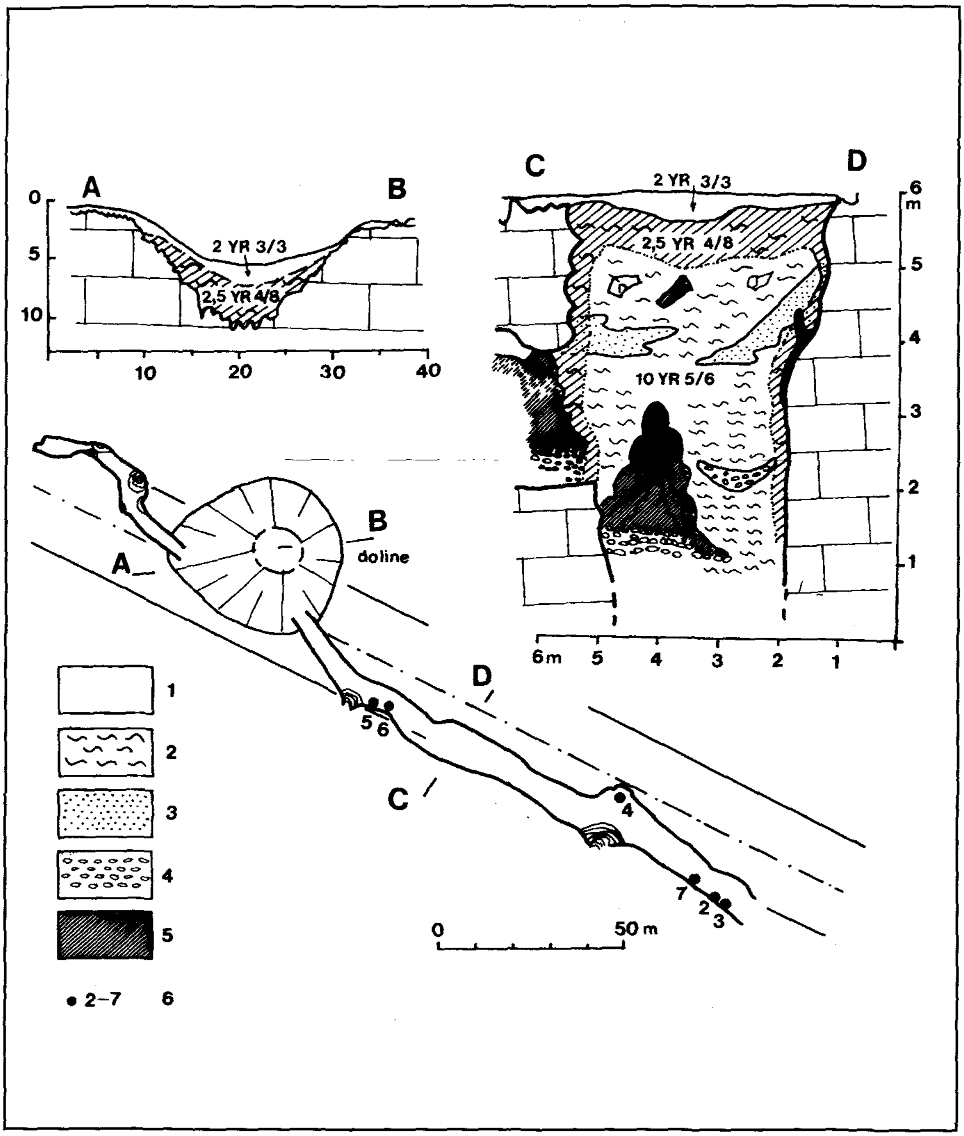


Fig. 2: The Cave without Roof near Gorenje, ground plan of the cave and location of samples
Legend: 1. soil, 2. loam, 3. sand, 4. pebbles, 5. flowstone, 6. samples A-B and C-D, schematic cross section of the cave's sediments

Sl. 2: Brezstropa jama pri Gorenju, tloris jame in lega vzorcev
Legenda: 1. prst, 2. ilovica, 3. pesek, 4. prodniki, 5. siga, 6. vzorci A-B in C-D, shematska prereza zapolnitve Brezstrope jame

parts of the cave roof or rocks that had fallen off the upper parts of the walls. Within the sediment some stalactites, up to half a metre long, were found. On the surface there was a layer about 10 cm thick of dark reddish brown soil (2YR 3/3) followed downwards by a 0,5 to 1 m thick layer of terra rossa (2,5YR 4/8) which passed to clastic sediments, loam, sand, and gravel mostly of yellow brown colour.

Most sediments are fom the non-carbonate vicinity. In the passage the sedimentation conditions changed within short distances. The lenses of sand and gravel disappeared and passed over to thinner fractions. In some places the gravel was cemented in a base of massive flowstone. The deposit layers were rotated, indicating that the sediment moved after it had been deposited in the cave. Characteristic types of sediments were sampled. Fig. 2 shows the ground plan of the cave and locations of single analysed samples. We were mostly interested in the origin of clastic sediments and in the possibility comparing them with sediments from elsewhere on the route of the motorway. Due to rapid changes in granulometry and because the excavation was performed by machines we could not reconstruct the sedimentation conditions.

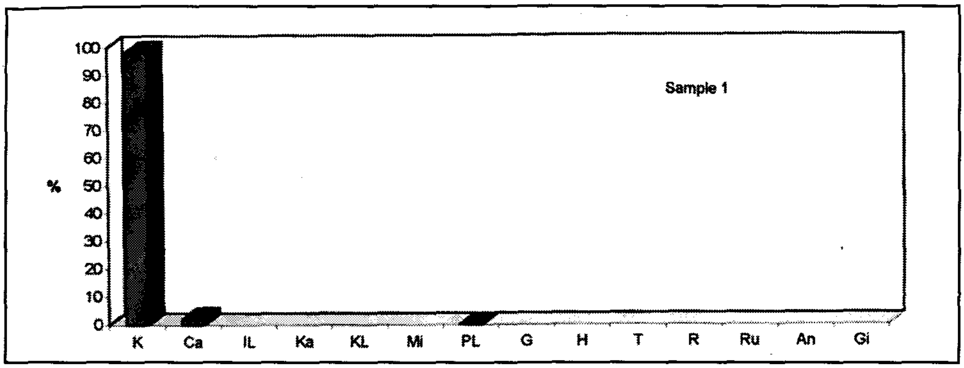
a. Gravel

Well rounded non-carbonate pebbles of flysch sandstone, about 5 cm in size, prevailed in the caves. The largest pebble among them was 25 cm on the longer axis. Some of them dried, cracked and disintegrated into smaller pieces. There were also some patinated carbonate pebbles. Even the largest pebbles were lying in quartz sand. The conglomerate that occurred where the flowstone-depositing water flowed through a gravel bar indicates gravel deposition and flowstone accretion at the same time. The conglomerate consists of up to 15 cm large pebbles of flysch sandstone together with some limestone pebbles. The rate of limestone pebbles was higher than in unconsolidated gravel evidencing the corrosion within it.

Chert nodules are very weathered, porous forms, up to 20 cm in size and specially among the gravels. They are angular, with rounded edges and with numerous smoothed semi-circular recesses excluding the possibility that they were rounded during the fluvial transport. Their surface is smooth with a shiny black coating. They were found all over the passage, among the gravels but also among the quartz sand in the south-eastern part of the cave.

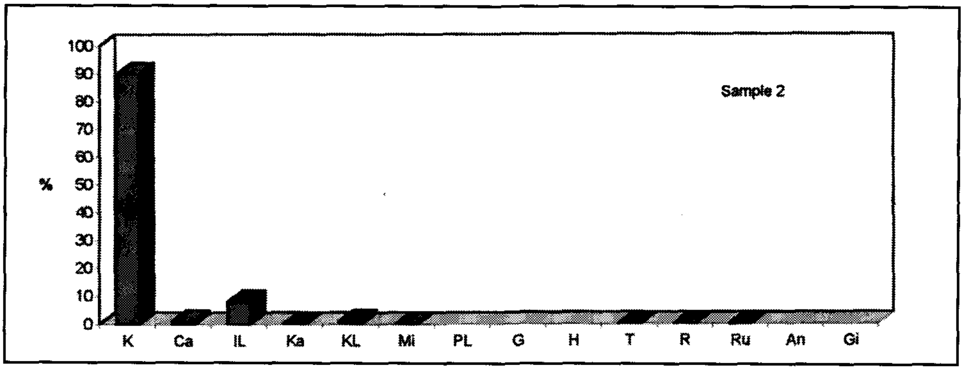
Sample 1

presents a chert pebble of the NW part of the cave. Quartz predominates by 98%, there are only 2% of calcite and plagioclase in traces. A thin section was made. The silification of biomicritic limestone is obvious.



Sample 1: Quartz pebble from the NW part of Brezstropa Jama
X-ray: K - quartz 98%, Ca - calcite 2%, in traces is PL - plagioclase; IL - illite, Ka - kaolinite, KL - chlorite, Mi - microcline, G - goethite, H - hematite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 1: Kremenov prodnik iz NW dela of Brezstrope jame
Rentgen: K - kremen 98%, Ca - kalcit 2%, v sledovih je PL - plagioklaz; IL - illit, Ka - kaolinit, KL - klorit, Mi - mikroklin, G - goethit, H - hematit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit



Sample 2: Yellow brown loam from Brezstropa Jama
X-ray: K - quartz 90%, IL - illite 8%, Ca - calcite 1%, KL - chlorite 1%, in traces are T - turmaline, Ka - kaolinite, Mi - microcline, R - hornblende and Ru - rutile; PL - plagioclase, G - goethite, H - hematite, An - anatase, Gi - gibbsite

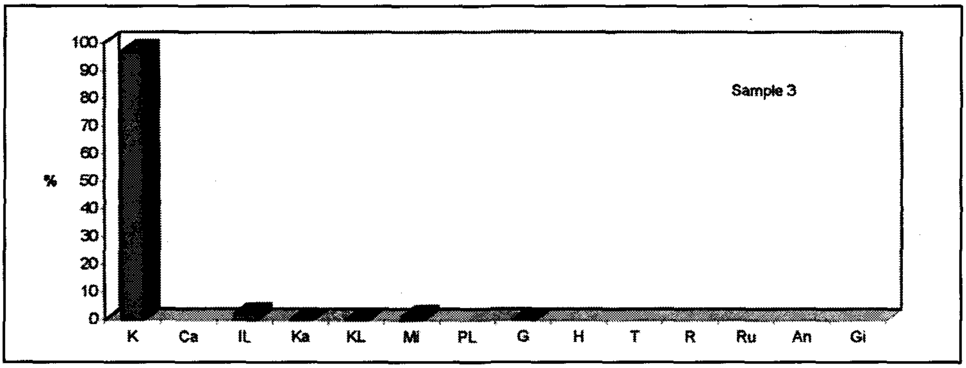
Vzorec 2: Rumenorjava ilovica iz Brezstrope jame
Rentgen: K - kremen 90%, IL - illit 8%, Ca - kalcit 1%, KL - klorit 1%, v sledovih so T - turmalin, Ka - kaolinit, Mi - mikroklin, R - rogovača and Ru - rutil; PL - plagioklaz, G - goethit, H - hematit, An - anataz, Gi - gibbsit

b. Sands and loams

Sands appeared in the form of lense bodies or lamellas within loam, or gravel or independently. The prevailing colour of the sand is yellow-brown in the upper part; at the contact with terra rossa it passes to red. The same happened to pure sands of yellowish brown colour (10YR 5/6) that change into red (2,5YR 4/8) although it is undoubtedly the sediment of the same layer. In the sand there are in places the remains of non-disintegrated pebbles of flysch sandstone. The cave loam is mixed with layers or lenses of sand, and also gravel. A speciality of the loam is a very rotated varve-like sedimentation structure evidencing strong moulding of plastic sediments after they were deposited. The prevailing colour of the loam in the lower part of the profile is yellowish brown (10YR 5/8), sharply passing in the upper part to red (2,5YR 4/8). The same change in colour occurred at the walls of the passage where yellowish brown loam passes into a belt of a red loam.

Sample 2

Yellow brown loam is located in the SE part of the cave. This is a yellow brown loam with sand lenses that passes on the top into red loam. Yellow brown loam consists of 90% of quartz, 8% of illite, 1% of calcite, 1% of chlorite and in traces tormaline, kaolinite, microcline, hornblend and rutile. This sample is a cave yellow flood loam deriving from flysch sediments. The rate of clayey minerals is higher than in Sample 3.

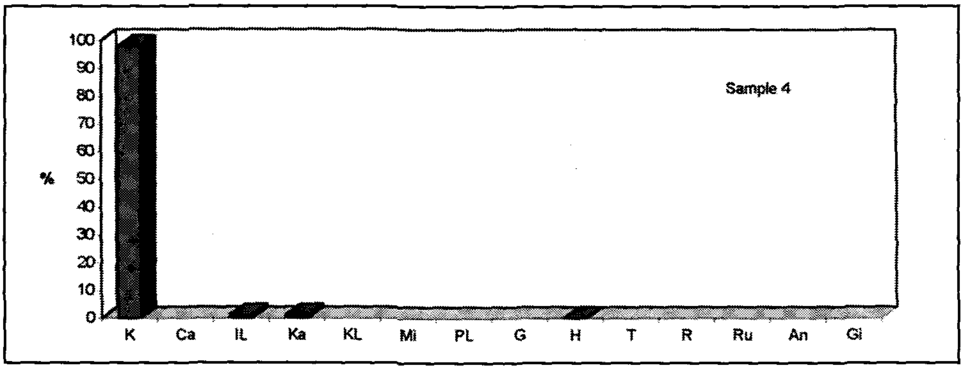


Sample 3: Sandy lamina out of yellow brown loam No. 2 from Brezstropa Jama X-ray: K - quartz 97%, IL - illite 2%, Mi - microcline 1%, in traces are Ka - kaolinite, KL - chlorite and G - goethite; Ca - calcite, PL - plagioclase, H - hematite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite.

Vzorec 3: Peščena lamina iz rumenorjave ilovice št. 2 iz Brezstrope jame Rentgen: K - kremen 97%, IL - illit 2%, Mi - mikroklin 1%, v sledovih so Ka - kaolinit, KL - klorit and G - goethit; Ca - kalcit, PL - plagioklaz, H - hematit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit.

Sample 3
belongs to sandy lamina in yellow brown loam. The mineral composition is 97% of quartz, 2% of illite, 1% of microcline and traces kaolinite, chlorite and goethite. Sand from yellow loam is well washed thus almost only quartz grains are seen. The mineral composition of this sediment corresponds to flysch sediment.

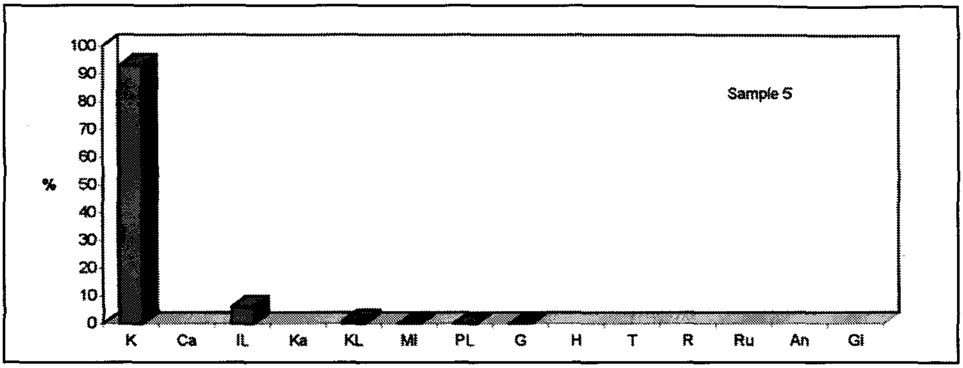
Sample 4
A sample of red sand was taken from the right side of the cave near the contact with wall. It consists of 98% quartz, 1% illite, 1% kaolinite and *hematite in traces. It seems that the hematite dyed the other minerals.* Also this sand may have its origin in flysch; its red colour, however is due to dehydration of goethite to hematite. It probably happened at the wall where the sand was exposed to weathering.



Sample 4: Red sand at the contact with the cave wall in Brezstropa Jama
X-ray: K - quartz 98%, IL - illite 1%, Ka - kaolinite 1%, in traces is H - hematite; Ca - calcite, KL - chlorite, Mi - microcline, PL - plagioclase, G - goethite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

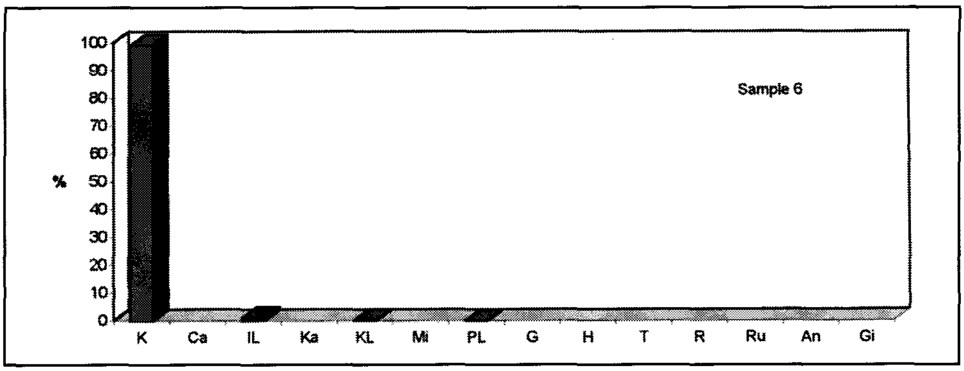
Vzorec 4: Rdeč pesek s stika z steno jame v Brezstropi jami
Rentgen: K - kremen 98%, IL - illit 1%, Ka - kaolinit 1%, v sledovih je H - hematit; Ca - kalcit, KL - klorit, Mi - mikroklin, PL - plagioklaz, G - goethit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit

Sample 5
Yellow loamy sand from below the flowstone consists of 93% quartz, 6% illite, 1% chlorite and goethite, microcline, plagioclase in traces. The sample represents cave sediment and may have its origin in flysch sediments.



Sample 5: Yellow loamy sand from bellow the flowstone in Brezstropa Jama
X-ray: K - quartz 93%, IL - illite 6%, KL - chlorite 1%, in traces are G - goethite, Mi - microcline and PL - plagioclase; Ca - calcite, Ka - kaolinite, H - hematite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 5: Rumen ilovnat pesek izpod sigove kope v Brezstropi jami
Rentgen: K - kremen 93%, IL - illit 6%, KL - klorit 1%, v sledovih so G - goethit, Mi - mikroklin and PL - plagioklaz; Ca - kalcit, Ka - kaolinit, H - hematit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit



Sample 6: Yellow washed sand vis-a-vis the flowstone in Brezstropa Jama
X-ray: K - quartz 99%, IL - illite 1%, in traces are KL - chlorite and PL - plagioclase; Ca - calcite, Ka - kaolinite, Mi - microcline, G - goethite, H - hematite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 6: Rumenizpran pesek nasproti sigovi kopi v Brezstropi jami
Rentgen: K - kremen 99%, IL - illit 1%, v sledovih so KL - klorit and PL - plagioklaz; Ca - kalcit, Ka - kaolinit, Mi - mikroklin, G - goethit, H - hematit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit

Sample 6

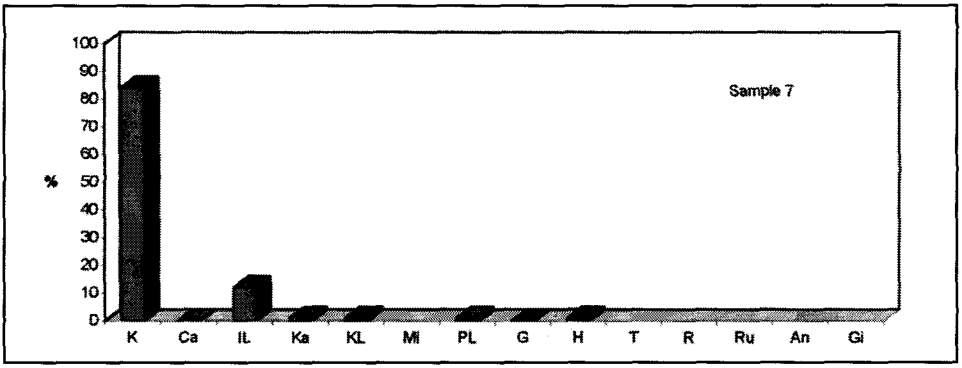
Yellow washed sand opposite to the flowstone in the cave. The X-ray method recorded 99% of quartz, 1% of illite and chlorite and plagioclase in traces. A thin section was made of this sample. Quartz predominates by 99%, there are also some grains of tormaline, muscovite and zircon. A thin film of goethite coats other minerals. This sample is a cave sediment and as it was well washed it does contain almost only quartz.

Sand and loam mostly derive from flysch sandstone that disintegrated during the weathering in situ, during fluvial transport or in the cave from sandstone pebbles. Various colouring of sands is controlled by the recent sedimentation environment where they had been deposited. In respect of mineralogical composition there are no essential differences between both types of loam, red and yellowish brown. In both, quartz (more than 90%) and illite prevail. Eolian origin of the grains is not probable as neither gravel nor loam and flowstone indicate a dry climate; they were deposited at the time when a river flowed through the cave.

c. Deposits from the surface

Sample 7

Red loam (2,5YR 4/8) infiltrated from the surface lies near to yellow sand and loam. It consists of 84% quartz, 12% illite, 1% chlorite, 1% kaolinite, 1%



Sample 7: Red fill from the surface in Brezstropa Jama
X-ray: K - quartz 84%, IL - illite 12%, KL - chlorite 1%, Ka - kaolinite 1%, PL - plagioclase 1%, H - hematite 1%, in traces are G - goethite and Ca - calcite; Mi - microcline, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

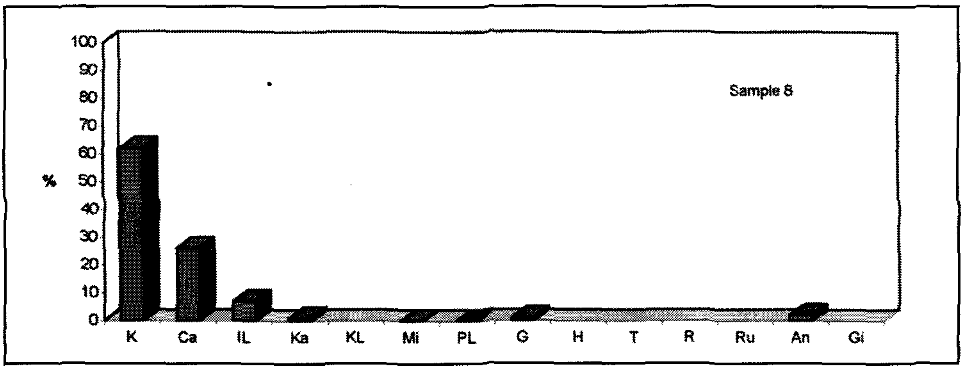
Vzorec 7: Rdeča zapolnitev s površja v Brezstropi jami
Rentgen: K - kremen 84%, IL - illit 12%, KL - klorit 1%, Ka - kaolinit 1%, PL - plagioklaz 1%, H - hematit 1%, v sledovih so G - goethit and Ca - kalcit; Mi - mikroklin, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit

plagioclase, 1% hematite and goethite and calcite in traces. The location of this material and the ratio of clay minerals are slightly higher than in a previous sample and their association indicates the origin of the infill from the karst surface.

A doline (profile A-B in Fig. 2) that intersected the cave in its middle part was destroyed by earth works first and thus the relationship between the cave and doline was not assessed. We assume that it was filled up by up to 2 m thick red loam without the yellow layers that are typical of cave sediments. Although the passage was opened towards the doline the sediment from the passage did not move into it. The centre the of doline was slightly out of the axis of the passage itself. Obviously the doline and the passage came into existence and developed independently controlled by various initial structures and various conditions. The effect of the doline on the cave was very small.

SEDIMENTS IN PROFILE 650 + 10

In the profile that lies at 408 m a.s.l. about 1 km SE from the Cave without Roof, two caves filled up by sediment were intersected. One was filled up by rubble and the other by loamy and sandy allochthonous sediments. Due to similarity of these sediments with to from the Cave without Roof only a few samples were analysed.



Sample 8: Grey yellow loam from the cave on the highway layout at the profile 650 + 10
X-ray: K - quartz 62%, Ca - calcite 26%, IL - illite 7%, An - anatase 2%, Ka - kaolinite 1%, G - goethite 1%, in traces are Mi - microcline and PL - plagioclase; KL - chlorite, H - hematite, T - turmaline, R - hornblende, Ru - rutile, Gi - gibbsite

Vzorec 8: Sivorumena ilovica iz jame na avtocesti na profilu 650 + 10
Rentgen: K - kremen 62%, Ca - kalcit 26%, IL - illit 7%, An - anataz 2%, Ka - kaolinit 1%, G - goethit 1%, v sledovih so Mi - mikroklin and PL - plagioklaz; KL - klorit, H - hematit, T - turmalin, R - rogovača, Ru - rutil, Gi - gibbsit

a. Loams

The profile of the first passage was filled up by laminated loam sediment with strongly rotated layers. In the lower part of the profile the yellowish brown (10YR 5/8) loam with thin grey layers prevailed. The upper part of the infill was of the same colour as the subsurface red loam (2,5YR 4/8) in the Cave without Roof.

Sample 8

Grey-yellow loam from the cave in the motorway's route consists of 62% quartz, 26% calcite, 7% illite, 2% anatase, 1% kaolinite, 1% goethite and microcline and plagioclase in traces.

This yellow loam is a cave sediment; it probably originated at the time when the cave walls were mechanically eroded, thus explaining high ratio of calcite.

b. Rubble

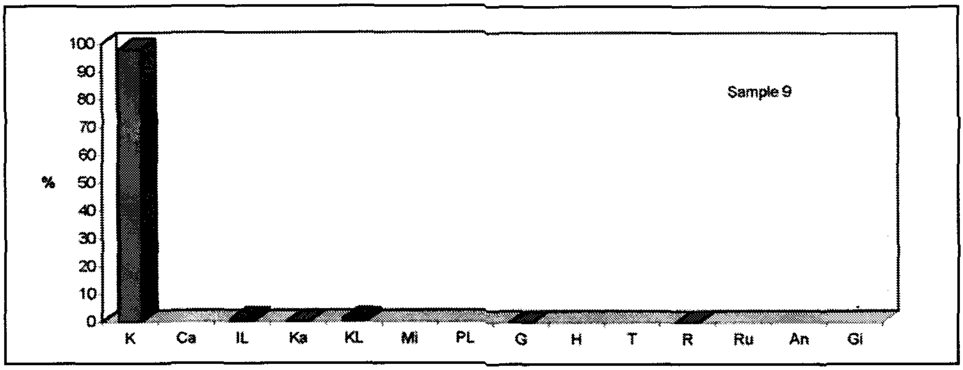
Some meters distant in the same road cutting there was a karst cave filled by angular rubble; the pieces were about 10 cm in size. Unconsolidated rubble was mixed with red loam. There were also a few pieces of stalactite, about 10 cm across. Obviously this was an older, void cave later filled up by Pleistocene climatic rubble.

LOAM FROM DIVAŠKI HRIB

A road cutting in Divaški Hrib at 450 m a.s.l. intersected a large cavern. Within the cutting it was seen as a 4 m high and 10 m wide infill of red and yellow brown loam. On the top the roof of this cavern is preserved, about 2 m thick. The cave was filled up by laminated, strongly moulded yellow loam with lenses and layers of sand and macroscopically similar loam of red colour. Layers, lenses and laminas were moulded and rotated. Some rubble intensively dyed by red loam was deposited above. Due to the fact that the road cutting only intersected the cave we could not assess its geometry. It is obvious that the sediments had undergone considerable internal movements (displacements). In one part the cave sediment was controlled by vertical percolation and transport controlled actions of rubble into fossil deposits and became red. Two samples of the infill were analysed.

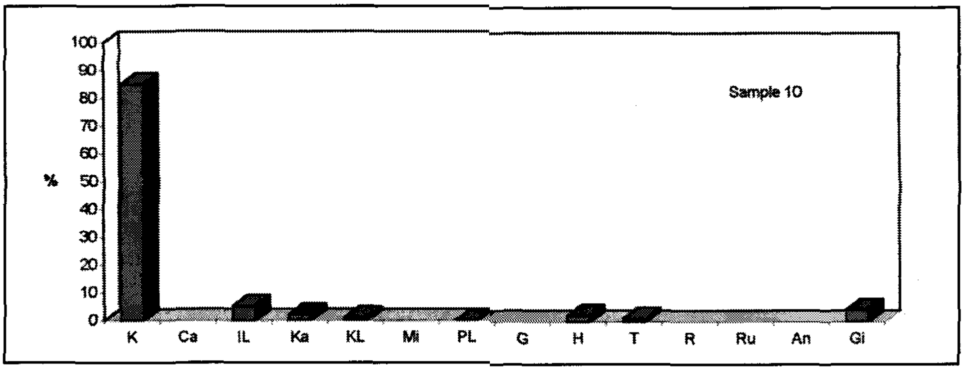
Sample 9

Yellow loam with lamine of fine sand (10YR 6/6), the size of poorly rounded grains varies from 0,1 to 0,025 mm. The sample consists of 98% quartz, 1% illite, 1% chlorite and kaolinite, goethite, and hornblende in traces. It is a cave sediment



Sample 9: Yellow sand and loam from the cave below Divaški Hrib
X-ray: K - quartz 98%, IL - illite 1%, KL - chlorite 1%, in traces are Ka - kaolinite, G - goethite and R - hornblende; Ca - calcite, Mi - microcline, PL - plagioclase, H - hematite, T - turmaline, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 9: Rumen pesek in ilovica iz jame pod Divaškim hribom
Rentgen: K - kremen 98%, IL - illit 1%, KL - klorit 1%, v sledovih so Ka - kaolinit, G - goethit and R - rogovača; Ca - kalcit, Mi - mikroklin, PL - plagioklaz, H - hematit, T - turmalin, Ru - rutil, An - anataz, Gi - gibbsit



Sample 10: Red loam, deposit from the surface into the cave below Divaški Hrib
X-ray: K - quartz 85%, IL - illite 5%, Gi - gibbsite 4%, Ka - kaolinite 2%, H - hematite 2%, KL - chlorite 1%, T - turmaline 1%, in traces is PL - plagioclase; Ca - calcite, Mi - microcline, G - goethite, R - hornblende, Ru - rutile, An - anatase

Vzorec 10: Rdeča ilovica infiltrirana s površja, v jami pod Divaškim hribom
Rentgen: K - kremen 85%, IL - illit 5%, Gi - gibbsit 4%, Ka - kaolinit 2%, H - hematit 2%, KL- klorit 1%, T - turmalin 1%, v sledovih je PL - plagioklaz; Ca - kalcit, Mi - mikroklin, G - goethit, R - rogovača, Ru - rutil, An - anataz

Sample 10

Mineral composition of the red loam overlying the yellow sand is 85% quartz, 5% illite, 4% gibbsite, 2% kaolinite, 2% hematite, 1% chlorite, 1% turmaline and plagioclase in traces.

From its mineral composition one may conclude that this material infiltrated into the cave from the surface.

OPEN CAVE ON GRINTAVCA SW OF DIVAČA

Between two larger dolines, Dol Češnjevec to the west and Dol Rebidnik, the motorway passes a series of connected shallow dolines. Its altitude is about 449 m a.s.l. and the bottom of the dolines at 446 m. The larger dolines display wide flat bottoms at 433 and 431 m a.s.l. The aerial infrared photographs in white and black technique (cyclic filming of SRS 1980) show a series of dolines as a belt of lighter, thus warmer soil. The bottoms of both dolines have the same shape. On removing the soil it was proved that dolines, shallow relief depressions in fact, developed above an old cave passage, up to 6 m wide, without a roof. Due to the relatively small part excavated we were not able to study this cave in more detail. By digging, both walls were cleared without reaching the bedrock of the passage although the excavation was about 5 m in depth (441 a.s.l.). At two places affected by digging the passage was interrupted as the roof there was still preserved at 448 m a.s.l. Most of the passage was filled up by allochthonous fluvial sediments.

a. Gravel

In the lowest part a gravel of coloured cherts mixed with quartz sand was deposited. The size of pebbles varied from 1 to 3 cm. There were no pebbles of flysch sandstone. In the lower part sedimentary sequences were not prominent.

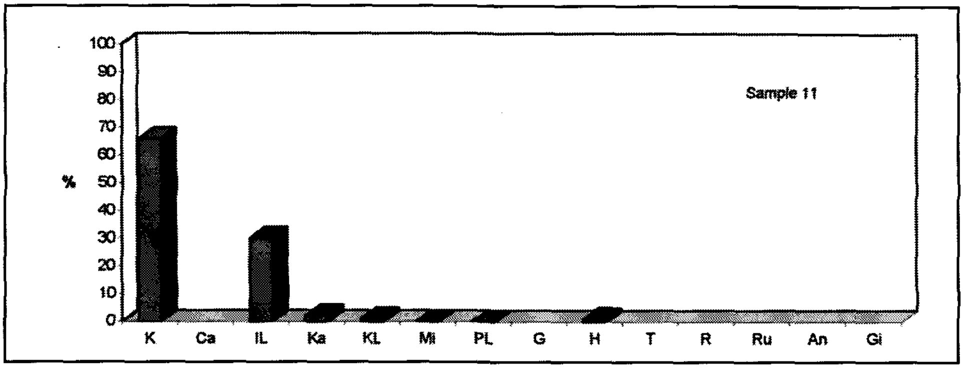
b. Sand and loam

Upwards, the gravel dam passes without a sharp boundary to yellow sand (2,5Y 6/6) mixed with thin layers of loam of the same colour. The thickness of this dam was about 3 m. In its upper part and sometimes at the walls the sediment colour passed to red (5YR 4/4). At one place this sedimentation sequence was covered by flowstone, up to 1 m thick, several aquare meters wide.

Above the flowstone another layer of red loam, up to 0,5 m in thickness, was deposited. In the loam that could possibly be a cave sediment or maybe a later superficial sediment, there were single smaller rocks of Cretaceous limestone. Above it was a humus horizon, up to only 10 cm thick.

Sample 11

Only the red loam from upper part of the profile was analysed. It consists of 66% quartz, 30% illite, 2% kaolinite, 1% hematite, 1% chlorite and



Sample 11: Red loam from the open cave on Grintavca
X-ray: K - quartz 66%, IL - illite 30%, Ka - kaolinite 2%, H - hematite 1%, KL - chlorite 1%, in traces are Mi - microcline and PL - plagioclase; Ca - calcite, G - goethite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 11: Rdeča ilovica iz odprte jame na Grintavci
Rentgen: K - kremen 66%, IL - illit 30%, Ka - kaolinit 2%, H - hematit 1%, KL - klorit 1%, v sledovih so Mi - mikroklin and PL - plagioklaz; Ca - kalcit, G - goethit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit

microcline and plagioclase in traces. In terms of the mineral composition and the high ratio of clay minerals, the red loam had originated at the surface.

Similar mineral composition of fluvial sediments from a fossil cave only 450 m southwards in Lipove doline was described by Pleničar (1954). The cave became evident by digging the quartz sand and thus massive flowstones and speleothems were revealed. The excavated cave may be followed at the surface in both directions corresponding to a series of elongated depressions/dolines where flowstone periodically appears.

BOJNI DOL

Bojni Dol is a large shallow depression. Its bottom lies at 423 m a.s.l. and in its southern part a large doline filled by sediments has been cleared. Autochthonous rubble mixed with larger rocks and red loam predominated; in this lower part of this doline were yellowish brown sand and loam and some fragments of conglomerate.

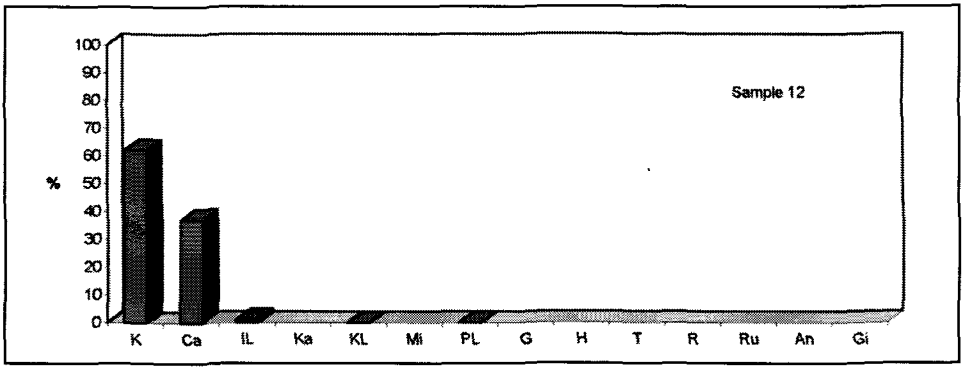
a. Conglomerate

The conglomerate consists of coloured chert pebbles, up to 2 cm across, and single limestone pebbles. It was deposited in layers and well sorted. The shape of the sedimentary body could not be established but obviously it is an old cave sediment cut by a doline.

b. Sand with slope rubble

Sample 12

The sample of yellow sand from the bottom of the doline near Bojni Dol is mixed with slope rubble. The following minerals are represented: 62% of quartz, 37% of calcite, 1% of illite and chlorite and plagioclase in traces. In terms of mineral composition this is a cave sediment mixed with slope ruble.



Sample 12: Yellow sand mixed by slope rubble at the bottom of doline near Bojni dol
X-ray: K - quartz 62%, Ca - calcite 37%, IL - illite 1%, in traces are KL - chlorite and PL - plagioclase; Ka - kaolinite, Mi - microcline, G - goethite, H - hematite, T - turmaline, R - hornblende, Ru - rutile, An - anatase, Gi - gibbsite

Vzorec 12: Rumen pesek pomešan s pobočnim gruščem v vrtači pri Bojnem dolu
Rentgen: K - kremen 62%, Ca - kalcit 37%, IL - illit 1%, v sledovih so KL - klorit and PL - plagioklaz; Ka - kaolinit, Mi - mikroklin, G - goethit, H - hematit, T - turmalin, R - rogovača, Ru - rutil, An - anataz, Gi - gibbsit

CONCLUSION

The samples of gravel, sand and loam from the Cave without Roof, from the profile 650+10, from the lower part of the cave on Divaški Hrib, from the open cave Grintavca and from the Bojni Dol derive, according to their mineral composition, from weathered remains of flysch rocks.

The infiltration of the material from the surface is obvious in the last sample from the Cave without Roof, from the upper part of the cave on Divaški Hrib, and from the Grintavca cave. But the mineral composition of the red infill is different from sample to sample, as red soils and loams in karst are different in mineral composition and age (Urushibara-Yoshino 1988).

In Bojni Dol the cave sediment is mixed with slope rubble according to its mineral composition.

There is a difference between the minerals identified by x-ray diffraction method and those by thin sections; the fact is due to difficulty in detecting the lesser represented minerals especially when a lot of different minerals are mixed. Another problem arises in detecting hematite and goethite when they exist in thin coating over other minerals.

In the given examples the sediments have without doubt a cave origin but they were deposited in various periods or maybe they differ due to different speleogenesis.

When caves are opened by erosion proceses or intersected by dolines, flood loam and sand appearing in them may be attributed to surface. A yellow brown colour is typical; however, sometimes if the flood sediments are near the surface their colour may change to red. Due to diagenesis brown goethite is transformed to red hematite, but the association of minerals slightly differs from that in surface red soils. The mineral composition of red soils on karst can be totally different and is controlled by their origin.

Similar sediments to those found in the Cave without Roof were discovered at several other places during the construction of the motorway. All these sediments were cave sediments and they displayed some typical common characteristics but also some differences which are due to the individual development of each cave. The most marked differences are occurrence of flowstone, breakdown blocks or sharp rubble underlain to allochthonous sediments indicating the way how a particular cave had been opening towards the surface. In some places the sediments of loam, silt, sand or gravel size were assessed and elsewhere one of the fractions only. These are either caves developed at different levels, belonging to different water flows, or they developed in various time sequences.

In several cases we found cave sediments that filled up dolines and other depressions on the motorway route, for instance around Grintavca between Češnjevec and Rebidnik Dol, in a doline in Bojni Dol, and in several dolines between Povirje and Žirje, and thus we got an impression how the fluvial cave sediments were distributed on the karst surface.

Fluvial cave sediments found in caves that are already affected by corrosional surface lowering are an important source of superficial soils in karst. Their location is either original or they may be partly or entirely resedimented.

Helped by sediments and cave passages one may partly reconstruct the time when these caves had developed. The Cave without Roof is a relic of a larger cave system that had drained the water from the flysch. The external effects did not affect the quantity of deposited flowstone thus indicating at least some ten metres thick roof. The growth of speleothems was at least once interrupted by erosion. The water that flowed through the cave transported large pebbles. From their size and to the great ratio of pebbles from a flysch sandstone which is very loose and does not endure longer fluvial transport (Kranjc 1986, 1989), one may conclude that the swallow holes had not been far away. Today similar pebbles can only be found in the caves of Brkini sinking flows, up to 1 km distant from the limestone-flysch contact. The water discharge varied from some ten l/s to several cubic metres. One may suppose that the cave was entirely filled up by fluvial sediments when the surface above it was still at an altitude of about 450 m and the swallow-holes at the contact of flysch and limestone were at the same level at least but not more than one to two kilometers away. Today the nearest flysch to the cave lies in the Raša valley, some 5 km away and the flysch-limestone contact is found at about 500 m a.s.l. The flysch of Brkini lies still further away, about 7 km. As both flysch areas are too far one may suppose that an area of flysch sandstone must had existed somewhere nearer. A possible origin of gravel might be around Divaški Gabrk, 1 km north-east of the cave, yet there is no flysch there today. As Gabrk consists of younger Paleocene and Eocene alveoline and nummulitic limestones and, according to stratigraphic column, there are only about 120 m missing up to the Eocene flysch layers, this region seems to be the most appropriate origin of the sediments. If this region is truly the original site of these pebbles then the Reka must have already had to disappear into underground at that time, but in separated swallow-holes. Similar conditions controlled other caves discovered but it is more difficult to reconstruct all other circumstances that were in control, as they are smaller or less preserved. Probably they were developed by various sinking streams and the modern speleohydrological conditions are very different. The most important sinking stream is the Reka river that disappears at Škocjanske Jame at 317 m a.s.l. and flows into a siphon at 214 m a.s.l. Close to the described sites of cave sediments there is a free water surface found in Kačna Jama at altitudes between 156 to 180 m fluctuating by about 100 m (Mihevc 1984). Near the Cave without Roof one may expect vadose zone about 220 m deep; this is a zone where the vertical percolation predominates giving rise to shafts and washing the soil downwards. Temporarily this area may be defined as a space where the caves are preserved while free water surface and the water level of karst aquifer was lowered from 400 to 180 m and the surface has suffered some 50 m lowering. According to some calculations the surface has lowered approximately 60 m in the last million years (Gams 1962). If we suppose that the thickness of the roof was 50 m then the Cave without Roof was filled up by sediments about 800.000 years ago.

In such a period the dolines on the surface could have been formed as all the conditions were fulfilled, that is vertical gradient and sufficient water drainage through karst. In spite of an existing vertical gradient the passages remained filled up by sediments. A large amount of sediments had been removed by erosion and resedimented, and these are found today on the surface, sometimes in dolines, and there the former cave sediments have been partly altered.

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KLASTIČNI SEDIMENTI IZ VRTAČ IN JAM NA TRASI AVTOCESTE PRI DIVAČI, KLASIČNI KRAS

Povzetek

Vzorci proda, peska in ilovice iz Brezstrope jame, jame v profilu 650+10, spodnjega dela jame v Divaškem hribu, odprte jame v Grintavci in Bojnega dola, glede na mineralno sestavo izvirajo iz preperelih ostankov flišnih kamnin.

V vseh v članku navedenih primerih je šlo za nedvomno jamske sedimente, ki pa so nastali v različnih časovnih obdobjih ali pa so različni zaradi različnega razvoja jam.

Infiltracija materiala s površja je očitna v zadnjem vzorcu iz Brezstrope jame, zgornjega dela jame v Divaškem hribu in jame v Grintavci. Toda njegova mineralna sestava je različna po posameznih vzorcih, ker so rdeče prsti in ilovice na krasu različne glede na mineralno sestavo, starost ter izvor. (Urushibara-Yoshino, 1988).V Bojnem dolu je glede na mineralno sestavo vzorca, jamski sediment pomešan s pobočnim gruščem.

Razlika med mineralno sestavo določeno z metodo rentgenske difrakcije in v zbruskih obstaja, ker je s prvo metodo težko zaslediti količinsko manj zastopane minerale, posebno kadar je v istem vzorcu veliko število različnih mineralov. Težava obstajala pri določitvi hematita in goethita v primerih, kadar prekrivta ostale minerale v obliki tanke prevleke.

Kadar so jame odprte proti površju s procesi erozije ali presekane z vrtačami, se poplavne ilovice in peske, ki izvirajo iz njih, lahko najde na površju. Zanje je značilna rumena barva, v primeru kadar pa so v bližini površja, se pa obarvajo rdeče. Ta prehod rumene barve v rdečo je povezan s procesi oksidacije med potekom diageneze. Pri teh procesih se rjavi goethit pretvori v rdeči hematit. Mineralna združba teh rdečih klastičnih sedimentov je pa malo drugačna kot mineralna združba rdečih prsti, ki so nastale pri površinskih procesih pedogeneze. Tako, da je lahko mineralna sestava rdečih prsti na krasu popolnoma različna in vedno zavisi od njihovega izvora in načina nastanka.

Podobni sedimenti, kakršni so bili najdeni v Brezstropi jami so bili ob gradnji avtoceste najdeni še na več drugih mestih. Pri sedimentih, v vseh primerih je šlo za jamske sedimente, se je pokazalo nekaj izrazitih skupnih potez, pa tudi nekaj razlik, ki so posledica individualnega razvoja vsake jame. Izrazite razlike so pojav sige, podornih skal ali ostrorobega grušča na alohtonih sedimentih, kar kaže način, kako so se posamezne jame odprle proti površju. Ponekod so bili najdeni sedimenti velikosti od gline, melja, peska, do proda, drugod pa le ena od frakcij. Gre bodisi za jame, ki so nastale v različnih višinah, pripadale različnim vodnim tokovom ali nastale v različnih časovnih obdobjih. V več primerih smo našli jamske sedimente, ki so zapolnjevali vrtače ali druge depresije na trasi, na primer na ledini Grintavca med Češnjevcem in Dolom Rebidnik, v vrtači v Bojnem dolu, v več vrtačah med Povirjem in Žirjami, kar nam da dimenzijo razširjenosti fluvialnih jamskih sedimentov na površju krasa.

Fluvialni sedimenti najdeni v jamah, ki jih je že dohitelo korozijsko zniževanja površja so pomemben vir površinskih prsti na krasu. Njihova lega je lahko prvotna, ali pa so delno ali povsem presedimentirani.

S pomočjo sedimentov, ter jamskih rovov lahko tudi delno rekonstruiramo čas v katerem so te jame nastale. Brezstropa jama je ostanek večjega jamskega sistema, ki je prevajal vode ponikalnic s fliša. Zunanji vplivi se v času nastanka niso odrazili na oblikovanje kapnikov in sigovih kop, količina odložene sige kaže na vsaj nekaj deset m debel strop. Rast kapnikov je bila vsaj enkrat prekinjena z erozijo. Skozi jamo je tekla ponikalnica, ki je nosila velike prodnike. Po njihovi velikosti in po velikem deležu prodnikov iz flišnega peščenjaka, ki je zelo krhek ter ne prenese daljšega rečnega transporta (Kranjc 1986, 1989), lahko sklepamo, da ponori niso bili daleč stran. Podobne prodnike danes najdemo le v jamah Brkinskih ponikalnic, do 1 km stran od stika fliš-apnenec. Pretok vode je variral od nekaj deset l/s do več m^3. Lahko predpostavimo, da je bila jama popolnoma zapolnjena s fluvialnimi sedimenti, ko je bilo površje nad njo še v višini okrog 450 m, ponori na stiku fliša in apnenca pa vsaj v enaki višini, a ne več kot 1 - 2 km stran. Danes je najbliže jami fliš nad dolino Raše, oddaljen okrog 5 km, stik fliša in apnenca pa je v višini okrog 500 m. Brkinski fliš, ki leži SE je še dlje, 7 km stran.

Ker sta obe flišni področji predaleč, lahko predpostavimo, da je moralo obstajati bližje izvorno področje flišnega peščenjaka. Možen izvor proda bi bil na območju Divaškega Gabrka 1 km NE od jame, kjer fliša danes ni več. Ker Gabrk grade mlajši paleocenski in eocenski alveolinski in numulitni apnenci, nad katerimi manjka po stratigrafskem stolpcu do eocenskih flišnih plasti le okrog 120 m, se zdi to področje najverjetnejši vir sedimentov. V podobnih razmerah so se oblikovale tudi druge odkrite jame, vendar je zanje teže rekonstruirati ostale okoliščine nastanka, saj so manjše ali slabše ohranjene.

Sedanje speleohidrološke razmere so precej drugačne. Najpomembnejša ponikalnica je Reka, ki ponika v Škocjanskih jamah v nadmorski višini 317 m ter teče v sifon, ki je v višini 214 m. V bližini opisanih nahajališč jamskih sedimentov pa je prosta gladina vode v Kačni jami višinah med 156 in 180 m in niha za okrog 100 m (Mihevc, 1984). V okolici Brezstrope jame lahko torej računamo na 220 m globoko vadozno cono, to je cono kjer prevladuje vertikalno prenikanje, rast brezen ter spiranje sedimentov in prsti navzdol. Časovno lahko ta prostor opredelimo kot prostor v katerem so se ohranile jame, medtem ko se je gladina prostotekočih rek in gladina kraške vode v jamah spustila od 400 m na 180 m, površje znižalo za najmanj 50 m. Po nekaterih izračunih naj bi se površje v zadnjih milijon letih znižalo za približno 60 m (Gams, 1962). Ob predpostavljeni debelini stropa 50 m je bila Brezstropa jama zapolnjena s sedimenti pred okrog 800 000 leti.

V tem času so se na površju lahko oblikovale tudi vrtače, saj so bili izpolnjeni vsi pogoji, to je vertikalni gradient ter zadovoljivo odvajanje vode skozi kras. Klub obstoječem vertikalnem gradientu pa so rovi ostali zapolnjeni s sedimenti. Velik del sedimentov je bil iz jam, ki jih je erozija že popolnoma odstranila, presedimentiran in jih najdemo danes na površju, ponekod tudi v vrtačah, kjer so se nekdanji jamski sedimenti lahko tudi delno spremenili.

VELIKA VODA - REKA - A KARST RIVER

VELIKA VODA - REKA - KRAŠKA REKA

DANIEL ROJŠEK

Izvleček UDK 551.444.3(450+497.4)

Daniel Rojšek: Velika voda - Reka - kraška reka

Veliko vodo-Reko najdemo v naravoslovni in drugi literaturi od antike naprej. Reka je klasični primer kraške reke na otoku neprepustnih kamenin sredi obsežnega kraškega sveta. O Reki imajo na Inštitutu za raziskovanje krasa ZRC SAZU v Postojni obdelanih kar 399 bibliografskih enot (1*). Hidro-geografske značilnosti (2*) fluvialno kraškega porečja Velike vode-Reke smo v tem prispevku povzeli po objavljenih študijah, rečni režim 40-letnega obdobja (1953-1992) (3*) pa smo obdelali na novo.

Ključne besede: rečni režim, fluvialno-kraško porečje, Seznam svetovne dediščine pri UNESCO, Velika voda-Reka, Timav, matični Kras, Slovenija, Italija

Abstract UDC 551.444.3(450+497.4)

Daniel Rojšek: Velika Voda - Reka - a Karst River

The Velika voda-Reka river is known in natural sciences and in literature since antiquity. The river is a classical representative of a karst river, isolated in a huge karst area. In the Postojna Karst Institute a rich bibliography containing 399 units exists (1*). Hydro-geographical features (2*) of the Velika voda-Reka fluviokarst basin have been studied, published and summarized in this paper. The river regime for a period of 40 years (1953-1992) (3*) is presented for this paper.

Key words: river regime, fluvio-karst drainage area, the World Heritage List by UNESCO, Velika voda-Reka, Timav - Il Timavo, Karst, Slovenia, Italy

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3 Many thanks for the data to Mr M. Kolbezen and Mrs D. Medvešček from Hidrometeorološki zavod Slovenije in Ljubljana.*

INTRODUCTION

The Velika Voda-Reka is a living name for the world famous karst river used by locals of the drainage area (Rojšek, 1992, 1993-2). Less adequate synonyms as the Notranjska Reka, Brkinska Reka, Timavo Superiore and similar can be found in the literature, too.

The Velika voda-Reka is narrowly linked by the the Škocjan Cave System. The Reka is one of the most interesting natural features of the Škocjan World Heritage Site by U.N.E.S.C.O. (Rojšek, 1995).

Sinking of the river into the Kras region, karst springs of Timav - Il Timavo and Brojnice - Sorgenti di Aurisina - Nabrežina and hydro-geographical properties of the Reka have been admired and studied since antiquity.

The Velika Voda-Reka is a classical representative of a karst river. The Reka drainage basin is caught between karst areas of the Snežnik massif, the upper Pivka fluvio-karstic drainage area, the Košansko-Slavinski ravnik karst plain and the Kras region (Fig. 1).

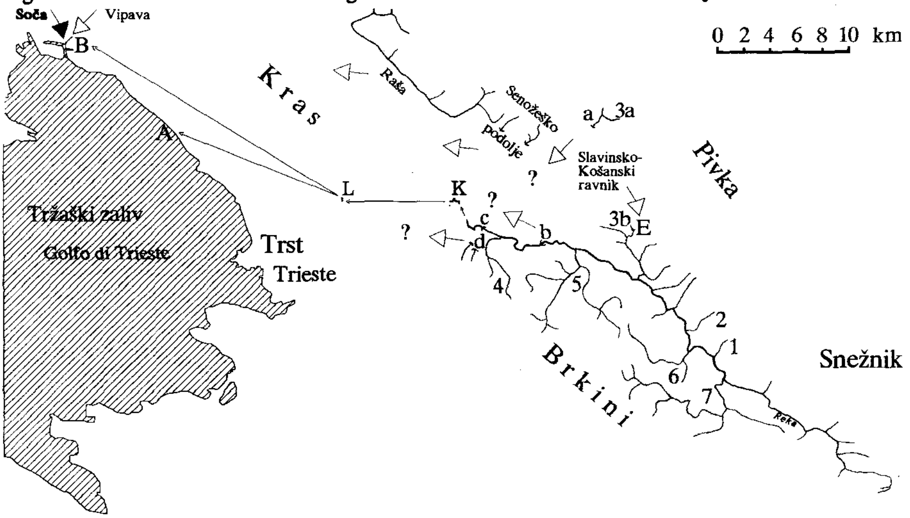
KARST RIVER

The karst river is a stream influenced by karst features. A surface karst river or its tributary can either spring out of a karst massif or the river sinks into it. The underground flow is either shallow or deep in the karst massif.

The Velika Voda-Reka is the widest known sinking stream of the classical Kras. The drainage basin lies on the Brkini sinkline Eocene flysch rocks, that are isolated in a huge Mezozoic karst area. There are four karst tributaries to the Reka drainage network: the Bistrica, Podstenjšek, and Rakulšca Sušica-Mrzlek are the right ones, and the Završka Sušica is the left one (Fig. 1).

About one cubic meter per second of the Reka water sinks into the Požiralnik Reke and in other swallow-holes near Gornje Vreme at the contact of Eocene flysch and Paleocene limestones at the beggining of the Vremska dolina blind valley (Rojšek, 1984). Sinking conditions at the contact change. The pothole that had opened on the 14th September, 1982 was flooded by high waters on the 2nd October, 1982. Cavers descended 22 m, 26 m and 20 m into the pothole for three times and found different levels of the cave. Its entrance was 9.4 m long and 5.5 m wide in August 1983 later it was widened (10.3 x 7.1 m in October 1985), but it was filled up with gravel few years ago.

Fig. 1: The *Velika voda-Reka* drainage network and the *Kras* karst water junctions



KARST TRIBUTARIES:
1 Bistrica
2 Podstenjšek
3a Rakulšca - 3b Sušica
4 završka Sušica

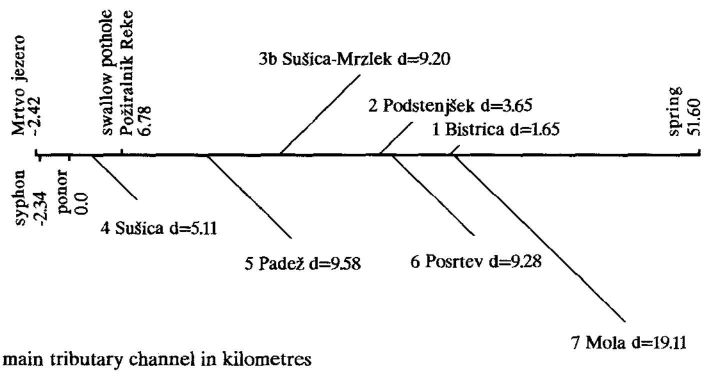
PONOR CAVES:
a Markov spodmol
b Požiralnik Reke
c Škocjanska jama
d Mejame

KARST SPRINGS:
A Brojnice - Sorgenti di Aurisina - Nabrežina
B Timav - Il Timavo

ESTAVELLE:
E Gabranca

WATER CAVES:
K Kačja jama
L Lobodnica - Grotta di Trebiciano

Scheme of the main channel network



d=5.11 - lenght of the main tributary channel in kilometres

6.78 - distance from the ponor in kilometres

The main quantity of the water sinks into Škocjanska jama, the first cave of the Škocjan Cave System. Frequent floods make damages in the System's show part, and Šumeča jama is flooded up to the cave ceiling from Müllerjeva dvorana downwards. Waters of Senoželško Podolje, the Raša, Branica, Vipava and Soča rivers, sink in the Kras aquifer, too. Brojnice - Sorgenti di Aurisina - Nabrežina and Timav - Il Timavo springs represent direct outlets of the aquifer into the Adriatic Sea. The Brojnice submarine spring is the Reka's basic runoff outlet, but the Soča underground water prevails in Timav springs average discharge (Rojšek, 1987, 1993-3, Fig. 1).

Basic hydro-geographic parameters of the basin:
* the basin surface = 335 km^2,
* the mean sea level = 570 m,
* the mean basin slope (without the Bistrica karst basin) = 26 %,
* the permeability coefficient = 0.40,
* the Velika voda-Reka length from the spring to
- the swallow pothole Požiralnik Reke = 45.07 km,
- the ponor Škocjanska jama = 51.60 km,
- the syphon in Marchesettijevo jezero = 53.94 km.
- the Mrtvo jezero underground lake = 54.02 km (Fig. 2),
* the Velika Voda-Reka mean channel slope from the spring to
- the swallow-hole Požiralnik Reke = 0.330 %,
- the ponor in Škocjanska Jama = 0.332 % and
- the syphon in Marchesettijevo Jezero = 0.676 % (Fig. 2).

Some authors divided the basin into three parts: the upper, the middle and the lower one, but from hydro-geographical point of view there are three main hydro-geographical units: the Velika Voda-Reka fluvio-karstic drainage area, the classical Kras aquifer and marshy basin of the Timav springs (the Potok river - Il Timavo) at the coast, where karst water drain into the Adriatic Sea. There are many drainage zones with different permeability in the Kras aquifer. The Reka underground course belongs to one zone of the aquifer, but the main affluent throughflow of the Timav belongs to the zone with underground water from the Soča drainage basin. The Kras aquifer surface of different limestones is estimated to 700 km^2, where about 70 km^2 belong to the Senoželško podolje and the Raša fluvio-karst drainage area and about 20 km^2 to other smaller areas. The aquifer permeability coefficient is estimated to 0.79 (Rojšek, 1981: 18).

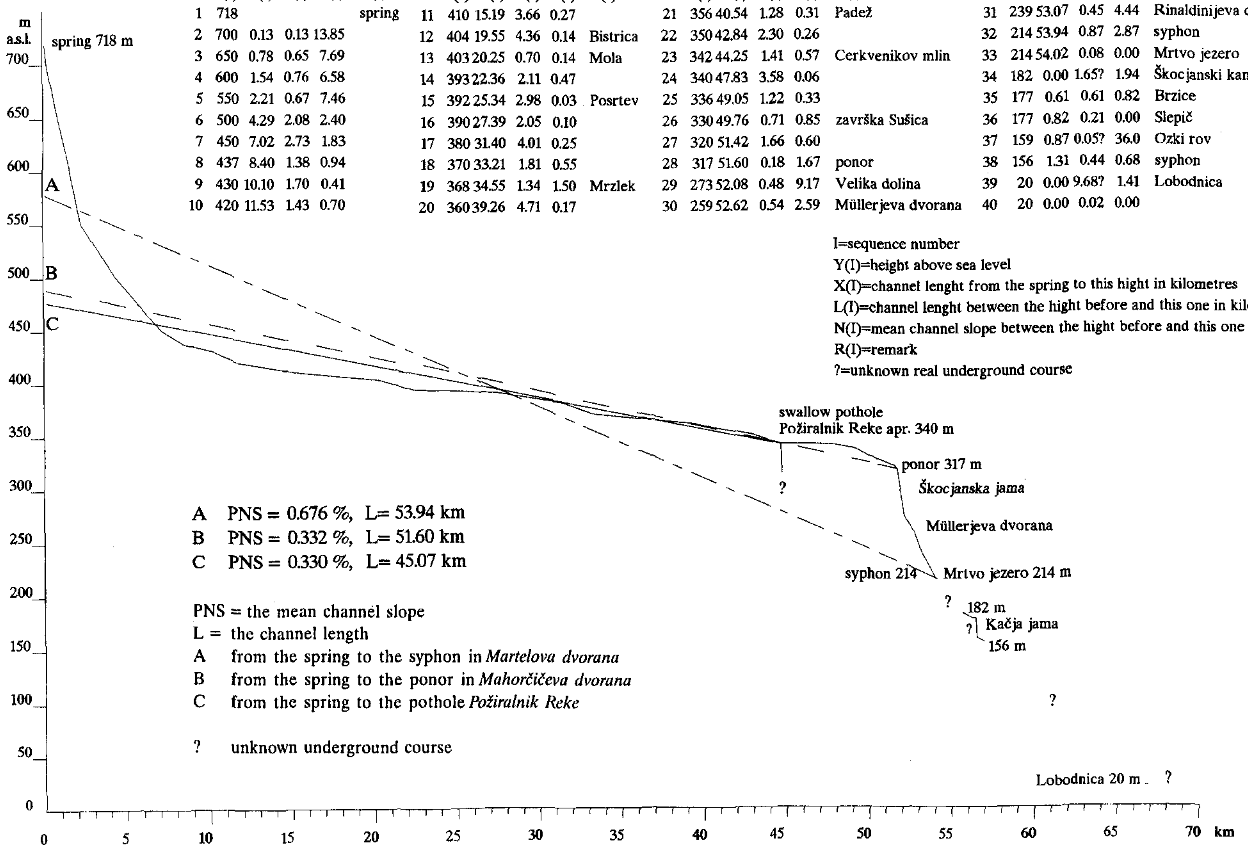
Data for the Velika Voda-Reka longitudinal profile were read in the 1:25.000 scale map and in works of Mihevc (1984-1, 2)*1 and Rojšek (1981).

**1 Many thanks for the unpublished data to Mr A. Mihevc MSc from Inštitut za raziskovanje krasa ZRC SAZU in Postojna.*

Fig. 2: The *Velika voda-Reka* longitudinal channel profile and the mean channel slopes

I	Y(I)	X(I)	L(I)	N(I)	R(I)
1	718				spring
2	700	0.13	0.13	13.85	
3	650	0.78	0.65	7.69	
4	600	1.54	0.76	6.58	
5	550	2.21	0.67	7.46	
6	500	4.29	2.08	2.40	
7	450	7.02	2.73	1.83	
8	437	8.40	1.38	0.94	
9	430	10.10	1.70	0.41	
10	420	11.53	1.43	0.70	
11	410	15.19	3.66	0.27	
12	404	19.55	4.36	0.14	Bistrica
13	403	20.25	0.70	0.14	Mola
14	393	22.36	2.11	0.47	
15	392	25.34	2.98	0.03	Posrtev
16	390	27.39	2.05	0.10	
17	380	31.40	4.01	0.25	
18	370	33.21	1.81	0.55	
19	368	34.55	1.34	1.50	Mrzlek
20	360	39.26	4.71	0.17	
21	356	40.54	1.28	0.31	Padež
22	350	42.84	2.30	0.26	
23	342	44.25	1.41	0.57	Cerkvenikov mlin
24	340	47.83	3.58	0.06	
25	336	49.05	1.22	0.33	
26	330	49.76	0.71	0.85	završka Sušica
27	320	51.42	1.66	0.60	
28	317	51.60	0.18	1.67	ponor
29	273	52.08	0.48	9.17	Velika dolina
30	259	52.62	0.54	2.59	Müllerjeva dvorana
31	239	53.07	0.45	4.44	Rinaldinijeva dvorana
32	214	53.94	0.87	2.87	syphon
33	214	54.02	0.08	0.00	Mrtvo jezero
34	182	0.00	1.65?	1.94	Škocjanski kanal
35	177	0.61	0.61	0.82	Brzice
36	177	0.82	0.21	0.00	Slepič
37	159	0.87	0.05?	36.0	Ozki rov
38	156	1.31	0.44	0.68	syphon
39	20	0.00	9.68?	1.41	Lobodnica
40	20	0.00	0.02	0.00	

I=sequence number
Y(I)=height above sea level
X(I)=channel lenght from the spring to this hight in kilometres
L(I)=channel lenght between the hight before and this one in kilometres
N(I)=mean channel slope between the hight before and this one in %
R(I)=remark
?=unknown real underground course



The Bistrica stream is the strongest karst tributary of the river. Water springs out of the Snežnik massif and the Koritniška Kotlinica small relief basin in the hinterland. There are some registered, but not explored and surveyed caves in the spring area, which is dammed for the reginal water supply. Basic hydro-geographical parameters are published (Rojšek, 1987: 14, 16).

The Podstenjšek springs are located at the contact area of flysch and limestones. The highest water flows out of Kozja luknja, 85 m long and 20 m deep cave, where Proteus anguinus has been found.

The Stržen-Sušica-Mrzlek channels network is the most developed among the right tributaries. The network of 45 channels with total lenght of 43.17 km is located in the area of 49.25 km². Orographic watershed of this fluvio-karstic basin is uncertain and from the estavelle pothole Gabranca high waters of the Rakulšca stream from the other side of the Košansko-Slavinski ravnik flow off (Fig. 1). The Rakulšca karst water is accessible in the cave Vodna jama v Lozi between Markov spodmol and estavelle (F. Habe, F. Hribar, 1964).

The Završka Sušica stream is the tributary without permanent flow consisting of 24.90 km long channel network of 11.04 km² fluvio-karstic drainage basin.

THE VELIKA VODA - REKA RIVER REGIME

Ilešič (1947: 101-102) was the first who was studied the Velika Voda-Reka river regime for the period 1898-1913. He determined the regime as pluvio-nival with poor nival influence related only to water level at the gauging station Ilirska Bistrica.

Dukić (1968: 138-145) defined it as Mediteranean variant of the pluvial type regime with the highest average runoff in December and the lowest in August, but he used unrelevant data and his hydro-geographical study of the Reka is worthless.

Rojšek (1981, 1983, 1984, 1987, 1990) studied and published the regime of the limnigraph gauging station Cerkvenikov mlin (25 and 30 years period 1953-77 and 1953-1982). According to data of 40 years period 1953-92 the last average regime was ascertained, illustrated with histogram and runoff regimes of the lowest and the highest waters (Figs. 3-6).

Fig. 3: HISTOGRAM OF THE MEAN RUNOFF
Velika voda-Reka
gauging station Cerkvenikov mlin
period 1953-1992

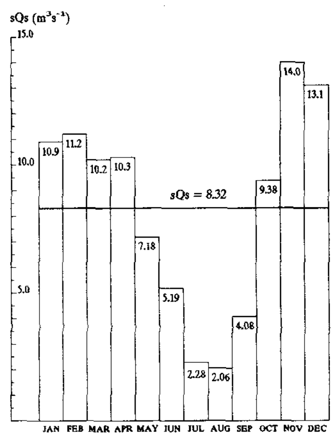


Fig. 4: Velika voda-Reka
runoff regime of the mean waters - **Qs** in m^3s^{-1}
gauging station Cerkvenikov mlin
period 1953-1992
sQs*[1] = 8.32 sQs(n)*[2] = 1.20 sQs(v)*[3] = 27.2

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
15.9	6.66	2.20	4.76	5.85	6.95	6.98	1.01	2.73	7.32	9.09	3.28	1953
6.47	4.84	10.7	3.49	12.4	4.78	2.24	0.50	1.33	3.16	9.56	12.7	1954
10.9	20.1	19.3	3.98	4.03	6.19	4.63	4.23	3.28	8.12	8.21	9.86	1955
10.9	11.6	3.98	15.1	11.2	6.98	2.31	0.64	0.48	4.09	14.3	2.00	1956
9.57	15.8	2.73	9.10	4.34	2.97	1.28	0.73	0.63	1.70	7.19	7.65	1957
13.9	14.7	11.8	9.01	1.96	2.88	1.36	0.69	0.62	3.13	8.45	23.8	1958
10.8	1.97	2.88	13.8	13.6	2.31	1.22	1.39	0.71	5.27	21.7	39.1	1959
13.7	26.8	20.8	4.10	1.21	1.31	2.47	3.90	19.1	41.7	24.6	39.3	1960
18.4	5.28	1.96	8.34	3.10	8.20	4.52	1.93	0.47	10.7	23.6	11.0	1961
19.8	4.39	15.6	16.8	9.70	2.94	4.06	0.51	0.60	0.45	29.2	10.8	1962
20.1	9.26	14.2	8.07	5.25	7.88	1.16	4.11	7.18	12.4	21.8	8.35	1963
6.27	3.76	15.1	10.6	3.34	1.27	1.00	1.01	2.37	37.1	7.00	19.6	1964
20.2	5.72	13.6	6.66	10.6	16.0	3.46	1.76	35.4	4.57	16.8	24.3	1965
5.79	15.0	4.77	10.7	3.93	2.78	3.33	6.63	3.16	17.1	25.6	20.0	1966
8.20	11.8	8.76	19.2	8.47	4.94	1.02	0.62	1.06	1.05	8.33	4.92	1967
7.11	32.6	5.76	2.90	6.94	4.96	1.32	4.05	5.96	2.17	22.8	9.88	1968
9.16	21.3	9.24	5.61	8.98	6.25	1.86	6.42	10.3	0.92	19.0	6.99	1969
17.1	7.51	24.6	32.8	6.23	3.13	2.35	2.15	2.02	1.07	8.19	8.76	1970
15.7	12.5	15.3	12.4	4.93	7.13	1.16	0.58	0.53	0.49	5.23	4.34	1971
6.47	11.8	13.2	8.08	25.4	3.66	1.59	1.15	2.66	1.74	16.6	12.2	1972
6.14	8.05	1.60	6.42	1.40	1.61	0.98	0.38	6.80	8.41	10.0	8.67	1973
7.26	10.6	6.17	5.42	11.3	11.5	2.80	0.91	3.34	25.4	7.70	4.35	1974
3.47	2.45	23.5	22.0	5.96	4.35	4.56	1.19	1.77	1.75	16.1	13.1	1975
1.20	14.1	6.90	9.50	2.93	1.96	0.83	1.77	9.91	8.20	19.5	31.0	1976
27.4	22.7	4.43	10.6	2.94	1.73	2.14	11.3	1.66	3.56	7.54	6.88	1977
17.7	14.5	12.0	15.5	12.4	3.00	0.97	1.53	1.70	12.2	2.46	14.2	1978
28.2	28.2	20.9	18.4	4.61	1.06	0.60	0.58	5.54	6.34	20.6	11.1	1979
8.59	6.85	5.76	5.56	3.50	9.39	5.46	1.60	3.03	23.4	25.9	11.7	1980
3.29	2.73	11.7	3.42	10.6	3.68	1.52	0.89	4.66	14.1	3.63	24.5	1981
15.4	1.84	6.17	4.42	8.53	7.26	1.50	1.82	0.92	18.7	14.7	20.7	1982
3.80	3.42	12.6	10.5	2.77	1.17	0.86	0.91	1.03	1.01	0.64	12.2	1983
9.21	11.2	7.29	12.1	6.74	6.10	2.49	1.54	4.91	25.0	6.85	14.1	1984
16.4	8.11	17.4	14.6	10.4	4.01	2.03	1.21	1.23	0.75	3.20	3.42	1985
8.57	6.67	10.0	11.7	3.62	8.77	1.19	1.15	1.29	1.11	3.69	4.84	1986
4.44	24.6	4.11	6.61	10.2	3.45	2.47	2.29	3.19	9.46	26.6	10.1	1987
12.0	17.5	12.3	12.3	4.69	9.25	1.19	1.76	2.51	5.43	0.91	3.49	1988
1.23	3.99	14.0	11.6	2.96	10.2	4.26	3.15	3.72	2.05	10.1	5.12	1989
4.18	3.44	2.11	10.7	1.99	5.51	1.52	1.75	2.54	11.1	22.3	18.1	1990
9.05	8.71	2.87	3.76	24.8	7.59	1.56	1.23	1.19	4.18	31.7	3.72	1991
1.84	4.27	11.2	11.5	3.37	2.32	2.98	1.33	1.49	28.6	18.3	24.2	1992
1.20	1.84	1.60	2.90	1.21	1.06	0.60	0.38	0.47	0.45	0.64	2.00	1.20
10.9	11.2	10.2	10.3	7.18	5.19	2.28	2.06	4.08	9.38	14.0	13.1	8.32
28.2	32.6	24.6	32.8	25.4	16.0	6.98	11.3	35.4	41.7	31.7	39.3	27.2

*[1] the mean water of the period
*[2] the lowest month mean water of the period
*[3] the highest month mean water of the period

Fig. 5: Velika voda-Reka
runoff regime of the lowest waters - **Qn(k)** in m^3s^{-1}
gauging station Cerkvenikov mlin
period 1953-1992
nQn(k)*1 = 0.12 vQn(k)*2 = 13.7

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2.37	1.98	1.28	1.28	1.19	1.28	0.58	0.30	0.12	0.44	0.79	0.34	1953
2.65	1.28	2.65	0.56	1.28	1.28	0.51	0.20	0.16	1.00	1.75	2.49	1954
1.88	3.82	6.95	1.63	1.39	1.88	1.18	0.92	0.67	1.00	2.33	2.33	1955
3.00	3.40	1.27	3.20	2.60	2.60	0.80	0.36	0.29	0.36	3.62	1.05	1956
1.94	1.56	1.04	1.68	1.80	0.74	0.48	0.50	0.46	0.68	0.56	0.40	1957
2.22	3.22	6.32	3.58	0.80	0.62	0.68	0.37	0.43	0.50	1.12	1.12	1958
4.12	1.32	0.69	3.40	1.44	1.04	0.56	0.50	0.40	0.40	3.94	10.2	1959
2.50	4.40	6.32	1.68	0.74	0.56	0.96	1.20	1.04	12.2	5.84	9.04	1960
1.80	1.44	1.04	1.20	1.04	1.20	0.62	0.62	0.37	0.37	3.94	2.36	1961
4.83	2.52	2.85	3.34	1.93	1.30	0.80	0.28	0.28	0.19	0.53	2.52	1962
2.52	3.01	3.34	3.34	1.65	1.53	0.46	0.39	1.52	1.52	1.52	2.52	1963
2.95	1.20	2.62	3.97	1.41	0.86	0.53	0.53	0.48	0.78	1.65	1.89	1964
4.88	0.94	1.10	1.30	1.77	1.10	0.71	0.38	3.62	0.53	0.38	7.55	1965
2.84	4.11	2.84	3.25	2.47	1.94	1.87	2.00	1.94	3.25	8.76	4.47	1966
4.64	2.67	3.98	6.36	4.82	1.17	0.39	0.46	0.46	0.56	0.92	1.48	1967
2.50	2.50	2.85	1.70	2.04	1.56	1.03	1.03	1.27	1.07	1.17	1.96	1968
1.71	3.37	3.22	2.75	2.60	2.25	1.31	1.03	1.68	0.60	0.32	3.16	1969
0.90	2.79	3.28	13.7	2.70	1.71	0.42	0.30	0.67	0.80	0.92	1.88	1970
2.70	2.70	1.71	3.18	2.56	1.62	0.86	0.22	0.32	0.22	0.22	1.19	1971
1.66	1.10	2.29	1.80	2.95	0.80	0.65	0.57	0.52	0.57	1.66	1.80	1972
1.15	2.08	1.25	1.25	0.57	0.39	0.48	0.30	0.30	1.35	1.35	1.35	1973
1.75	1.75	1.75	1.05	2.41	2.41	0.75	0.48	0.70	3.78	2.10	1.80	1974
1.66	1.10	2.16	2.55	1.74	1.42	1.26	0.97	0.90	0.84	1.03	2.94	1975
0.78	0.91	1.70	2.11	1.18	0.68	0.49	0.63	1.11	0.97	2.11	2.00	1976
4.48	4.55	2.15	2.05	1.76	1.43	1.46	1.68	0.73	2.45	2.10	1.30	1977
2.20	5.49	5.29	2.80	4.10	0.80	0.68	0.52	0.64	0.80	0.56	1.30	1978
2.76	5.08	1.80	1.60	0.80	0.68	0.48	0.39	0.39	0.90	1.40	2.28	1979
2.30	2.00	1.90	2.30	1.90	2.30	1.80	1.30	1.30	1.20	5.05	2.90	1980
0.75	1.11	1.47	1.29	2.94	1.47	0.75	0.53	0.53	2.19	2.01	3.14	1981
2.37	1.35	1.07	1.69	1.35	1.52	0.55	0.64	0.28	0.37	2.55	3.07	1982
1.21	2.20	2.72	1.69	1.21	0.55	0.46	0.46	0.28	0.28	0.19	0.55	1983
1.75	1.26	2.10	1.26	0.83	1.58	0.83	0.83	0.70	4.85	3.21	3.78	1984
2.48	2.48	3.07	6.84	1.39	1.39	0.91	0.91	0.60	0.50	0.91	1.52	1985
2.29	1.79	2.64	2.82	0.96	1.08	0.35	0.44	0.28	0.28	0.62	1.08	1986
2.02	2.98	2.02	2.59	2.39	2.02	0.63	0.31	0.31	2.02	3.18	3.58	1987
4.31	5.31	4.56	3.34	2.44	2.23	0.47	0.18	0.97	0.97	0.58	0.82	1988
0.50	0.87	2.04	2.64	0.87	1.67	1.67	0.87	1.33	1.33	1.49	1.67	1989
1.34	1.50	1.03	3.30	1.18	1.18	1.03	0.88	1.18	1.68	2.65	5.26	1990
1.15	2.25	1.31	2.48	2.71	1.47	0.88	0.76	0.65	0.46	1.15	0.14	1991
1.32	1.57	1.32	2.45	1.40	1.25	1.40	0.74	1.11	1.11	3.03	2.45	1992
0.50	0.87	0.69	0.56	0.57	0.39	0.35	0.18	0.12	0.19	0.19	0.14	
4.88	5.49	6.95	13.7	4.82	2.60	1.87	2.00	3.62	12.2	8.76	10.2	

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*1the lowest recorded peak of the lowest waters
*2the highest recorded peak of the lowest waters

Fig. 6: Velika voda-Reka
runoff regime of the highest waters - **Qv(k)** in m^3s^{-1}
gauging station Cerkvenikov mlin
period 1953-1992
nQv(k)*[1] = 0.32 vQv(k)*[2] = 305

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
192	74.9	4.24	29.9	18.0	19.6	36.3	7.00	17.6	65.8	96.0	18.0	1953
25.4	24.2	36.4	28.6	63.3	20.3	10.4	0.61	28.2	13.4	129	54.3	1954
102	68.2	167	14.4	16.7	40.8	27.4	31.4	30.2	68.2	27.8	47.1	1955
63.7	49.9	12.8	81.2	48.6	25.4	17.0	1.16	3.40	56.7	92.6	12.2	1956
54.0	76.7	7.36	42.9	23.3	24.9	11.2	1.94	1.04	12.5	66.7	44.3	1957
115	136	40.0	39.4	4.88	29.7	4.40	3.58	1.32	41.2	57.3	203	1958
46.5	4.12	14.9	65.7	107	13.8	4.40	7.08	2.50	103	115	174	1959
69.7	147	128	11.2	1.80	15.6	6.56	21.5	182	235	85.1	186	1960
198	66.2	6.08	55.3	17.0	58.7	93.6	13.5	0.74	142	145	5.20	1961
88.9	14.9	84.5	62.1	67.6	12.4	47.8	0.80	3.88	1.08	109	62.6	1962
166	94.8	65.6	16.6	33.7	83.3	6.80	36.7	34.9	169	183	33.9	1963
31.1	26.6	81.5	44.5	9.56	5.65	2.62	5.45	30.7	248	30.7	109	1964
87.8	26.2	105	52.6	111	110	19.8	68.7	277	25.5	85.1	185	1965
36.6	49.8	12.2	49.8	24.0	18.9	14.2	61.2	26.3	93.0	195	204	1966
32.2	149	17.4	119	63.7	54.7	2.93	0.85	3.57	4.82	87.8	29.8	1967
48.7	147	18.3	26.3	96.0	56.1	4.69	61.7	59.6	8.61	231	276	1968
115	157	28.8	17.7	198	39.4	3.53	37.6	77.7	1.55	240	19.6	1969
109	16.8	174	123	19.0	12.4	9.15	42.2	14.3	3.56	72.7	131	1970
86.7	151	162	134	11.3	44.0	3.05	0.86	1.08	7.00	48.7	23.0	1971
77.4	61.5	126	19.1	305	23.4	25.6	6.31	14.2	16.6	101	68.8	1972
11.3	63.3	2.61	23.1	7.49	3.71	0.83	0.32	0.32	11.1	8.13	61.1	1973
39.3	116	94.8	65.1	58.6	97.2	21.1	8.10	34.2	172	41.9	13.6	1974
44.6	8.57	204	91.8	57.7	61.0	43.2	21.6	13.6	13.9	262	116	1975
2.11	174	23.1	39.4	10.9	8.00	1.51	26.3	151	188	77.7	178	1976
98.4	115	14.9	94.8	23.6	2.80	22.3	118	9.61	14.4	65.1	96.6	1977
224	56.2	36.2	93.0	63.5	22.1	2.44	50.0	11.1	104	54.7	94.2	1978
101	69.9	85.2	138	22.5	3.82	1.00	1.40	93.6	105	214	96.6	1979
101	48.2	26.7	46.4	15.7	67.8	23.9	25.3	73.2	119	119	84.0	1980
10.4	13.1	52.8	29.8	106	18.6	4.31	7.52	39.7	91.2	9.65	159	1981
104	2.72	65.1	21.0	75.3	65.6	5.20	12.0	2.90	97.2	157	73.2	1982
13.2	7.13	102	60.5	9.84	2.90	2.03	1.69	4.80	10.4	5.41	121	1983
94.0	81.4	62.1	112	47.7	23.6	16.8	4.15	45.2	233	53.7	150	1984
113	54.3	118	40.8	44.2	17.1	43.3	5.67	1.82	1.82	16.1	22.9	1985
56.1	54.6	49.2	79.8	30.1	83.3	6.95	8.39	9.35	5.09	61.4	34.5	1986
15.0	124	32.4	21.7	36.6	18.1	9.78	27.2	66.9	76.7	235	27.9	1987
53.9	77.5	101	68.9	18.0	75.7	4.56	12.8	38.1	68.9	2.44	16.0	1988
3.30	64.3	106	56.0	8.86	67.5	22.5	37.2	33.9	9.16	162	20.1	1989
16.0	7.72	7.72	47.0	6.33	30.9	6.33	10.7	8.86	73.1	168	229	1990
52.3	110	5.71	6.83	160	66.2	3.80	3.27	20.8	31.5	243	15.0	1991
4.01	20.8	117	59.3	23.0	12.0	23.8	3.42	8.54	175	84.4	259	1992
2.11	2.72	2.61	6.83	1.80	2.80	0.83	0.32	0.32	1.08	2.44	5.20	
102	115	105	79.8	63.7	61.0	22.5	31.4	39.7	105	162	159	
104	116	106	81.2	67.6	65.6	23.8	36.7	45.2	119	168	174	
109	124	117	91.8	75.3	66.2	23.9	37.2	59.6	142	183	178	
113	136	118	93.0	96.0	67.5	25.6	37.6	66.9	169	195	185	
115	147	126	94.8	106	67.8	27.4	42.2	73.2	172	214	186	
115	147	128	112	107	75.7	36.3	50.0	77.7	175	231	203	
166	149	162	119	111	83.3	43.2	61.2	93.6	188	235	204	
192	151	167	123	160	83.3	43.3	61.7	151	233	240	229	
198	157	174	134	198	97.2	47.8	68.7	182	235	243	259	
224	174	204	138	305	110	93.6	118	277	248	262	276	

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*[1]the lowest recorded peak of the highest waters
*[2]the highest recorded peak of the highest waters

The Velika Voda-Reka river regime of the 40 years period is determined as Submediteranean pluvio-nival with influence of karst retention. The average water level related to the period is 8.32 m^3s^{-1}. The highest mean water occurs in November, and the lowest in August. The highest mean monthly discharge belongs to the late autumn, winter and spring (Nov., Dec., Jan., Feb., Mar., Apr.). From November the average discharge decreases to January, it fluctuates from February to April and decreases again from May to August, to increase in November (Figs. 3, 4). Total subaverage discharge (20.79 m^3s^{-1}) does not reach one and the half of the highest average monthly discharge.

The runoff regime of the lowest waters shows that the lowest monthly peak of the period does not exceed one cubic meter per second, but one hundred and twenty liters per second (0.12 m^3s^{-1}) is the lowest recorded discharge. The highest monthly peaks of the lowest waters range from 1.87 to 13.7 m^3s^{-1} (Fig. 5).

Oscillating flood waves are characteristics of the highest runoff regime. The highest discharges have been not measured. The Cerkvenikov mlin gauging station discharge curve is uncertain in the upper part, thus the highest discharges displayed in the Fig. 6 are too low. The highest peak was recorded in September 1965 with discharge 277 m^3s^{-1}, but in the Fig. 6 the highest discharge of 305 m^3s^{-1} (May 1972) is shown. Hidrometeorološki zavod Slovenije - the Slovene hydrological institute processed the data of both flood waves (Rojšek, 1987: 19). The wave computation showed lower peak discharges. By the curve 222 m^3s^{-1} was computed as the 1972 wave's peak, but afterwards by the runoff and precipitation comparative analysis the peak of 305 m^3s^{-1} was estimated. The analysis of the 1965 wave has not yet been done.

In six months of the period (Jan., Feb., Mar., Oct., Nov. and Dec.) the highest peaks at least ten times expand beyond 100 m^3s^{-1}. The peak more than 100 m^3s^{-1} appeared every month of the period, except in July (93.6 m^3s^{-1}). In seven months of the period (Jan., Mar., May, Sep., Oct., Nov. and Dec.) 200 m^3s^{-1} appeared in November six times even (Fig. 6). A ratio between the lowest and the highest discharge is unknown, but it is more than 1:3.000.

DEGRADATION

The Velika Voda-Reka river was also known by overpollution of its waters from the Ilirska Bistrica town downwards. The river was degraded to sewer and the Cave System to sewage outlet of the town and regional agricultural, communal and industrial waste waters.

The basic river pollution parameters were published by Rojšek (1987, 21, 1990). From that time quality of the water improved, particulary after the independance of Slovenia in 1991. After that time the last big pollutant the Tovarna organskih kislin (Factory of organic acids) collapsed; Yugoslav army left barracks, and they are abandoned as military objects, however some pollutants still exist.

Building of projected communal water treatment plant for town, which should be built up in the year 1991 did not even started; also the validity of the plan location permission expired. The location procedure must start again, because inhabitants of Topolc village opposed to the plant location. The main reason of their discontent was the presumable plant stinking.

The water is no more overpolluted, but it is still in the 2nd to 3rd class, according to discharge. Diluting of communal waste water by fresh outlets from two accumulations in the Mola drainage basin is not appropriate and sufficient method to maintain the Velika Voda-Reka quality in the 2nd class. The functional communal cleaning plant is the only right way and a guarantee to maintain the river quality in the 2nd class.

CONCLUSION

A karst river is a stream influenced by karst features. A surface karst river or its tributaries either flow out of a karst massif or sink into it. The underground flows are shallow or deep in the karst massif.

The Velika Voda-Reka is a classical representative of a karst river. Its drainage basin lies mostly on the Brkini sinkline of the Eocen flysch rocks, which is isolated in a huge Mezozoic karst area. The Reka is narrowly linked by the Škocjan Cave System, the World Heritage Site. The river frequently floods the cave system (Figs. 1 and 2).

The Reka has a Submediteranean pluvio-nival river regime with influence of karst retention. The average water level for the period 1953-1992 is 8.32 m^3s^{-1}. The highest average water appears in November, the lowest in August. The runoff regime of the lowest waters shows that the lowest monthly peak of the period does not exceed one cubic meter per second, but one hundred and twenty liters per second (0.12 m^3s^{-1}) is the lowest recorded discharge. Oscillating flood waves are characteristics of the highest runoff regime. The highest discharges were not measured. The Cerkvenikov mlin gauging station discharge curve is uncertain in the upper part, thus the highest discharges in the figure 6 are too low. The highest discharge of the period was estimated to 305 m^3s^{-1}, however the peak was higher (Figs. 3-6).

A ratio between the lowest and the highest discharge is unknown, but it exceeds 1:3.000.

The water is no more overpolluted, but it is still in the 2nd to 3rd class, according to discharge. The water treatment plant of the Ilirska Bistrica town and industry is the only appropriate way to guarantee that the river quality remains in the 2nd class.

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VELIKA VODA - REKA - KRAŠKA REKA

Povzetek

Med domačini v porečju je Velika voda-Reka živo ime za svetovno znano kraško reko (D. Rojšek, 1992, 1993-2). V literaturi najdemo bolj ali manj neustrezne sinonime: Notranjska Reka, Brkinska Reka, Timavo Superiore in podobno, reka Reka pa je zagotovo med najbolj nesmiselnimi.

Ponikanje Reke v matični Kras, kraška izvira Timav in Brojnice pod Nabrežino ter druge hidro-geografske značilnosti Reke so občudovali in preučevali od antike dalje, kajti Velika voda je klasični primer kraške reke.

Kraško reko bistveno zaznamujejo vplivi krasa. Površinska kraška reka oziroma njen pritok lahko izvira iz krasa ali pa reka vanj ponika, podzemeljska se skozenj pretaka bolj ali manj globoko.

Porečje Velike vode se razteza na eocenskih flišnih kameninah brkinske sinklinale, ki tvori otok neprepustnih kamenin v obsežnem, večinoma mezozojskem kraškem svetu Snežniškega pogorja, Košansko-Slavinskega ravnika in matičnega Krasa ter fluvialno-kraškega porečja zgornje Pivke. Velika voda je del Škocjanskega jamskega spleta, kjer ima svoje mesto med zagotovo najbolj zanimivimi naravnimi pojavi v naravni in kulturni dediščini, ki je vpisana v Seznam svetovne dediščine pri UNESCO. Poplave v jamskem spletu so pogoste. Najvišje poplavne vode zalijejo Šumečo jamo do stropa od Müllerjeve dvorane navzdol. Reka ima štiri kraške pritoke: Bistrica, Podstenjšek in Sušica-Stržen-Mrzlek so desni, završka Sušica pa levi (sliki 1 in 2).

Reka ima pri Cerkvenikovem mlinu submediteranski pluvio-nivalni rečni režim z vplivi kraške retinence. Srednja voda obdobja 1953-1992 znaša 8.32 m^3s^{-1}. Najvišji poprečni odtok je novembra, najnižji pa avgusta (sliki 3 in 4). V odtočnem režimu najnižjih voda vidimo, da najnižja konica nikdar ne preseže kubičnega metra v sekundi, stodvajset litrov v sekundi (0.12 m^3s^{-1}) pa je najnižji opaženi pretok (slika 5). Temeljna značilnost odtočnega režima najvišjih voda je nihanje višine silovitih poplavnih valov. Najvišjih pretokov niso nikdar izmerili, temveč so jih izračunali. Pretočna krivulja vodomerske postaje Cerkvenikov mlin v zgornjem delu ni zanesljiva, tako da so konice iz slike 6 prenizke. Obdobna konica iz 305 m^3s^{-1} (maj 1972) je ocenjena, najvišja se je pojavila septembra 1965, vendar je nihče še ni na novo ovrednotil.

Razmerje med najnižjim in najvišjim pretokom ni znano, presega pa 1:3.000.

Voda Reke ni več tako onesnažena kot pred leti, vendar njena kakovost še vedno niha med 2. in 3. razredom, kar je večinoma odvisno od pretoka. Razredčevanje odplak v Reki s svežo vodo iz zadrževalnikov Klivnik in Mola ni pravi niti zadovoljivi način čiščenja Reke. Učinkovita komunalna čistilna naprava bi bila edino, kar bi nedvomno jamčilo da Reka ostane v drugem kakovostnem razredu.

ROCKY RELIEF IN SOME CAVES OF "NOTRANJSKO PODOLJE"

SKALNI RELIEF V IZBRANIH JAMAH NOTRANJSKEGA PODOLJA

TADEJ SLABE

Izvleček: UDK 551.435.1:551.442(497.4)

Tadej Slabe: Skalni relief v izbranih jamah Notranjskega podolja

Skalni relief je pogosto pomembna speleogenetska sled. To nam potrdi tudi proučevanje skalnega reliefa izbranih jam Notranjskega podolja. Izsledki nam služijo pri opredeljevanju nastanka in razvoja tega morfogenetsko povezanega kraškega predela.

Ključne besede: jamski skalni relief, speleomorfogeneza, Slovenija, Notranjsko podolje

Abstract UDC 551.435.1:551.442(497.4)

Tadej Slabe: Rocky Relief in some Caves of "Notranjsko Podolje"

Rocky relief frequently serves as important speleogenetical evidence. This is also confirmed by study of rocky relief in selected caves of Notranjsko podolje. The results may be used to define the origin and development of this morphogenetically consistent karst area.

Key words: rocky cave relief, speleomorphogenesis, Slovenia, Notranjsko podolje

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INTRODUCTION

Studying the origin and formation of the cave rocky forms has shown that rocky relief frequently serves as an important speleogenetical evidence. This is confirmed by study of rocky relief in selected caves of *Notranjsko Podolje*. Podolje means the lowlend consisting of karst poljes of this area. The results may be used to define the origin and development of this morphogenetically consistent karst area (Fig. 1). I have chosen the caves at the inflow (Križna jama) and outflow (ponor caves Mala Karlovica and Zelške jame) sides of the Cerknica lake and an active effluent cave Planinska jama where the waters of Pivka and Rak flow together. At, NW, higher part of Notranjska depression, i.e. at the border of Črni vrh polje, I have studied Ciganska jama near Predgriže. Logaška jama is an old cave lying on the Logatec karst plain.

Fig. 1: Ceiling pocket in Križna jama (scale = 15 cm)
Sl. 1: Stropna kotlica v Križni jami (merilo = 15 cm)

KRIŽNA JAMA, MALA KARLOVICA AND ZELŠKE JAME ROCKY RELIEF

Progressive karstification has left several traces in the speleogenesis of the higher level Križna jama which were presented in detail in *Acta carsologica* (Slabe 1989). The cave was formed by the waters flowing to Cerkniško jezero. Slow flow in that phreatic zone left big scallops (fig.) and ceiling pockets in some parts of the entrance channels which are now dry. Water channel level lowering has resulted in water level horizons. In the passages which are no longer reached by the actual water flow above water level rocky forms developed. Today the cave is deepened by water flow of rather high velocity and seasonal high waters in smaller channels incise small scallops (Fig. 1) on leeward side of the bigger passages fine-grained sediments are deposited. The below-sediment half tubes and solution niches occur.

Relatively quick transformation of the rocky relief is reflected in the different kinds of development of Mala Karlovica and Zelške jame. Heterogeneous cave development is evidenced by sediments and flowstone, and the rocky relief is concordant with the last stage of the cave development. High waters seasonally flooding Mala Karlovica up to 550 m, up to the ceiling with the exception of the breakdown halls, have transformed the traces of the older cave development. The flow velocity through the passages is medium, in narrow parts obviously a bit quicker, and concordant with the distribution of variously sized facets. The water erodes the rocky perimeter of channel, the flowstone and deposits which cover the floor for several metres thick on some places. The actual flow did not everywhere reach the original rocky bottom of the channels. Similar is the formation of Zelške jame. The water flow in the cave already incises the rocky bottom at the level of 505 m, the while seasonal high waters reach Blatni rov at 515 m. Slow water flow which drained through Blatni rov left bigger scallops (Fig. 2) and ceiling pockets. It is a characteristic flooded channel. Today the highest waters reach the lower part of the channel only. The rocky relief is formed below the fine-grained sediment deposited by the outflowing waters. The water flowing downwards off the flooded channel through smaller pasages incised smaller scallops. It means that at the time of the last prominent transformation of the upper channels the lower-lying water channel already existed. In the final part of Vodni rov there are rather bigger scallops on the upper parts of the channel than those at the level of the actual water flow. The channel was thus entirely flooded and the discharge through it was slower.

According to the sediments in the caves Gospodarič (1970, 138) inferred that the most important speleogenetical process was the sediment fill of the caves at Cerkniško jezero in Karlovice up to 550 m and in Zelške jame up to 525 m. It caused the waters to start transforming the former channels, which were in Karlovice at 548 m and in Zelške jame at 520 m a.s.l. Such

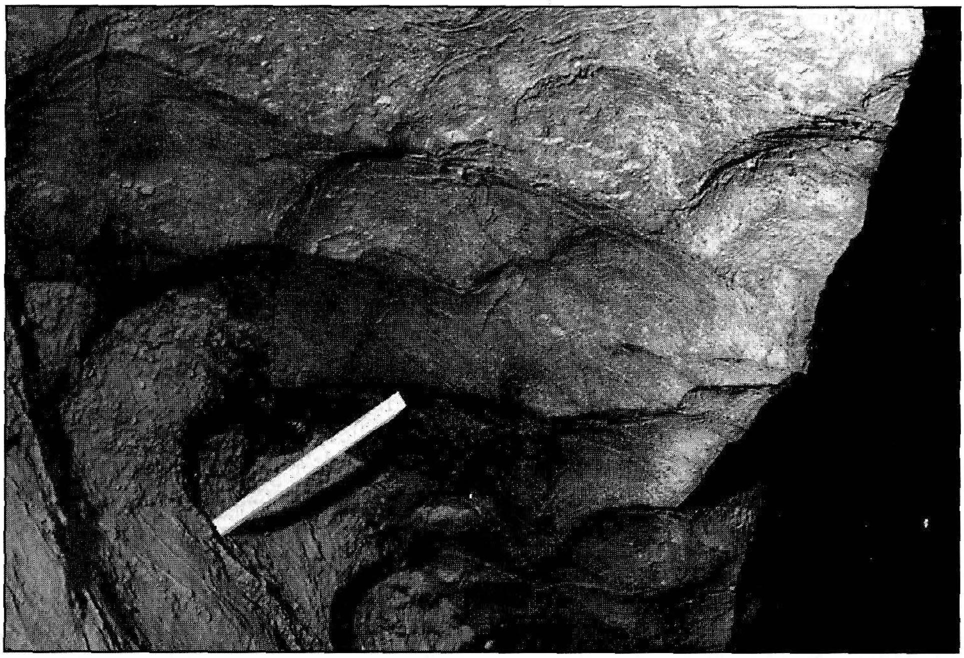

Fig. 2: Bigger scallops in Blatni rov of Zelške jame
Sl. 2: Večje fasete v Blatnem rovu Zelških jam

development is confirmed by rocky relief too. Reverse erosion advancing from Rak valley towards Cerkniško polje enables the transport of the sediments out of the caves and this is felt, even by deepening of the channels in Zelške jame.

PLANINSKA JAMA ROCKY RELIEF

Gospodarič (1974 a, 180)) studied the gravel in the cave. He stated that the speleogenesis of the passages between the Pivka basin and Planinsko polje is closely connected with various stages of sedimentation of the deposits. He continued this study two years later (Gospodarič 1976). He defined several erosion and accumulation phases of the development though they could not be identified in the rocky relief of the Rak branch. He connects the first erosion phase with gravel of coloured cherts transported by a water velocity of 2 m/s, while in the second phase a water velocity of 3 m/s transported gravel of white cherts. In Lower Würm the passages were filled up by laminated loam. Flood loam was deposited during Upper Würm too. During Holocene the sediments were washed away, the ground subsided, the speleothems collapsed and flowstone was deposited (Gospodarič 1976, 112). Kogovšek (1982) studied the hydrodynamics of water percolation into the cave and its corrosion efficiency.

The rocky relief of the Rak branch reveals two development phases. The first one is slow water flow through longitudinal and cross winding and flooded channels reaching in some sections 480 m above sea level. The results of such water flow are big scallops and ceiling pockets in the higher parts of the channel which are no more reached by the actual waters. The phase of erosion incision followed, probably with free water flow which levelled and deepened the channel. Nowadays we still witness the downcutting of the river which has not yet reached the rocky bottom from the period before the filling with older laminated loam (Gospodarič 1976, 68). The water washing the sediments out of the cave frequently flowed slowly and stagnated in front of the breakdowns. The walls were covered by manganese coating. The actual biggest discharges in the initial passages of smaller diameter reach velocities of 2-3 m/s. This is why the water flow forms smaller scallops.

In the Pivka branch also several development phases may be defined (Fig. 3) on the basis of the rocky relief. Slow water flow in the higher parts of the channel left ceiling pockets and big scallops (Slabe 1993, 150). In some places the gravel is stuck to them. The levelling and deepening of the channel was caused by water flow with bigger velocity and gradient. The channel deepened quickly and only the old rocky forms are preserved. Younger, progressive channel deepening and seasonally slower water discharge of higher waters in the wider parts of the conduit are evidenced by scallops of medium size on the walls above the level of medium high Pivka water. At the fifth bridge the river bed is already incised into the rocky floor. Flow at high velocity forms small scallops shapes the river bed nowadays also. The filling up the cave by fine grained sediments witness the above flood forms preserved in higher dry passages.

Gospodarič (1976, 65) considered that Pivka at first flowed through the Rak branch in Planinska jama and the former way towards Malni was later used by the Javorniki underground stream. The rocky forms really evidence similar development phases in the upper passages of Postojnska jama and in the upper parts of Pivka and Rak branches in Planinska jama. In both caves the oldest traces of the cave development are left by slow water flow. Referring to Gospodarič's (1981, 106) temporal definition of the development phases of the cave system on the base of the sediments and flowstone, one may infer that these channels were formed before the prominent erosion activity of the river and before the deposition of coloured chert gravel in Mindel. The origin of traces of faster epiphreatic water discharge through the caves may be connected. These are water level horizons on the walls evidencing the deepening of the Planinska jama channels and smaller and medium sized facets and ceiling pockets in the higher (520-530 m a.s.l.) passages of Postojnska jama.

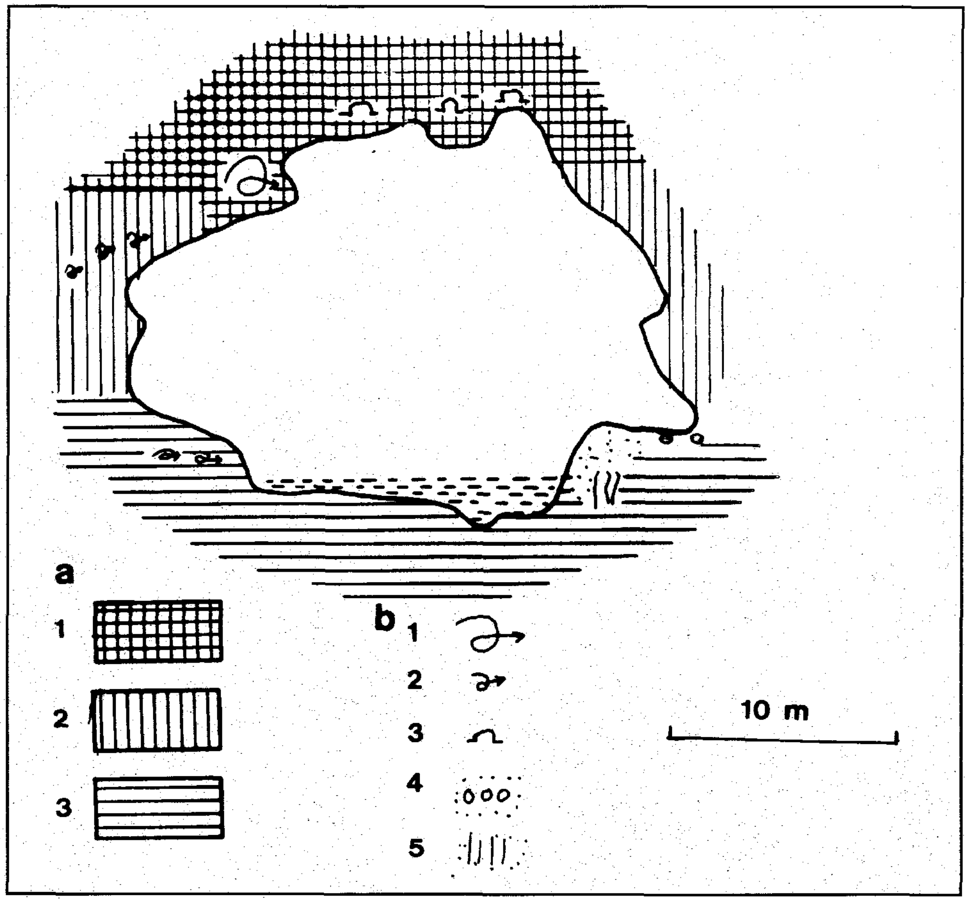

Fig. 3: Cross section of the Pivka branch in Planinska jama (Pri Golgoti) and hydrological zones of rocky relief formation

A 1. phreatic zone
2. epiphreatic zone
3. vadose zone

B 1. big scallops
2. medium or small scallops
3. ceiling pockets
4. below-sediment solution niches
5. below-sediment half tubes

Sl. 3: Prerez Pivškega rokava v Planinski jami (Pri Golgoti) in hidrološke cone oblikovanja skalnega reliefa

A 1. freatična cona
2. epifreatična cona
3. vadozna cona

B 1. velike fasete
2. srednje velike in majhne fasete
3. stropne kotlice
4. podnaplavinske vdolbinice
5. podnaplavinski žlebiči

SUHADOLICA ROCKY RELIEF

The rocky relief in the active cave below the higher outflow karst of Javorniki is accordant with the actual processes of its genesis. Due to high water pressure in the hills behind it, its discharge through relatively small periodically flooded channels is of high velocity. It therefore forms small ceiling pockets (Fig. 4). Smaller seasonal water level oscillations cause the deposition of fine-grained sediments on the rocky relief and thus corrosion typically transforms the rock.

Fig. 4: Ceiling pockets in Suhadolica
Sl. 4: Stropne kotlice v Suhadolici

ROCKY RELIEF OF CIGANSKA JAMA NEAR PREDGRIŽE

All over the cave (Fig. 5) the older traces of water flow in the phreatic zone mingle with dispersed vertical infiltration (Fig. 6), still active. The last process is less efficient as the traces of former cave development are well preserved. On the bottom of the narrow part of the passage, with rounded cross section, scallops are preserved; ceiling pockets may be found all over the

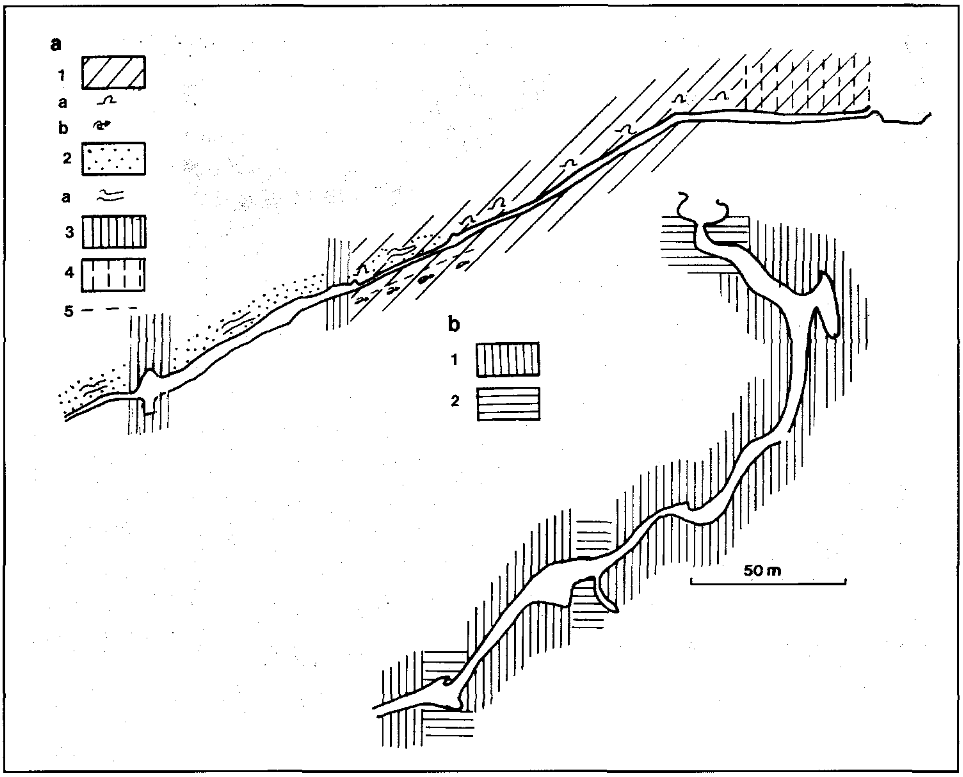

Fig. 5: Rocky relief and its hydrological zones of formation in Ciganska jama

A 1. rocky relief formed by water flow
a. ceiling pockets
b. scallops
2. rocky relief along the sediment
a. above-sediment channel
3. rocky relief formed by trickling water
4. rocky relief transformed by condensation corrosion
5. floor channel

B 1. epiphreatic zone
2. vadose zone

Sl. 5: Skalni relief in hidrološke cone njegovega oblikovanja v Ciganski jami

A 1. skalni relief, ki ga oblikuje vodni tok
a. stropne kotlice
b. fasete
2. obnaplavinski skalni relief
a. nadnaplavinski žleb
3. skalni relief, ki ga oblikuje polzeča voda
4. skalni relief, ki ga preoblikuje kondenzna korozija
5. talni žleb

B 1. epifreatična cona
2. vadozna cona

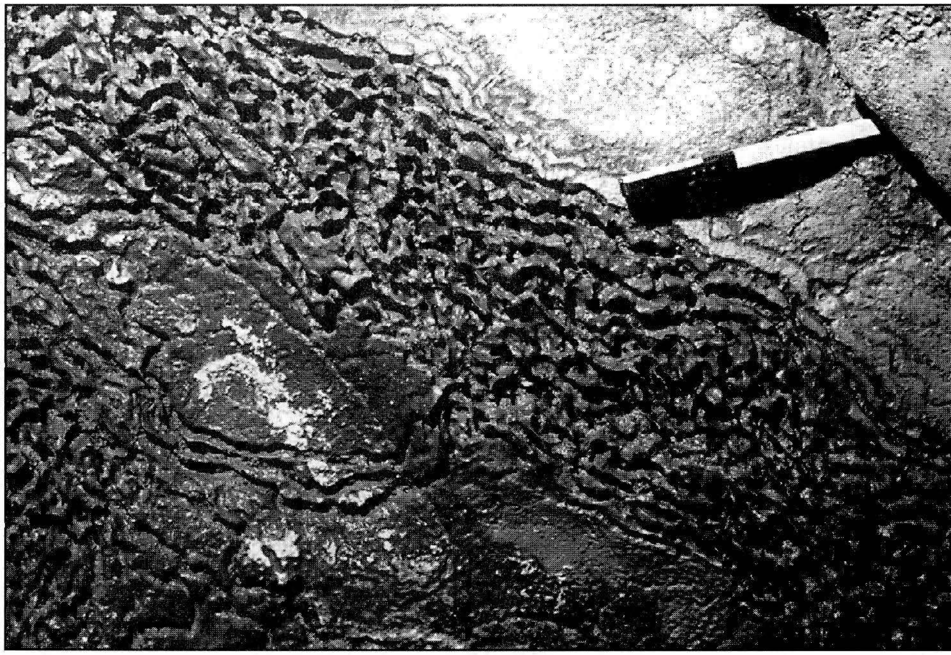

Fig. 6: Half tubes on overhanging wall due to trickling of smaller amount of water
Sl. 6: Žlebiči na previsni steni so posledica polzenja manjše količine vode

cave. The scallops developed in the phreatic zone, as an open conduit would cut smaller forms in a passage with considerable gradient. Large discharge is characteristic for the bottlenecks in the channels. In the spacious parts of cave, and in the fissures of the narrow part too, the ceiling pockets developed. Flood waters later filled the cave with fine-grained sediments and above them the smaller water quantity flowed over ceiling channels. The water flow that transported the deposits out of the cave partly transformed the ceiling channel too. Due to ground water lowering, the water only infiltrates through the old passages. It incises potholes and flutes. The transition period was progressive; in some floor pits caused by water dripping from the ceiling there is preserved the fine-grained sediment deposited by seasonal flood waters. They flooded the cave from down upwards. Today a weak condensation corrosion transforms the entrance parts of the cave.

LOGAŠKA JAMA ROCKY RELIEF

Logaška jama lies south from the old road leading from Logatec towards Vrhnika, below Veliki hrib. Below the 35 m deep entrance pothole the passage is oriented N and S. The central part of the passage, about 5 m wide and from 5 to 10 m high, has a semicircular ceiling. Part of the southern branch is similar; the northern branch ends in a smaller chamber from which a small passage leads along the fissure. A part of the cave is transformed by breakdown and covered by flowstone, on the bottom; in particular at the end of the northern branch there are many fine-grained deposits. Large scallops and ceiling pockets (Fig. 7) show that a slow water flow drained through the main flooded passage. Smaller scallops on the lower part of the walls of the same passage are covered by traces of larger discharge. It was free water flow. If the water flow had filled the entire passage it would have transformed the upper part of the rocky surface as well. Youngest may be the period of flooding of the lower chamber where the water deposited fine-grained deposits. The below-sediment flutes developed there. Gams (1964, 15) too infers that the water from this part of the cave drained through the corrosion fissure after the period of main accumulation. The entrance pothole was widened by trickling waters. Its walls are covered by flutes. Aggressive water dissected the ceiling of the main passage into chimneys and probably transformed the ceiling pockets along the fissures.

Fig. 7: Ceiling pockets in Logaška jama
Sl. 7: Stropne kotlice v Logaški jami

Logaška jama may be attributed to the former Ljubljanica river basin and the karstification to the subsidence of Ljubljana Moor. I do not have temporal indices of the cave development. Implying the caves to be of the same river basin I may presume that a slow stream drained through the water-filled cave at the beginning of the Quaternary while larger discharge flowed through the cave in the middle Pleistocene until the floods did not only occasionally appear from lower lying channels.

CONCLUSION

The karstification is mainly the result of vertical dissection of karst landscapes in terms of related impermeable rocks which reperesent the water barrier. The vertical karst dissection is the result of tectonics and erosional lowering of the valleys and lowered surfaces. The more intensive the karstification, the better the characteristic rocky relief is preserved in the vertical section of the caves. Tectonic dissection of the lowered surface and formation of a piezometric water table by depositing sediments and incising of the water flow into the rocky bottom of the passages enabled the progressive development of Križna jama. Cave development at almost the same altitude as the related impermeable barrier does not allow the preservation of the old rocky relief. Various formation processes appear, and the more distinct younger ones cover older traces of the cave development. It is characteristic in particular for the karst areas which subside and where the waters deposit sediments. In Cerknica cave systems younger processes occurred at approximately equal altitude above the sea level. This is evidenced by the Mala Karlovica and Zelške jame rocky relief composed rocky forms which are the traces of the youngest development phases. Ciganska and Logaška jama formed by water flows in lower zone and situated today high above the piezometric water level are transformed by percolating water only. They are clearly polygenetic caves.

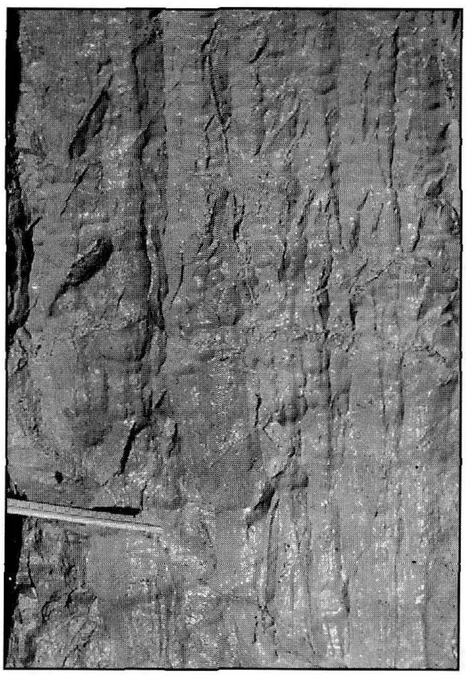

Fig. 8: The shafts wall shaped by trickling water
Sl. 8: Stena brezna, ki jo oblikuje polzeča voda

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SKALNI RELIEF V IZBRANIH JAMAH NOTRANJSKEGA PODOLJA

Povzetek

Pri proučevanju nastanka in oblikovanja jamskih skalnih oblik se je izkazalo, da so te, zlasti če jih povežemo v skalni relief, pogosto pomembna speleogenetska sled. To spoznanje nam potrdi tudi proučevanje skalnega reliefa izbranih jam Notranjskega podolja. Izsledki nam služijo pri opredeljevanju nastanka in razvoja tega morfogenetsko povezanega kraškega predela. Izbral sem jame na pritočni (Križno jamo) in odtočni (ponorno Malo Karlovico in Zelške jame) strani Cerkniškega jezera ter izvirno Planinsko jamo, v kateri se stekajo vode Pivke in Raka. Na SZ, višjem delu Notranjskega podolja, torej ob robu Črnovrškega polja (Gams 1974), pa sem proučil Cigansko jamo pri Predgrižah. Logaška jama je stara jama na Logaškem ravniku.

Zakrasevanje je predvsem rezultat navpičnega členjenja kraških predelov glede na okolne neprepustne kamnine, ki predstavljajo vodni jez. Navpično členjenje krasa pa je posledica tektonike in erozijskega nižanja okoliških dolin ter podolij. Hitrejše je zakrasevanje, lepše je v navpičnem prerezu votlin ohranjen značilni skalni relief. Tektonsko razčlenjevanje podolja in oblikovanje piezometričnega vodnega nivoja z odlaganjem naplavin in vrezovanjem vodnega toka v skalno dno rovov je omogočilo postopen razvoj Križne jame. Razvoj votlin na skorajda enaki nadmorski višini, glede na okoliški neprepustni jez, onemogoča ohranitev starega skalnega reliefa. V njih se lahko zvrstijo različni

oblikovalni procesi in izrazitejši, mlajši prekrivajo starejše sledi jamskega razvoja. To je značilno predvsem za kraške predele, ki se grezajo in v katerih vode odlagajo naplavine. Tudi v Cerkniškem jamskem sistemu so se mlajši procesi vrstili na približno enaki nadmorski višini. To nam dokazuje tudi skalni relief Male Karlovice in Zelških jam, ki ga sestavljajo skalne oblike, ki so sledi najmlajših razvojnih obdobij. Cigansko in Logaško jamo, ki sta se oblikovali z vodnimi tokovi v nižinski coni, danes pa sta visoko nad piezometričnim nivojem vode, preoblikuje prenikajoča voda. Sta torej izrazito poligenetski.

KARST FEATURES IN THE MOTORWAY SECTION BETWEEN ČEBULOVICA AND DANE

KRAŠKI POJAVI V TRASI AVTOCESTE MED ČEBULOVICO IN DANAMI

TADEJ SLABE

Izvleček: UDK 551.44:625.7/.8(497.4)

Tadej Slabe: Kraški pojavi v trasi avtoceste med Čebulovico in Danami

Pri načrtovanju in gradnji avtocest na krasu sodelujejo krasoslovci Inštituta za raziskovanje krasa ZRC SAZU. Na 14 km trase je bilo ob dveh že znanih jamah odkritih še 76 jam. Iz starih jam lahko razberemo več najstarejših obdobij razvoja vodonosnika. Nastale so v zaliti coni, nato bile preoblikovane s hitrejšimi vodnimi tokovi in zaradi znižanja vodne gladine v vodonosniku ostale suhe. V njih se je odlagala siga. Veliko jam so dosegle visoke poplavne vode in jih zapolnile z drobnozrnato naplavino. Priča smo torej zakrasevanju vodonosnika z nižanjem podzemeljske vodne gladine in njenemu občasnemu nihanju. Zaradi znižanja kraškega površja so mnoge jame, zapolnjene z naplavino, ostale brez stropa.

Ključne besede: krasoslovje, gradnja avtocest, slovenski kras

Abstract: UDC 551.44:625.7/.8(497.4)

Tadej Slabe: Karst features in the motorway section between Čebulovica and Dane

The karstologists of the Karst Research Institute ZRC SAZU are taking part at planning and constructing the new motorways over karst. The 14 km long laying-out where two caves were already known, revealed additional 76 caves. Old caves indicate oldest periods of the aquifer development. Caves developed in phreatic zone and were later transformed by faster water flows and due to lowering of water level in the aquifer remained dry. Flowstone was deposited in them. Many caves were reached by high flood waters and filled with fine-grained sediments. The karstification is due to underground water level lowering and its periodical variations. As the karst surface lowered many caves remained without roof.

Key words: karstology, motorway construction, the Slovenian karst

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INTRODUCTION

In Slovenia, an extensive part of the motorways is planned to be located in the karst. Denuding of the karstic surface and construction works for new roads reveal numerous karst phenomena. These are old karst caves which are hollow or filled up with alluvium, potholes with waters percolating from the surface into the ground, and various dolines. We, karstologists, take part in the planning of roads by making efforts to preserve characteristics of the karst landscape in the best possible way as well as taking part in the construction of these roads by surveying karstic phenomena, studying them and trying to suggest the ways for their preservation consistent with the safety of roads. The karstological control is carried out under a patronage of Zavod za varstvo naravne in kulturne dediščine Gorica (Institute of Natural and Cultural Heritage Protection Gorica) and financed by Družba za avtoceste RS (Motorways Company of Republic of Slovenia).

On this occasion I would like to present particularly the descriptions of the newly discovered karst features which should serve as the basis for more profound study of the formation and development of this part of the Slovenian karst. The recently discovered caves have been researched, surveyed and their plans completed. Some most typical samples of flowstone and deposits have been taken from the old caves. Different types of deposits have been systematically collected and prepared for mineralogical analyses by means of the Roentgen diffraction method as well as for microscopic, geochemical and pollen analyses. New perceptions will be of great help also in subsequent motorway construction.

THE KARST OF THE DIVAČA AREA

The Čebulovica - Divača road section (Fig. 1) runs transvers along the eastern edge of the karstic ridge, which extends from Štorje towards Čebulovica as far as the doline-pitted plain west of Škocjanske jame; between Divača and Dane the road section runs along the less karstified Divaško podolje around Divača (Melik 1960, 199).

Karstologists have come to the conclusion that in the Kras, the traces of the primary surface run off of water towards the north-west are well preserved. Melik (1960, 201) made conclusions on the basis of the slopes of the present surface, and Radinja (1972, 13) on the basis of the abandoned valleys and sediment remains on the karstic surface. In the past when carbonate rocks started to be denuded, the limestones must have been blocked and ground water held behind the barriers, which preserved the surface streams. The former surface run off from the area of Brkini across the Kras formed a longitudinal system of valleys between Divača and Brestovica (Habič 1974, 8). The study of the surface development between the poljes of Postojna and Cerknica by Gams (1965, 90) came to the conslusion that some morphological processes accelerated karstic dissection and the formation of doline-like features which were too often regarded as the remains of fluvial valleys. Relief characteristics of the Divaško podolje are also dependent on the structure and lithology as various lithostratigraphic elements and the main faults are directed from south-east towards north-west (Habič 1974, 8).

Near Divača the Palaeocene limestones (Fig. 1) of the Brkini syncline are in contact with Lower Cretaceous dark-grey bituminous dolomites along a distinctive Dinaric-directed fault (Habič 1974, 4). One part of the road section south of Divača is directed along the dark-grey bedded Cretaceous limestone alternating with the rudist Cretaceous limestone. Between Divača and Dane, that is along the Divača fault which is reflected also in the relief, there is a road section directed along the Palaeocene limestone (in smaller sections also along the Cretaceous limestone) and the dark-grey Cretaceous dolomite. Construction works for the road section revealed also tectonically fissured rock and numerous fault indicating the movement of the rock blocks into different directions. In the fault area the limestone is crushed into rubble and mylonite.

Characteristics of this part of the karst accord with the present hydrologic conditions. The present underground streams run at a depth of 200-300 m. South of Divača the river Reka, running from the sink at Škocjanske jame, is directed parallely to the road section, crosses it near Divača and runs beneath the Divaško podolje NW towards the sources of the Timavo. Precipitation waters reach the springs by vertical percolation. There have been warnings against the danger of pollution of underground waters which are being threatened due to karstic permeability. This fact can be proved also by studying the quality of waters which drain from the motorways (Kogovšek 1993) and by some experience in accidental spills of hazardous matters (Knez et al. 1994).

Regular karstological inspection has started relatively late. The major part of the road section had already been denuded, as well as vegetation and soil removed. Near Dane there is a hummocky rocky relief beneath the 0.5 m thick layer of brown soil. The two-metre wide, long rocky hummocks and fissures also, are rounded and smooth (Gams 1971). Individual thin layers of rock were crushed, and yellow rubble and red loam disclosed. Yellow rubble can be found also in some other fissured rocky zones of the road section.

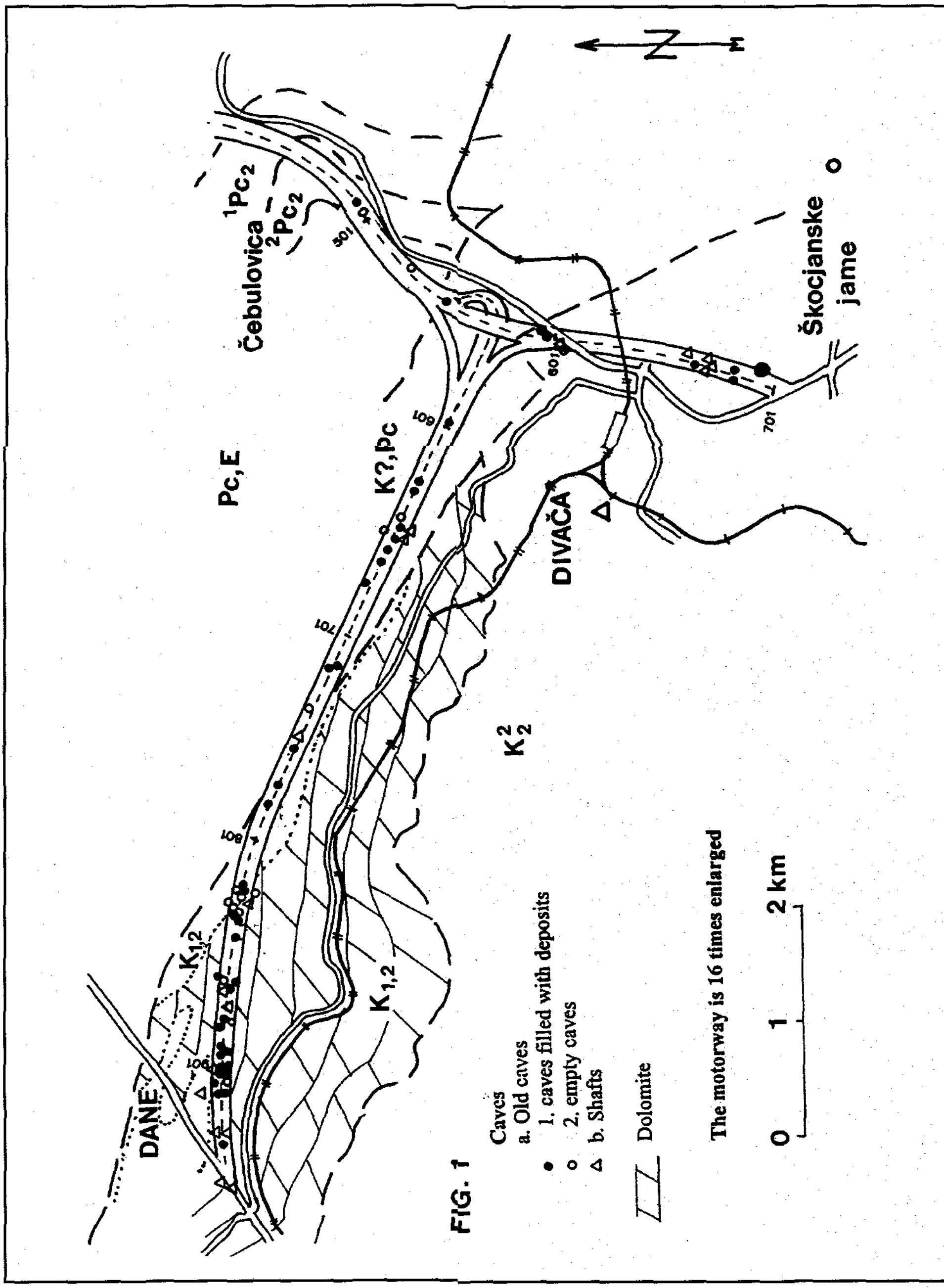

Fig. 1: Caves in a motorway
Sl. 1: Jame v trasi avtoceste

DOLINES

Due to their shape, dolines in the highway section were divided by Habič (1974, 6, 7) into funnel-shaped dolines from which loam is mostly rainwashed, bowl-shaped dolines with an extensive loam surface at the bottom, and shallow infilled dolines with slightly permeable loam at the bottom. The filled up dolines often contain water. Near Divača there are 11 dolines per km of the road section, and between Divača and Sežana only 5. In the southern motorway section of Čebulovica-Divača there are in the Cretaceous limestone large funnel-shaped dolines with only a little loam. Bowl-shaped and filled up dolines prevail in the limestone of Divaško podolje. The latter are small, 30 to 50 m in diameter and 5 to 15 m deep. The greatest depth of the doline, established by means of drilling, was 27,5 m (Habič 1974, 5). Red and brown karst loams prevail in the dolines. The loam is rainwashed from the doline slopes onto the rubble base which was formed by weathering of the rocky bedrock. Some dolines contain also flysch sand and gravel as well as yellowish and layered silt which is probably alluvium left behind by the former watercourses (Habič 1974, 6). By means of drillling Habič (1987) studied one partly excavated doline near Sežana. Small and rarely pitted filled up dolines etch into a hummocky dolomite surface which is covered by a thin layer of soil. The upper layer of the doline fill consists of brown soil, 1,5 m below the surface there is red loam.

The motorway construction works demanded removing the alluvium from the filled up dolines. The results obtained during the previos research by means of drilling into the doline alluvium were thus confirmed. The dolines often consisted of a considerable amount of older, mostly flysch alluvium. A doline in the section of Divača-Dane, at cross-section 752, consisted of flysch gravel reaching almost up to the surface. It has to be pointed out that there are many filled up dolines within the old caves, which are filled with alluvium and are already roofless. Shafts were formed beneath the channels filled with water streams which in their youngest development stages deposited also flysch loam and sand, and in dry periods flowstone was deposited. In the flysch alluvium rainwashed by the surface water, there formed funnel-shaped indentations filled with brown and red karst loam and rubble.

Near Povirje there was a sinkhole pond with permanent water at the bottom which was surrounded by walls. The pond was located on an elevation, on top of the anticline. The elevation had to be cut through, so the pond was not preserved. The digging works confirmed a supposition that surface water was held by impermeable loam which was deposited in an old channel, the floor of which was covered by a large mound of flowstone.

Shafts frequently opened up at the bottom or on the edge of the dolines in limestone and dolomite. Large dolines (Šušteršič 1985, 94) contain many shafts, which was reflected also in their shape.

Near Žirje and Dane, the construction works cut through filled up artificial dolines (Gams 1974, 177; Gams 1991, 39). The cross-section of an excavated doline gave clear evidence of filling up with rocks and stones which were collected during the removing of soil in the doline and clearing of the surrounding karstic surface. The stones and rocks had been put into the excavated doline and were covered by soil. In this way much more level cultivatable land was obtained.

During the road construction, loam and rubble were first removed from the dolines, and the bottom, particularly when cavernous, was stabilized with rocks which were fastened by concrete. The dolines were later filled up with 30 cm layers of rocky rubble which was simultaneously consolidated by means of the vibration roller (Fig. 2). Soil and loam which had been dug out from the dolines were used for filling up some dolines near the road.

CAVES

The caves investigated during the construction works for the motorway can be divided into old caves (57 newly discovered) and potholes (19). The old caves are empty (24) or filled with sediments (33). The caves Golobja jama and Mošenjska (Srnja) jama, which had to be blasted during the digging of the cuttings, had been discovered before. Altogether 76 caves were discovered on 14 km of a new road. These were mostly smaller old caves, only six of them had the passages of 5 m or more across. Parts of the same cave systems were cut several times. A lot of inaccessible fissures also opened that drained the water to the shafts. Smaller passages that developed along bedding-planes we did not consider as caves. However, the number of discovered caves is related to a sort of earth-works. The least caves were discovered in those parts where there were no important earth-works or digging.

Old caves

The caves, which are the remains of the oldest underground water courses in this part of the karst, consist of a maze of nearly gently sloping channels, which are 1 to 5 m in diameter, and small connecting chambers (Fig. 3, Fig. 7). The channels were formed by slow flowing streams, which is evidenced by the complex systems of channels, their meandering feature and in places the rocky relief. Their walls are partly covered in flowstone and dripstone formations. This type of cave (the caves are few) occurs particularly in a slightly higher part of the karst below Čebulovica. In dolomite, smaller chambers were frequently formed between nearly gently sloping beds of rock. The channels occur along the beds which were disintegraded into fine-grained sand.

More frequent are those caves filled with deposits (Fig. 4). Such caves are now roofless and meander on the surface like the water channels or filled-up

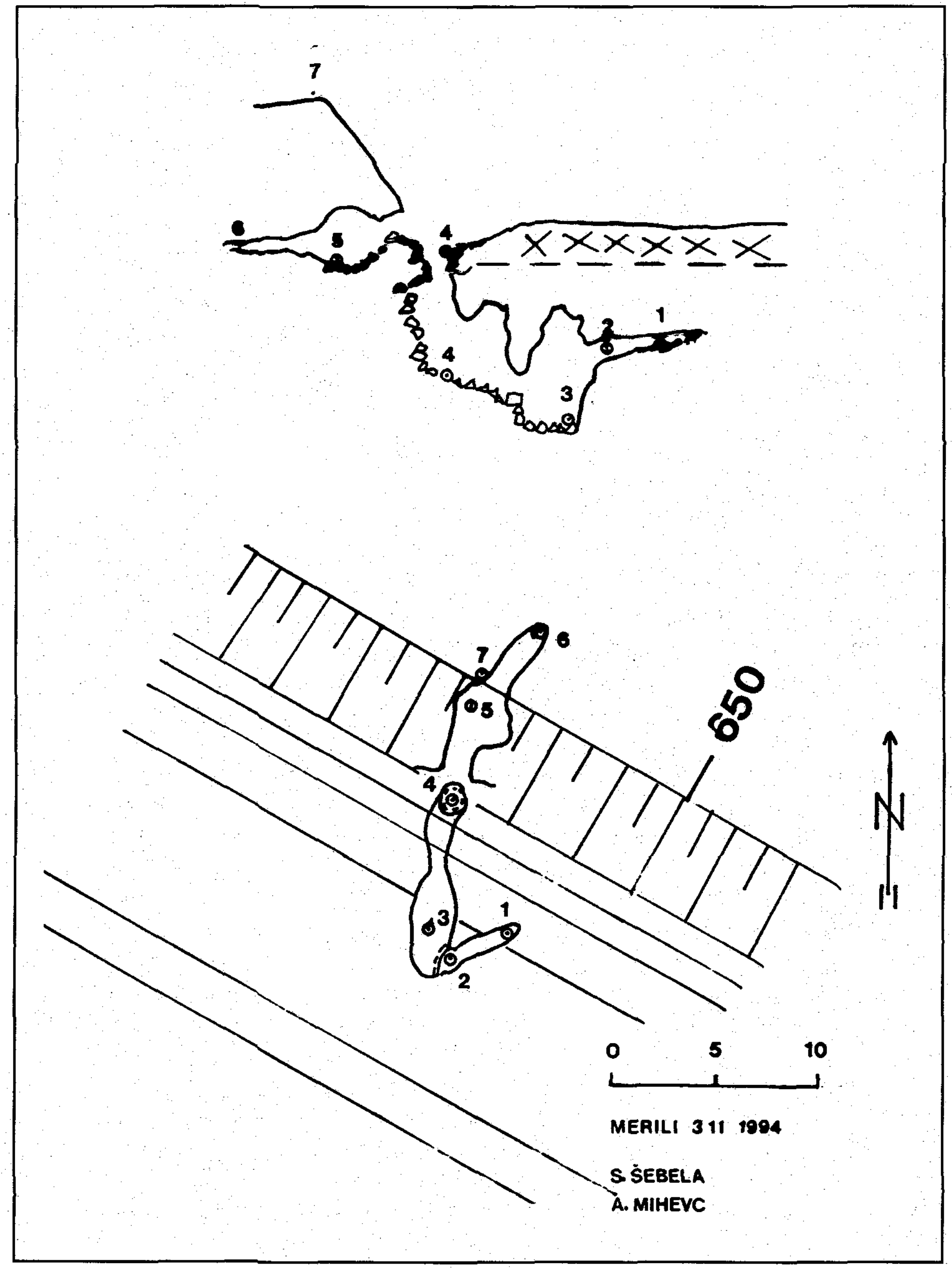

Fig. 3: Cave at the border of a roadway
Sl. 3: Jama na robu ceste

channels which can be observed in sides of the cuttings (Fig. 5). The cave channels are of different sizes and are even over 5 m in diameter. The cave walls are often flowstone encrusted and the bottoms are covered by large flowstone mounds. In the caves there are flysch and limestone gravel, flysch loam and sand. The caves filled with deposits can be followed along the whole road section Čebulovica-Divača-Dane. Several samples of deposits have been collected. The Roentgen diffraction method, mineralogical, granular-metric and pollen analyses will try to define the origin and age of the deposits. At present some characteristic periods of the cave development are evident. The meandering features and shape of the channels remind us of their primary formation in the flooded, phreatic zone. Small scallops on the walls of some channels and gravel give evidence of a relatively rapid watercourse which, as the last one and presumably for a short period, was hollowing out the channels. In dry periods of the cave development phase, flowstone was being deposited. In places it covers the scallops on the walls and also the deposits. The caves were consequently reached by flood waters which filled them with flysch loam.

In some caves below the flysch Brkini hills a fast water flow drained for shorter time and deposited a thin layer of gravel. Some caves are fissure-shaped. They were formed in the flooded zone with a relatively short period of water circulation.

The teeth and skull remains of the Pleistocene horse, which were found during the clearing of the deposit from a cave near Povirje, give evidence of life in this part of the karst. Archaeologist intend to define these finds also according to the geological period.

Shafts

In the highway section, many small entrance shafts and deeper potholes with many levels were opened up (Fig. 6). The deepest pothole reached a depth of 51 m. In this part of the karst, water streams run deeply underground (at a depth of 200 m and more). For a long period the underground streams have been reached by precipitation waters. Water worked its way along the fissures. Along less distinctive fissures with minor amounts of percolating water, caverns were formed only along the wider sections. The walls of fissured caverns are partly covered in flowstone.

Shafts with mostly circular cross-sections were formed along distinctive fissures with permanent water inflow. Their walls are dissected into large vertical grooves or solution runnels caused by the seeping water working its way underground. The walls of some large shafts are also covered in flowstone.

Most of active shafts are located in the bottom or on the edge of dolines. Some were formed beneath the old caves and dissected them, so that part of the older deposits were carried away through the potholes.

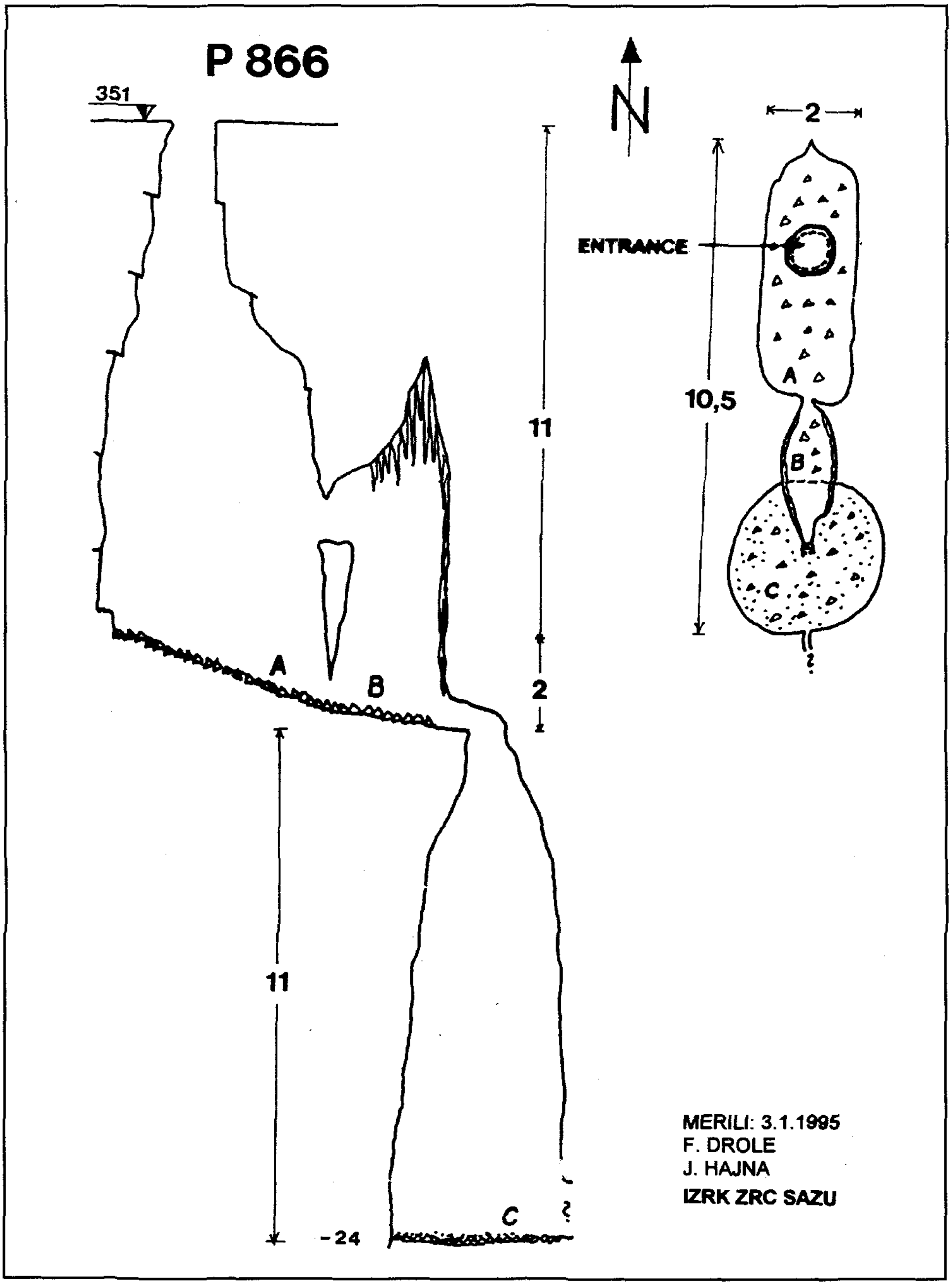

Fig. 6: A shaft below a roadway
Sl. 6: Brezno pod traso

CAVERNOSITY OF DIFFERENT ROCKS

Large old caves, empty ones or those filled with deposits, can be found in all rock types - in Palaeocene and Cretaceous limestones as well as in Lower Cretaceous bituminous dolomites near Dane. Dular (1993/a, b, 4) came to the conclusion that Palaeocene and Eocene limestones as well as Cretaceous dolomites are less karstified, but the Upper Cretaceous on the contrary are highly karstified. In the Palaeocene limestones near Čebulovica there are a few old caves but not a single pothole has been discovered. The sides of an extensive cutting section below Čebulovica with two small hollow old caves and one cave filled with deposit is example of weak cavernosity regarding big caves. In the wall of a cutting one may perceive thin beds of Paleogene limestones of varying structure. Some beds are strongly karstified with lot of channels up to one cm across (Otoničar 1994/95). In the road section Divača-Dane there is a relatively large number of caves occuring in Palaeocene limestone. In this area (segment 640-660) the old caves, empty ones (4) as well as those filled up with deposits (3), and fissured can be found.

Relatively frequent caves in dolomites are small. Their channels are usually less than a metre in diameter. Many more caves which are filled with deposits are flowstone decorated. Large caves rarely appeared, such as two 5 to 6 m deep canyon passages filled with deposits (Section D-D 872, 881).

Shafts can be found both in limestone and dolomite. The majority and the largest are in Cretaceous limestone in the vicinity of Škocjanske jame. They occur relatively rarely in Palaeocene limestone. Several shafts were in Lower Cretaceous dolomite also, but they are mostly small and inaccessible. Some 10 m east of the road section (Sector D-D 913), a 30 m deep fissured shaft opened on the edge of a doline, and at section 866 one with many levels.

The width of uncovered karst is the width of motorway and therefore it is difficult to conclude how cavernous is a single limestones. The composition of particular rock beds, how they are crushed and the ability of bedding-planes and fissures to generate caves along them prevail over general properties of rock. Also hydrological conditions that controlled the karstification of these carbonate rocks are important.

ROAD CONSTRUCTION AND CAVES

The caves were opening up during removing of vagetation and soil from the karstic surface, during the excavation of the cutting and consequently during the rubble embankement.

Blasting and excavation of cuttings resulted in the fracturing of rock in the surrounding caves. The cave P 607 in the road section Čebulovica-Divača opened up after the ceiling breakdown; in this cave the rock is fractured into pieces with a volume of some cm^3 to a depth of 12 m. The fissures which were formed by the blasting are up to 1 cm wide and reach down to the cave bottom. The majority of the dripstone decorations at the bottom of the cave remained hanging from the walls. In another cave which opened up in the side of the same road section at segment 606, the entrance part was highly fractured. For this reason the circumference of the entrance passage is partly disintegrated. In a small chamber within the cave small pieces of rock fell off the roof. The entrance part of the fissured pothole P 651, located in the road section of Divača-Dane, contains fractured rock. For this reason part of the roof was disintegrated together with a flowstone coating which fell off the roof. In the deeper section of the pothole, no consequences of blasting could be noticed.

In the southern part, the road section of Čebulovica-Divača approached the canyon passage Hanke Channel in the cave Škocjanske jame within 400 m, that is as far as the western boundary of the planned regional park of Škocjanske jame. Although it was presumed that blasting in the road section would not have any influence upon Škocjanske jame, it was decided to observe eventual consequences in the cave. The cave is relatively far away from the sites of blasting but in the terminal section of the cave there are immense underground caverns such as the 140 m high chamber Martelova dvorana with 2 million m^3 in volume. Besides, the site of the crossing of the Reka watercourse with the road section has not been precisely determined yet. Precursion has thus demanded continuous observing of eventual consequences of the blasting. Due to warnings they occured with small retarded explosions in the boreholes. The cuttings in this part of the road section are relatively small, that is the reason why the blasting was weaker and less deep. There has been no indirect influence of the highway construction on known parts of Škocjanske jame.

As far as the construction of the solid base of the road and its safe use are concerned it has been tried to preserve as many caves as possible and to investigate the ones which could not be preserved due to the technically road construction, which was an extremely difficult demanding task in the digging of the more extensive cuttings. Here the rock was blasted into relatively small rubble particles and there was not much left of the caves, in most cases only flowstone pieces and rubble. In this way a relatively large cave within the road section, Golobja jama under Čebulovica, was destroyed. The caves preserved were those located in the excavation sides. Due to the blasting, the rock is often too crushed and smaller caves are inappropriate for visiting. The entrances to some caves had to be walled up with large rocks.

Minor and speleologically less important caves within the road section are filled up, as well as dolines and the old caves from which thin-granular deposits were removed. Large excavations were filled in with 30 cm thick layers of rubble, which were consolidated with the vibration roller. Large caves and potholes with chimneys reaching up as far as the road section had to be

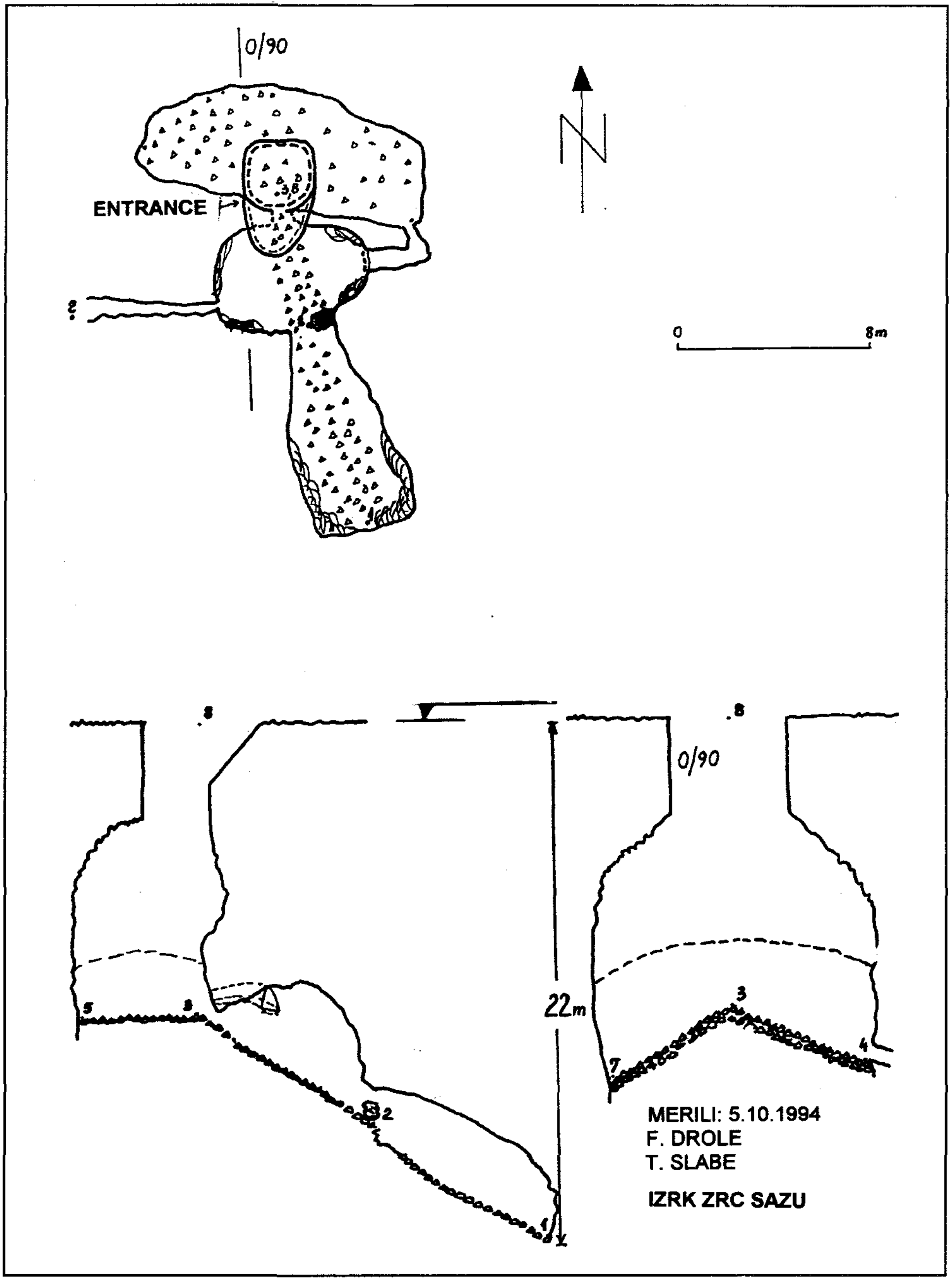

Fig. 7: A cave with collapsed roof
Sl. 7: Jama s podrtim stropom

blasted and filled up in the previously described way. Above the deeper potholes with narrow entrance parts there are concrete covers. During the investigation of the caves and the establishment of their eventual influence upon the road construction, some narrow sections were encountered. It was concluded that in the pothole within the road section of Divača-Dane, at segment 866, there is a large cavern beyond a narrow fissure which exteded up to the road section. It was tried to widen the narrow part with a vibration hammer, but the result was achieved only by blasting. In the excavation sides composed of solid rock, caves can remain untouched, but nevertheless it is necessary to consider the influence of blasting upon the permanence of their vaults and and to remove unstable and crushed rock. The rock remains solid particularly in dolomite (segment D-D 829). The caves in the excavation sides which are filled up with deposits had to be walled up because alluvium on the surface could be washed down onto the road by water.

CONCLUSION

Caves can be found in all rock types. This is evidenced by the Palaeogene limestone at Čebulovica, which is only slightly cavernous regarding large caves but in single beds there is plenty of small channels; on the contrary a part of the same limestone at Povirje is extremely cavernous. Old caves and potholes are to be found in all types of limestone and in dolomite. The majority of bigger potholes is in Cretaceous limestone. General properties of rock lithology are outweighed, regarding the cavernosity, by composition of a particular rocky bed, how it is crushed and competence of bedding-planes and fissures that the caves develop along them.

It has been tried to preserve the largest number of caves possible, which was rather difficult in the construction of a safe road. Caves opened up also during the final clearing of the surface, that is short by before the metalling and consolidation works on the road. Examples of subsidence occured even during the time of these works (Fig. 8). It is possible that there are even other caves located not far below the road section. Is there any possibility of road subsidence? It has been suggested to check the road section with the georadar. In this way at least the largest eventual caves, hidden below, could be discovered.

Experience obtained during the study of the new discovered karst phenomena have led to explanations of the development of this part of the karst. In the old caves, which are the oldest remains of karstification here, several development phases can be recognized. Empty and filled up old caves are located in Divaško podolje as well as in the karst ridge to the nord-east. The caves were probably formed in the flooded, phreatic zone. Subsequently they were partly modified by rapid water streams which deposited gravel and sand within the caves, and in places hollowed out small scallops on the walls.

Where is the origin of the watercourses? Perhaps it is the Brkini flysch edge, which was closer to the caves. Was the alluvium carried along by the watercourses from the flysch which surrounded the Kras in the north, or by the streams from the elevations where the flysch was preserved after the folding of the anticline (Gams 1974, 197)? In the Pliocene the Kras was lower than the flysch surface of the Vipava and Triest syncline despite the anticline construction (Radinja 1972, 212). Flysch pebbles are not carried far underground due to crumbling and grinding (Kranjc 1986, 114). In the intermediate dry climatic periods and after the lowering of the underground water level, flowstone was deposited in the caves. Some caves which subsequently were reached by flood waters remained filled with flysch loam. In places loam was carried away by means of percolation water. The roofs above the old caves situated at higher levels and filled up with alluvium, was already carried away. Caves dissect the karst surface like furrows. According to the flowstone in caves it can be concluded that the roofs above were several metres thick. Cucchi, Forti and Ulcigrai (1994, 61) have made some surveys which show that the karst surface which is exposed to climatic conditions is lowered by 0.02 mm a year. Gams (1965, 886) explains that in the Quaternary the surface above Postojnska jama was lowered by about 40 m. The surface has been profoundly changed. The alluvium of watercourses is present mostly only in caves. Dolines were frequently formed by the opening of potholes below the old channels. Beside rubble and karst loam formed by weathering on the surface, it is often possible to find also old flysch alluvium.

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KRAŠKI POJAVI V TRASI AVTOCESTE MED ČEBULOVICO IN DANAMI

Povzetek

Trasa med Čebulovico in Divačo poteka prečno po vzhodnem robu kraškega hrbta, ki se razteza od Štorij proti Čebulovici do vrtačastega ravnika, zahodno od Škocjanskih jam, med Divačo in Danami pa po manj zakraselem Divaškem podolju (Melik 1960, 199).

Krasoslovci so ugotavljali, da so na Krasu ohranjene sledi prvotnega površinskega odtoka vode proti SZ. Melik (1960, 201) je o tem sklepal po strmcih na današnjem površju, Radinja (1972, 13) pa po opuščenih dolinah in ostankih naplavin na kraškem površju. Apnenci naj bi bili, ko so se začele razkrivati karbonatne kamnine, namreč zaprti in podzemeljska voda zajezena, kar je ohranjalo površinske vodne tokove. Nekdanji površinski odtok z Brkinov čez Kras je oblikoval vzdolžno podolje od Divače proti Brestovici (Habič 1974, 8). Gams (1965, 90) je pri proučevanju razvoja površja med Postojnskim in Cerkniškim poljem ugotovil, da so nekateri morfološki procesi pospešili kraško razčlenjevanje in nastanek dolinastih oblik, ki so jih vse prepogosto razlagali kot ostanke rečnih dolin. Reliefne značilnosti Divaškega podolja so tudi zgradbeno in litološko pogojene, saj so različni litostratigrafski elementi in glavni prelomi usmerjeni od JV proti SZ (Habič 1974, 8).

Z zgradbenimi značilnostmi tega dela krasa se ujemajo tudi sedanje hidrološke razmere. Današnji podzemeljski tokovi se pretakajo 200 m globoko pod površjem. Reka teče od Škocjanskih jam, južno od Divače, vzporedno s traso, jo pri Divači preči in nato pod Divaškim podljem proti SZ k izvirom

Timava. Padavinske vode jih dosegajo z navpičnim prenikanjem. Vseskozi opozarjamo na nevarnost onesnaženja podzemeljskih voda, ki so spričo kraške prepustnosti, ogrožene. To nam dokazujejo tudi proučevanja kakovosti voda, ki se stekajo z avtocest (Kogovšek 1993) in izkušnje ob nesrečnih izlitjih škodljivih snovi (Knez et al. 1994).

Vrtače na teh odsekih avtoceste je Habič (1974, 6,7) po obliki razdelil na lijakaste, iz katerih je ilovica večinoma sprana, v skledatih vrtačah je na dnu večja ilovnata površina, zasute vrtače so plitve, ilovica v njih pa je malo prepustna. V zasutih vrtačah se pogosto zadržuje voda. Pri Divači je 11 vrtač ma km^2 trase, med Divačo in Sežano pa 5. Na južnem delu odseka avtoceste Čebulovica-Divača so na krednem apnencu velike lijakaste vrtače. V njih je bilo le malo ilovice. Na apnencu Divaškega podolja prevladujejo skledaste in zasute vrtače. Slednje so manjše, s 30 do 50 m premera in 5 do 15 m so globoke. V vrtačah prevladuje rdeča in rjava kraška ilovica, sprana s pobočij vrtače na gruščnato podlago. Nastala je s preperevanjem skalne podlage. V nekaterih vrtačah je tudi flišni pesek in prod ter rumenkasta ter pasovita glina. V grbinasto dolomitno površje, prekrito s tanjšo plastjo zemlje, se zajedajo manjše in redko posejane zasute vrtače. Zgornja plast zapolnitve vrtač je rjava zemlja, 1,5 m pod površjem pa je rdeča ilovica.

Različna kamnina je resda različno gosto prevotljena, a jame so v vseh njenih tipih. To potrjuje tudi primer paleogenskega apnenca, ki je pri Čebulovici le malo prevotljen, nasprotno pa je zelo prevotljen pri Povirju. V vseh tipih apnenca in v dolomitu so stare jame in brezna. Velikih brezen je največ v krednem apnencu. Po prerezu krasa v širini avtoceste je težko sklepati o prevotljenosti različnih apnencev. Sestava posameznih skladov kamnine, njihova pretrtost in lastnost lezik in razpok, da se ob njih razvijejo votline, prevladajo nad splošnimi lastnostmi kamninskih paketov.

Ohraniti smo skušali čimveč jam, kar pa je bilo zaradi izdelave varne ceste dokaj težavno. Tudi ob zadnjem čiščenju površja, tik pred nasipanjem in utrjevanjem grušča so se odpirale jame. Grezi pa so lahko nastajali celo med tem delom. Možno je, da je plitvo pod traso še kakšna jama. Lahko pride do ugreza na cesti. Predlagali smo, da se traso pregleda z georadarjem. Na ta način bi lahko razkrili vsaj morebitne največje jame, ki so skrite očem.

Iz spoznanj, pridobljenih pri proučevanju novo odkritih kraških pojavov, so se porodile razlage razvoja tega dela krasa. V starih jamah, ki so najstarejša sled zakrasevanja, lahko razberemo več obdobij razvoja. Votle in z naplavinami zapolnjene stare jame so tako v Divaškem podolju kot v kraškem hrbtu, ki ga obdaja na SV. Jame so po vsej verjetnosti nastajale v zaliti coni. Kasneje so bile deloma preoblikovane s hitrejšimi vodnimi tokovi, ki so v jamah odlagali tudi prod in pesek ter ponekod na stenah izdolbli manjše fasete. Od kod so pritekali vodni tokovi? S flišnega brkinskega roba, ki je bil bližje jamam? So naplavino prinašali vodni tokovi s fliša, ki je kras obrobljal na severu ali pa potoki z vzpetin, kjer se ohranil fliš po bočenju antiklinale (Gams 1974, 197)?

V pliocenu je bil kras kljub antiklinalni zgradbi nižji od flišnega površja vipavske in tržaške sinklinale (Radinja 1972, 212). Flišni prodniki se zaradi drobljenja in mletja ne prenašajo daleč v podzemlje (Kranjc 1986, 114). V vmesnih sušnejših klimatskih obdobjih in po znižanju gladine podzemeljske vode, se je v jamah odlagala siga. Veliko jam, ki so jih kasneje dosegle poplavne vode, so ostale zapolnjene s flišno ilovico. Strop nad višje ležečimi starimi jamami, ki so zapolnjene z naplavino, je že odnešen. Jame kot korita členijo kraško površje. Po sigi, ki je v jamah, lahko sklepamo, da je bil strop nad njimi debel več metrov. Cucchi, Forti in Ulcigrai (1994, 61) so namerili, da se kraško površje, ki je izpostavljeno vremenskim vplivom, znižuje 0,02 mm na leto. Gams (1956, 86) ugotavlja, da se je v kvartarju znižalo površje nad Postojnsko jamo za okoli 40 m. Površje se je že temeljito spremenilo. Naplavine vodnih tokov so se kot prvotne večinoma ohranile le v jamah. Vrtače so namreč pogosto nastale z odpiranjem brezen pod starimi rovi. Ob grušču in kraški ilovici, ki sta nastala s preperevanjem na površju, je zato moč v njih pogosto najti tudi starejše flišne naplavine.

Fig. 2: Filling up a doline
Sl. 2: Zasipanje vrtače

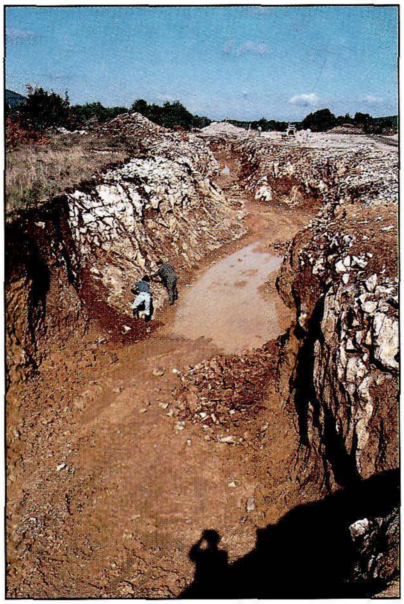

Fig. 4: Cave that was filled with sediments
Sl. 4: Jama, ki je bila zapolnjena z naplavino

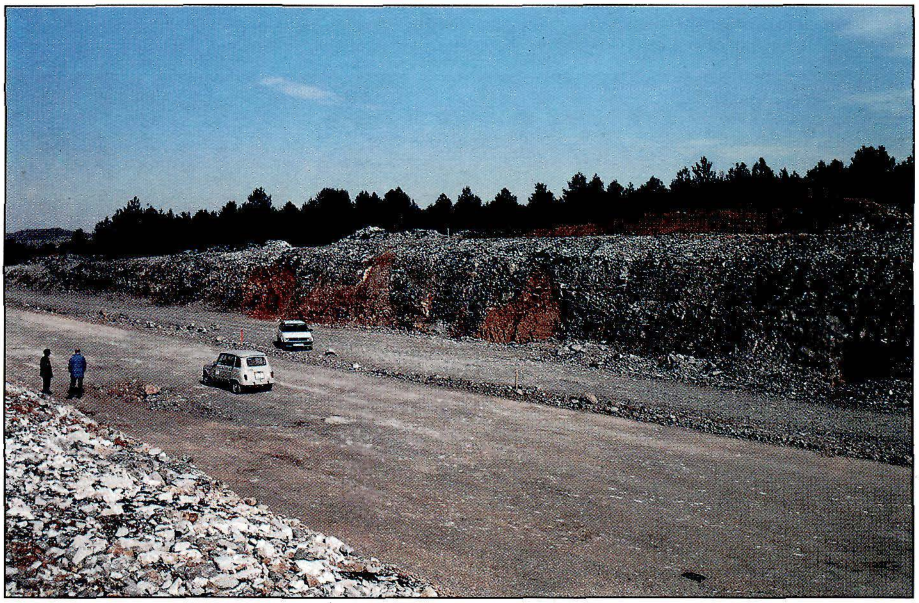

Fig. 5: Caves, filled with sediments on a slope of a cutting
Sl. 5: Jame, zapolnjene z naplavino, na brežini useka

Fig. 8: Collapse above a cave
Sl. 8: Udor nad jamo

THE DOLINES ABOVE THE COLLAPSE CHAMBERS OF POSTOJNSKA JAMA

VRTAČE NAD PODORNIMI DVORANAMI POSTOJNSKE JAME

STANKA ŠEBELA

Izvleček UDK 551.435.84(497.4)
551.442(497.4)

Stanka Šebela: Vrtače nad podornimi dvoranami Postojnske jame

Na površju nad Postojnsko jamo je 22 vrtač in dve udornici. Nekaj manj kot polovica (40,9 %) vrtač je oblikovanih nad podornimi dvoranami. Te so oblikovane v regionalno najmočneje izraženih prelomnih conah na terenu in so tako genetsko vezane na tektonsko pretrte cone. Podorne dvorane predstavljajo področja najmlajšega spreminjanja jamskih rovov. Vertikalno prenikanje v vadozni coni je na takih mestih običajno zelo dobro, kar dokazujejo tudi kamini v stropih podornih dvoran. Vrtače nad podornimi dvoranami najdemo nad Rovom brez imena, Pisanim rovom in Koncertno dvorano.

Ključne besede: vrtača, podorna dvorana, geološka struktura, Postojnska jama, Slovenija

Abstract UDC 551.435.84(497.4)
551.442(497.4)

Stanka Šebela: The dolines above the collapse chambers of Postojnska Jama

On the surface above the passages of Postojnska Jama there are 22 dolines and two collapse dolines. Slightly less than half the dolines (40,9 %) developed above collapse chambers. These are formed in regionally the most significant tectonically fractured zones and are genetically related to tectonically crushed zones. Collapse chambers represent places of the youngest transformations of cave passages. Vertical percolation in the vadose zone is in these places normally very good, evidenced by chimneys on the ceilings of collapse chambers. The dolines above collapse chambers in Postojnska Jama are found above Rov Brez Imena, Pisani Rov and Koncertna Dvorana.

Key words: doline, collapse chamber, geological structure, Postojnska Jama, Slovenia

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INTRODUCTION

In recent years (Šebela, 1992 and 1994) I have been working in detailed geological investigations in Postojnska Jama (Fig. 1) which is the c. 13 km long part of the largest Slovene cave, the Postojna cave system, 20 km long. The cave was tectonico-lithologically mapped at the scale 1:1.000 (Šebela, 1994).

My doctorial thesis was financed by Ministry of Sciences and Technology of Slovene Republic from 1991 to 1994.

As a main method of my work I used prof. Čar's (1982) method of *detailed tectonico-lithological mapping* which divides tectonically fractured zones into:
- fissured (the least fractured, stratification still visible)
- broken (more fractured, rock often occurs as blocks, may be physically displaced)
- crushed (the most fractured, stratification has been destroyed, tectonic breccia often present).

For understanding the geology of cave passages it was necesarry to study the surface above the cave to place the data in regional geological conditions. The surface was mapped at the scale 1:2.500 (Šebela, 1994). Besides the geology I also observed karst phenomena like dolines and collapse dolines on the surface and I tried to find any connections with geological structure.

The highest density of dolines on the surface is north from the collapse doline Stara Apnenica (Fig. 1). These dolines developed in a fissured to broken zone more than 100 m wide, whose directions are N-S and cross Dinaric orientation NE-SW. Under these dolines there are no known cave passages; we can find just some little vertical shafts. In the dolines the stratification which dips towards SW is very visible. It forms the NE slope of the dolines.

Some other dolines developed in crushed zones and especially in the Dinaric crushed zones NW-SE.

All the dolines were marked on the morphological map. On the surface directly above the cave passages of Postojnska Jama there are 22 dolines (Fig. 1) and 9 of them are directly above the collapse chambers. All the collapse chambers in the cave developed in regionally the most significant tectonically crushed zones. This is important, because on the surface there is almost no morphological difference between 22 dolines above the cave passages.

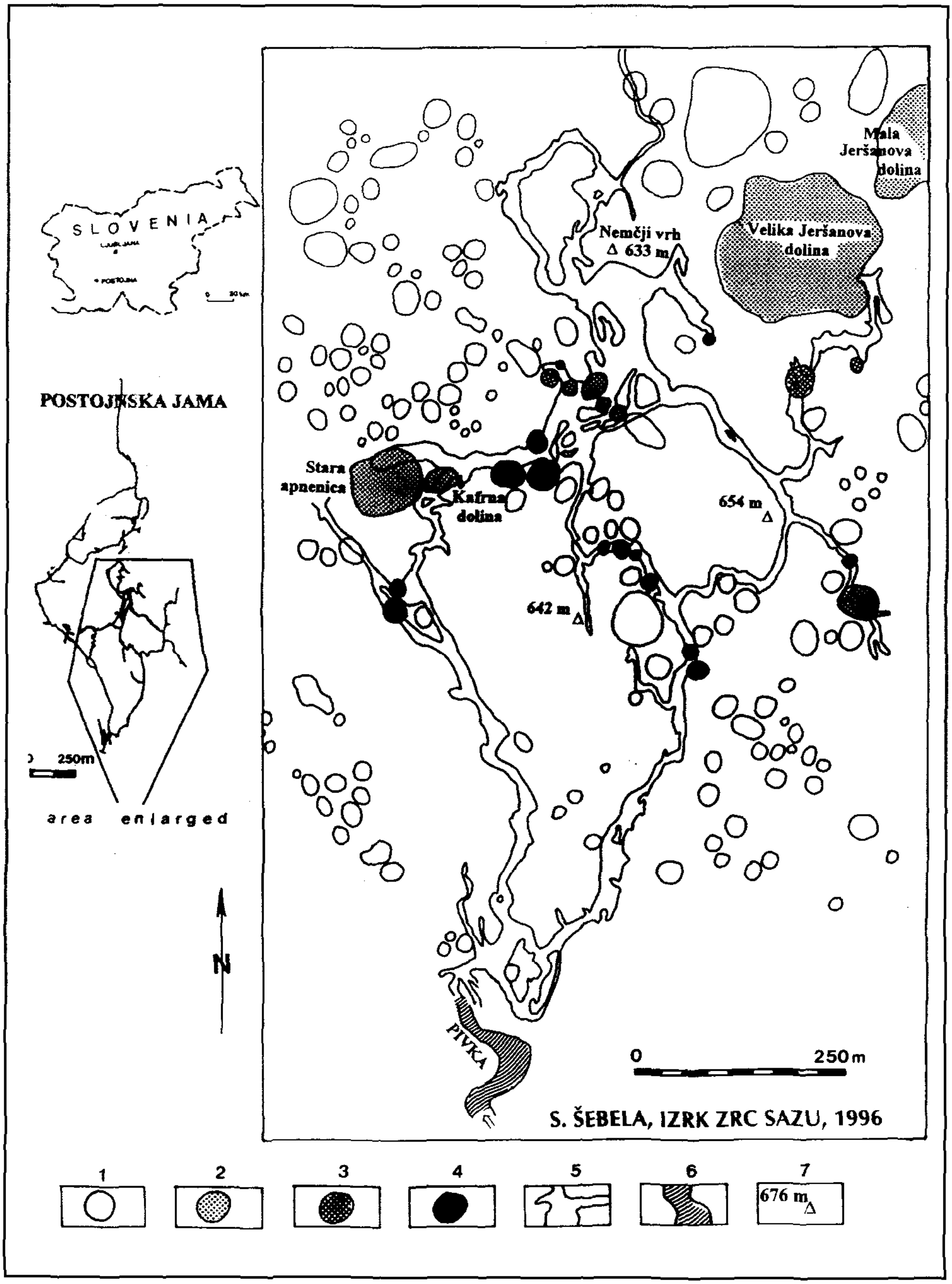
SLOVENIA
POSTOJNSKA JAMA
250m
area enlarged
N
Mala Jeršanova dolina
Velika Jeršanova dolina
Nemčji vrh
Δ 633 m
Stara apnenica
Kafrna dolina
654 m Δ
642 m Δ
PIVKA
0 250 m
S. ŠEBELA, IZRK ZRC SAZU, 1996
1
2
3
4
5
6
7
676 m Δ

Fig. 1: Cave passages of Postojnska Jama and dolines on the surface:
1 - doline
2 - collapse doline
3 - dolines above collapse chambers of Postojnska Jama
4 - dolines above passages of Postojnska Jama
5 - ground plan of cave passages
6 - river
7 - altitude a.s.l. of hills

Sl. 1: Rovi Postojnske jame in vrtače na površju:
1 - vrtača
2 - udornica
3 - vrtače nad podornimi dvoranami Postojnske jame
4 - vrtače nad rovi Postojnske jame
5 - tloris jamskih rovov
6 - reka
7 - nadmorska višina vzpetin

Gospodarič (1965, 1976) made an important geological investigation of the area above and near Postojnska Jama.

Čar & Gospodarič (1984) made a detailed tectonico-lithological mapping on the surface above Pivka and Črna Jama. They determined some types of dolines according to geological structure.

GEOLOGICAL CONDITIONS IN COLLAPSE CHAMBERS AND DOLINES ABOVE THEM

In Postojnska Jama the collapse chambers (Fig. 2) where we did not find signs of phreatic conditions after the last breakdown are:

- Rov Brez Imena
- Pisani Rov
- Velika Gora
- and Koncertna Dvorana.

Postojnska Jama developed in the Upper Cretaceous limestone $K_2^{2,3}$. Gospodarič (1965) determined old overthrusting and folding deformations. For development of cave passages the Postojna anticline (Gospodarič, 1965; 1976) is very important. The axis of anticline crosses Ruski Rov and Čarobni Vrt (Fig. 2). In Pisani Rov the intensity of axis decreases. Most of passages developed in the SW part of the Postojna anticline.

In "Javorniško-Snežniške Grude" tectonic unit (Pleničar, 1970) younger faulting deformations as Dinaric (NW-SE) and cross Dinaric (NE-SW) fault zones prevail.

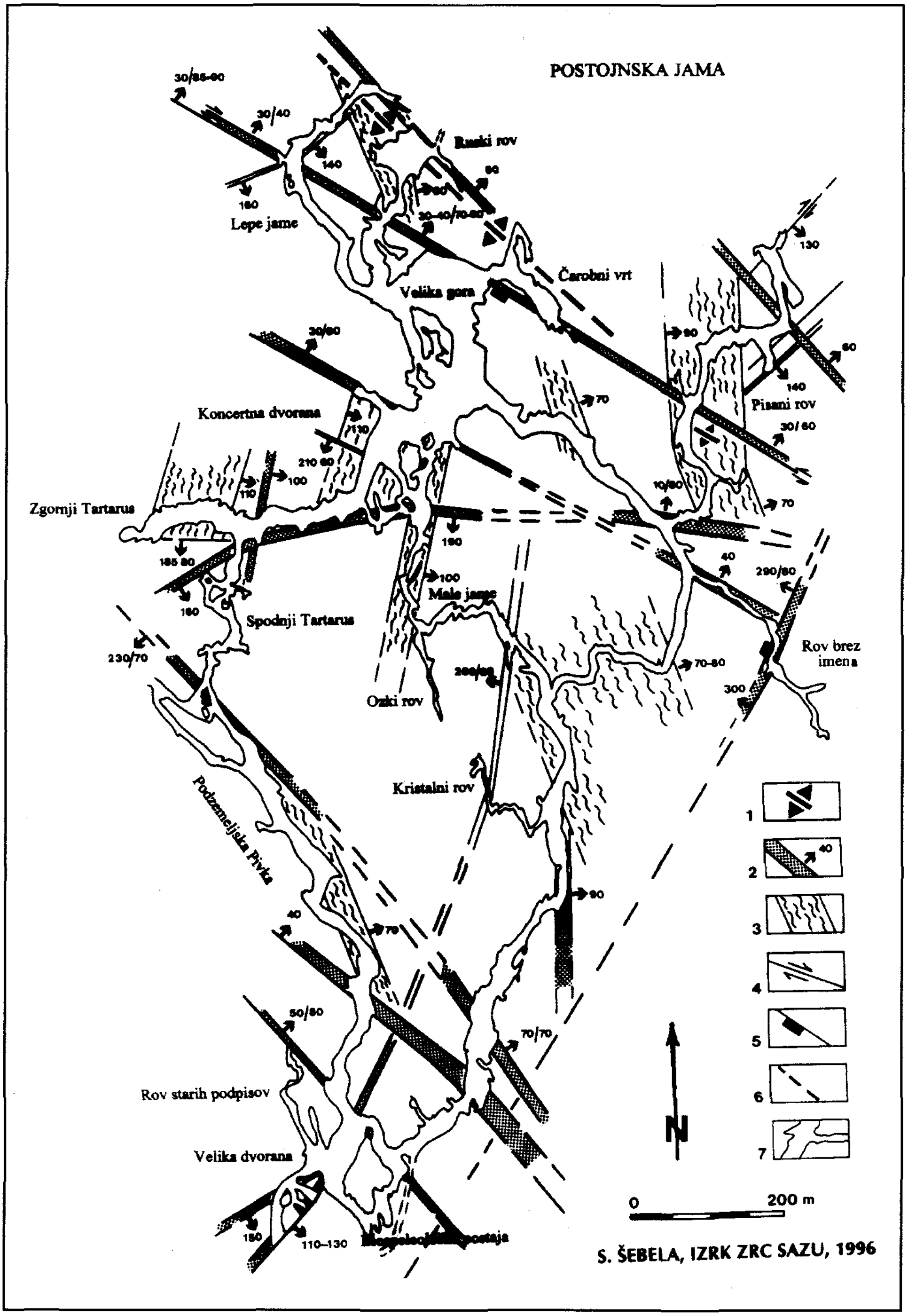
POSTOJNSKA JAMA
Ruski rov
Lepe jame
Čarobni vrt
Velika gora
Pisani rov
Koncertna dvorana
Zgornji Tartarus
Spodnji Tartarus
Male jame
Rov brez imena
Ozki rov
Kristalni rov
Podzemeljska Pivka
Rov starih podpisov
Velika dvorana
1
2
3
4
5
6
7
0
200 m
S. ŠEBELA, IZRK ZRC SAZU, 1996

Fig. 2: Structural geology of Postojnska jama:
1 - anticline
2 - crushed zone with geological structural elements
3 - broken and fissured zone
4 - horizontal movement
5 - vertical movement
6 - supposed fault zone
7 - ground plan of cave passages

Sl. 2: Strukturna geologija Postojnske jame:
1 - antiklinala
2 - zdrobljena cona z geološkimi elementi
3 - porušena in razpoklinska cona
4 - horizontalni premik
5 - vertikalni premik
6 - domneven potek prelomne cone
7 - tloris jamskih rovov

The same situation is visible in Figure 2. From Spodnji Tartarus to the beginning of Pisani Rov we follow an important crushed zone with an almost E-W trend which is relatively older than the Dinaric crushed zones.

The collapse chamber in Rov Brez Imena developed in a crushed zone of cross Dinaric orientation 290-300/80-90 (Fig. 2). On the fault plane which limits the fault zone there are traces of vertical movements where the NW block is moved down and the SE block up. On the surface 67 metres above the colllapse chamber there is a doline with diameter at the top of 75 metres and a depth of 17,7 metres. Through the doline there is the same fault zone as may be observed in the cave 67 metres below the surface.

Pisani Rov has two collapse chambers. The northern one is very small and the chamber is closed with breakdown blocks. On the surface we have a little doline which is 10 metres in diameter and 2 metres deep. In the cave the collapse chamber is formed in crushed zone 140/90, but on the surface in the doline it is impossible to determine the same fault zone, because the terrain lies in the SE slope of Velika Jeršanova Dolina (Fig. 1), where processes of erosion changed the surface.

A better example in Pisani Rov is the collapse chamber in the middle of the channel 30 metres under the surface. It developed in Dinaric crushed zone 30/60 with horizontal movements left movement. The same fault zone, but with steeper dip (20/90), crosses the doline above the collapse chamber. The doline is 6,7 metres deep and 20 metres wide.

Above the biggest collapse chamber in Postojnska Jama called Velika Gora (Šebela, 1995) there are no dolines. Velika Gora developed under the southern slope of hill the Nemčji Vrh (Fig. 1).

30 metres above Koncertna Dvorana there are 6 dolines which are all genetically connected with the Dinaric crushed zone 30-40/80-90. In the cave we can observe vertical movements, where the NE block is moved up and SW block down.

The other 13 dolines are just above cave passages and not above collapse chambers.

I have to mention also two collapse dolines Kafrna Dolina and Stara Apnenica (Fig. 1) which are above cave passages and whose origin is closely connected with important crushed zone in the direction almost E-W (160-190/90). The collapse doline Velika Jeršanova Dolina lies a little away from Pisani Rov. But the bottom of the doline is at the same as Pisani Rov.

CONCLUSIONS

Directly above the passages of Postojnska Jama there are 22 dolines and two collapse dolines. If we observe 22 dolines it is not possible to find the differences between them to determine if they are overlying collapse chambers in the cave. It is easier if we know where collapse chambers in the cave are and then determine the dolines above the cave.

According to geological and especially tectonic conditions the important regional fault zones are the reasons for collapse chambers and also for dolines above them. Almost half of the dolines above the cave are tectonically controlled. The activity of the same fault zone resulted in formation of collapse chambers in the cave and the dolines on the surface.

In collapse chambers the vertical percolation is very good. In Pisani Rov and in Koncertna Dvorana at the top of collapse chamber there are chimneys.

40,9 % of dolines above passages of Postojnska Jama developed in tectonically crushed zones. Important tectonic zones influenced also underlying cave passages where collapse chambers developed.

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VRTAČE NAD PODORNIMI DVORANAMI POSTOJNSKE JAME

Povzetek

Postojnska jama je 13 km dolg del Postojnskega jamskega sistema (Sl. 1), ki je z 20 km najdaljši jamski sistem v Sloveniji. V obdobju od 1991 do 1994 sem v Postojnski jami in na površju nad njo, pod mentorstvom prof. dr. Jožeta Čarja, opravljala doktorsko nalogo, ki jo je financiralo Ministrstvo za znanost in tehnologijo RS.

Na površju nad rovi Postojnske jame je 22 vrtač (Sl. 1) in dve udornici (Kafrna dolina in Stara apnenica). Skoraj polovica vrtač, in sicer 9 primerov predstavlja vrtače, pod katerimi so podorne dvorane. Vrtače, ki so nad podornimi dvoranami, se od ostalih vrtač na terenu morfološko ne razlikujejo. Edino povezavo v nastanku med podornimi dvoranami in vrtačami nad njimi lahko najdemo v regionalno močneje izraženih prelomnih conah (Sl. 2).

Vrtače nad podornimi dvoranami najdemo nad Rovom brez imena, Pisanim rovom in Koncertno dvorano (Sl. 2).

V Rovu brez imena sta podorna dvorana in vrtača, ki je 67 m nad njo, oblikovani v prečno dinarski tektonski coni 290-300/80-90. Na zunanji prelomni ploskvi opazujemo sledove vertikalnega premikanja, kjer se je SZ blok glede na JV spustil.

Nad Pisanim rovom sta 2 vrtači nad podornima dvoranama. Severnejša podorna dvorana je manjših dimenzij, saj je zaprta s podornimi bloki. Razvita je v prelomni coni 140/90, ki ji na površju ne moremo slediti, saj leži teren v JV pobočju Velike Jeršanove doline in je morfološko precej spremenjen.

Boljši primer predstavlja druga vrtača v Pisanem rovu, ki se je oblikovala v dinarski prelomni coni 20/90. 30 m pod površjem lahko sledimo isti prelomni coni, ki pa ima nekoliko drugačno smer in vpad (30/60). Ob tej prelomni coni lahko določimo horizontalne premike, in sicer levi zmik.

Nad Koncertno dvorano je razdalja do površja 30 m. Nad podorno dvorano je 6 vrtač, ki so v genetski zvezi z dinarsko prelomno cono 30-40/80-90. V podorni dvorani lahko določimo vertikalno premikanje, kjer se je SV blok glede na JZ dvignil.

Ostalih 13 vrtač je le nad rovi Postojnske jame, ne pa tudi nad podornimi dvoranami.

Geološka zgradba terena kaže jasno sliko, ki kaže, da so podorne dvorane in vrtače nad njimi genetsko vezane na pomembnejše regionalne prelomne cone.

Nekaj manj kot polovica, in sicer 40,9 % vrtač, ki so nad rovi Postojnske jame je tektonsko pogojena. Močnejše tektonske cone so pomembno vplivale tudi na spodaj ležeče rove, saj so nastale podorne dvorane.

Seveda pa ne moremo posploševati trditve, da so pod skoraj polovico vrtač, in sicer tudi v predelih, kjer jamski rovi niso znani, razvite podorne dvorane.

Z gotovostjo lahko trdimo le, da se vrtače, oblikovane v istih tektonsko pretrtih conah kot spodaj ležeče podorne dvorane, morfološko ne razlikujejo od ostalih vrtač na tem terenu. Povezava med nekaterimi vrtačami in spodaj ležečimi jamskimi rovi ter predvsem podornimi dvoranami je na primeru Postojnske jame zelo očitna in predstavlja genetsko povezavo med vrtačami in podornimi dvoranami z istimi tektonsko pretrtimi conami.

POLJES AND CAVES OF NOTRANJSKA

KRAŠKA POLJA IN JAME NOTRANJSKE

FRANCE ŠUŠTERŠIČ

Izvleček UDK 551.435.83(497.4)

France Šušteršič: Kraška polja in jame Notranjske

Kritično je podan pregled poznavanja notranjskih kraški polj in vodoravnih jam v njihovem območju. Avtor ugotavlja, da je proučevanje izhajalo iz predpostavke, da so polja posledica postopnega zakrasevanja predkraških rek. Podobno se tudi študij okoliških jam ni mogel odtrgati od iste predpostavke, kar je vodilo k zaključku, da so polja in jame genetsko neposredno povezane. Raziskovanja zadnjih let, ki izhajajo iz drugačnih pogledov, kažejo, da je povezava polj in jam slučajna. Nekateri danes aktivni jamski sistemi so celo starejši od idrijskega zmika, medtem ko so polja mlajša in posledica dinamike znotraj prelomne cone.

Ključne besede: kraško polje, jamski sistem, speleogeneza, Notranjski kras

Abstract UDC 551.435.83(497.4)

France Šušteršič: Poljes and caves of Notranjska

Given is critical survey of the research of the poljes of south-central Slovenia, and the horizontal caves in their neighbourhood. Author is of an opinion that the research has stemmed from a supposition that the poljes are the consequence of gradual karstification of the prekarstic rivers. Similarly, the understanding of the close by caves could not forget this idea, what led to the conclusion that poljes and caves must be genetically interrelated. The very recent research, founded on different paradigms, revealed that the interrelations are merely coincidental. Some cave systems are older than the Idrija strike-slip displacement, while poljes are younger, very probably due to the dynamics within the Idrija fault zone.

Key words: polje, cave system, speleogenesis, karst of Slovenia

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0. FOREWORD

E. Silvestru (1995, p.503) suggested that the phenomenon of the karst polje is a paramount example of how terms/notions were introduced into karst science. "*There is one... extremely important characteristic which makes karstology almost unique: long before being a self-standing science, geography was already coining terms that subsequently became standard karstological terms, without being actually re-defined according to new criteria*". The situation with poljes is much worse: the popular term was introduced without defining its popular and its scientific meanings. The latter would hardly be possible, because the students of poljes did exactly what G. H. Dury (1967, p.220) described in somewhat different circumstances: "*... Davis's statements to be regarded, not as descriptions of what actually happens, but as expressions of personal views of what may be happening.*"

This paper is not meant to suggest a new definition of the polje. It sets out to compare the present level of knowledge about the poljes with the actual understanding of the neighbouring caves, and to consider the poljes together with the caves of the area, in a way that appears to be a stepping stone towards building the poljes into the surrounding karst.

1. INTRODUCTION

The area of the Classical Karst in Slovenia is best considered as a triangle with vertices that just encompass the cities of Ljubljana, Rijeka and Gorica/Gorizia. One of its gravity lines runs from Ljubljana to Trieste and the present centre for karst studies, Postojna, lies close to the triangle's centre of gravity. Traditionally, the area is sub-divided into the Karst (Slovene: Kras) or the Lower Karst, which lies southwest of the line from Gorica/Gorizia through Postojna to Rijeka, and the High Karst, which covers the rest of the triangle.

The eastern part of the High Karst is known popularly as Notranjska. It approximates to the catchment area of the sinking river Ljubljanica, which is the backbone of the area that drains into the Danube and onward to the Black Sea. The Ljubljanica is widely known as a string of surface and underground stream segments, with the streams emerging onto closed basins that more or less fit the traditional view of poljes.

Fig. 1: The Ljubljanica basin: main dyed connections (simplified), main active caves
a: well determinable border of the karstic Ljubljanica catchment area
b: approximative border of the karstic Ljubljanica catchment area
c: outflow border of the karstic Ljubljanica catchment area
d: main superficial streams
e: dyed connections
f: alluvial bottoms of major poljes and of the Pivka basin
g: international boundary
h: accessible spring cave
I: siphon spring cave
j: unpenetrable karst spring
k: major water caves accessible inside the system
l: accessible ponor cave
m: non accessible ponor
A: Pivka basin
B: Babno polje
C: Loško polje
D: Bloke (Bloško polje)
E: Cerkniško polje
F: Rakovško polje
G: Planinsko polje
H: Logaško polje
J: Ljubljansko Barje (Ljubljana Marsh)

Numeration: numbers[2] of registred caves. See text!

Sl. 1: Porečje Ljubljanice - poglavitne obarvane vodne zveze (poenostavljno), glavne aktivne jame
a: jasno opredeljiva razvodnica
b: približno določena razvodnica na kraških ozemljih
c: odtočni rob kraškega dela porečja Ljubljanice
d: glavni površinski tokovi
e: obarvane vodne zveze
f: aluvialna dna najvažnejših kraških polj in Pivške kotline
g: mednarodna meja
h: dostopna izvirna jama
I: sifonska izvirna jama
j: nedostopen kraški izvir
k: najpomebnejše vodne jame, dostopne iz sredine sistema
l: dostopne ponorne jame
m: nedostopne ponorne jame
A: Pivška kotlina
B: Babno polje
C: Loško polje
D: Bloke (Bloško polje)
E: Cerkniško polje
F: Rakovško polje
G: Planinsko polje
H: Logaško polje
J: Ljubljansko Barje

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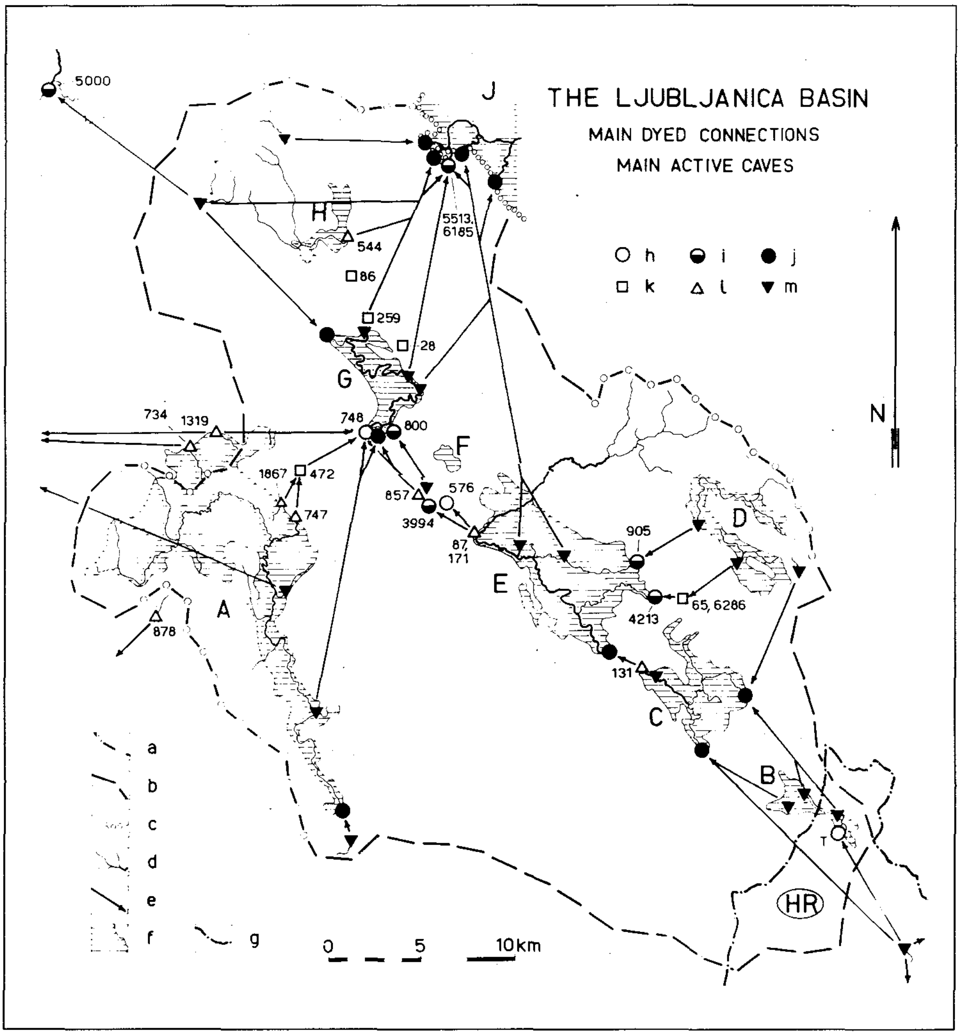
[2] *Numeration according to the central register of caves of Slovenia, maintained by the Speleological association of Slovenia and the Karst research institute, ZRC SAZU, Postojna.*


THE LJUBLJANICA BASIN
MAIN DYED CONNECTIONS
MAIN ACTIVE CAVES
h
i
j
k
l
m
N
a
b
c
d
e
f
g
0
5
10km
A
B
C
D
E
F
G
H
J
HR
5000
544
86
259
28
5513, 6185
734
1319
748
800
1867
472
747
857
576
3994
87, 171
905
65, 6286
4213
131
878
T

Though the surface and underground streams form an interconnected network, the river is divided traditionally into two branches. The bulk of the western part encompasses the Pivka basin (A in Fig. 1), which is in fact a relatively large basin, within predominantly flysch (i.e. non-karstic) rocks, that drains underground. I. Gams (1994, p.289) views it as a peripheral polje, but in the further discussions below it is of no direct interest.

On the other hand, the poljes of the eastern branch plus the Planinsko polje (G[1]), which can be considered as the confluence of the two branches (Fig. 1), are formed in karstic rocks. The recognition of the single basins as poljes developed along with the development of the term polje itself. Planinsko, Cerkniško and Loško polje (G, E and C respectively in Fig.1) have been considered poljes from the very beginning (J. Cvijić, 1893). In 1916 F. Kossmat introduced the Logaško (H) and Rakovško (F) poljes and in 1924 N. Krebs added the Babno polje. A composite of F. Kossmat's (1916) and J. Rus' (1925) map (Fig. 2) documents what the pioneers did. Not until the work of A. Šerko (1948) were all the poljes in the area recognized and classified systematically, including the Rakov Škocjan. The latter, however, is not a polje but a (karst) valley, with a surface stream that emerges from a cave and disappears into the karst again.

F. Kossmat (o.c) noted that the previously listed poljes are arranged in a nearly straight line along the Idrija Fault. He also noted that the string of poljes lies within a stripe of relatively low relief that is now called the Notranjsko podolje (Notranjsko lowlands) (Figs. 2, 3). Kossmat recognised similarities between the Notranjsko podolje and the Čepovanski dol, a magnificent dry valley at the foot of the Julian Alps. This led him to explain the formation of poljes as a stage in the karstification of a primarily non-karstic superficial river, and this remained the tenet of further explanations until very recently.

Consequently, the caves in this area have been regarded as being fundamentally more or less epiphreatic in origin, with their development bound intimately to the formation of the poljes and the presumed river terraces at their margins (R. Gospodarič and P. Habič, 1979). On the other hand, extensive speleological work has made this explanation less and less acceptable. Though I. Gams (1963) remarked that this key probably did not fit the lock, it was not until the nineteen-nineties that studies founded upon other paradigms began to appear (M. Brenčič, 1992; S. Šebela, 1994; F. Šušteršič, 1992, 1994; M. Knez, 1996).

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[1] *Labels of poljes according to Figs. 1 and 3.*

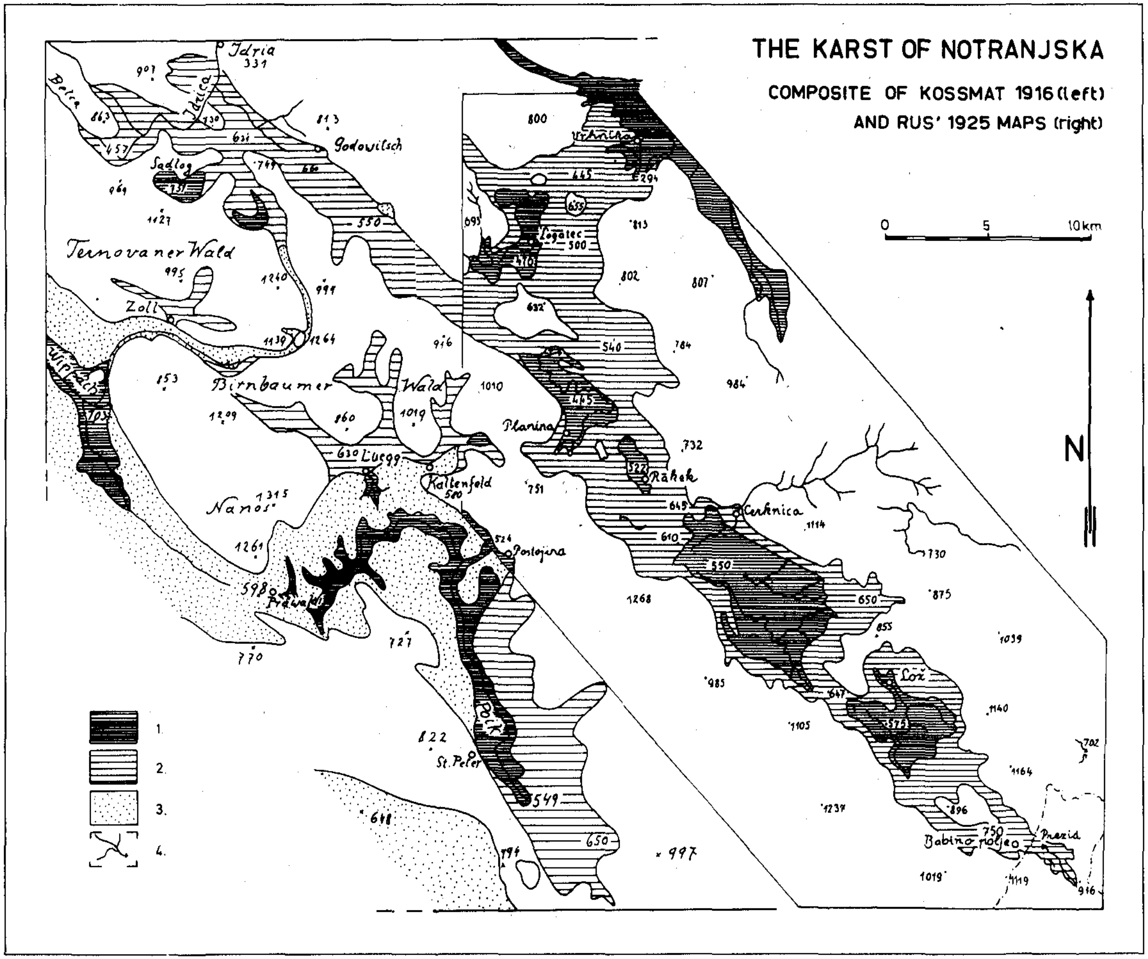
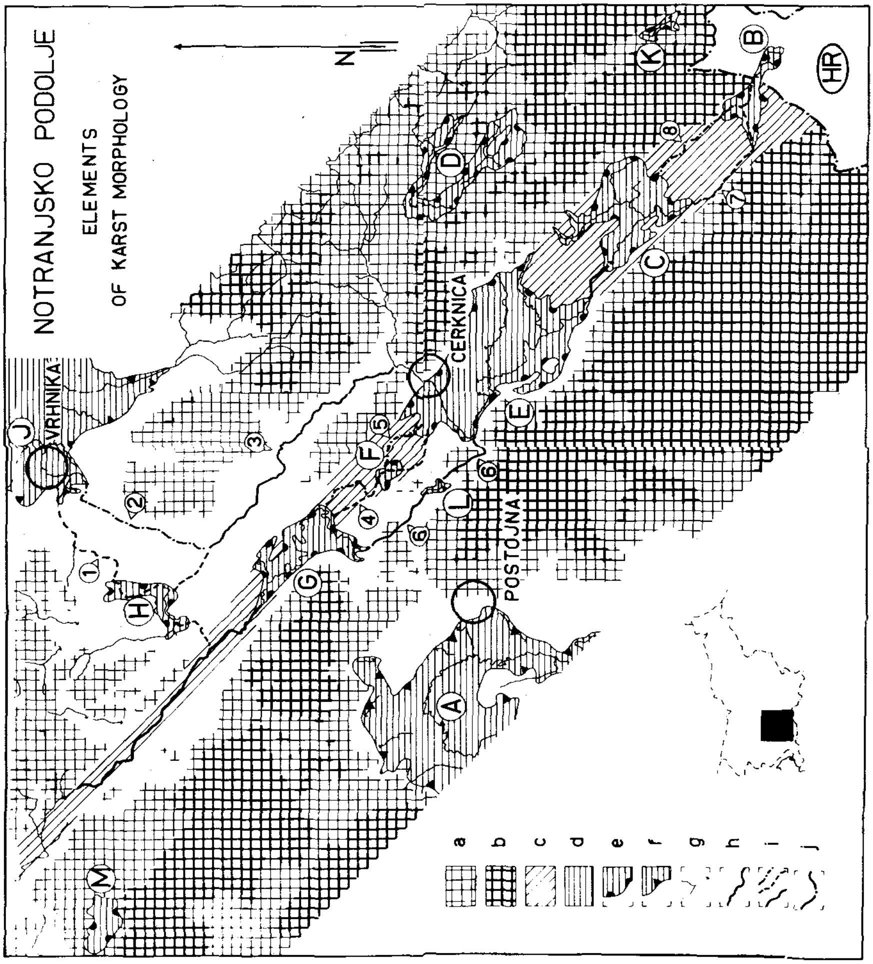

THE KARST OF NOTRANJSKA
COMPOSITE OF KOSSMAT 1916 (left) AND RUS' 1925 MAPS (right)
0 5 10 km
N
Idria
331
Idrica
Belca
Godowitsch
Sadlog
Ternovaner Wald
Zoll
Birnbaumer Wald
Wippach
Nanos
Luegg
Kaltenfeld
Prawald
Postojna
Planina
Logatec
Vrhnika
Rakek
Cerknica
Lož
Babno polje
Prezid
St. Peter
Pivka
550
540
650
1.
2.
3.
4.

Fig. 2: The composite of F. Kossmat's (1916, 654) and J. Rus' (1925, 31) maps
1. Alluvial bottoms of poljes and active river valleys
2. Flattened areas in limestone and dolomite
3. Fliysch areas
4. Surficial streams

Sl. 2: Sestavljenka F. Kossmatove (1916, 654) in J. Rusove (1925, 31) karte
1. Aluvialna dnesa kraških polj in aktivnih rečnih dolin
2. Uravnave na apnencu in dolomitu
3. Flišna ozemlja
4. Površinski tokovi

Fig. 3: Notranjsko podolje, elements of karst morphology
a: Elevations 800m a.s.l.
b: Elevations between 610m and 800m a.s.l
c: Zone of the Idrija fault
d: Alluvial bottoms of closed basins
e: Borders of flat bottoms within closed basins
f: Outflow border of the karstic Ljubljanica basin
g: Active surficial streams
h: Main "talwegs" (Fig. 4)
I: Parallel "talwegs"
j: International boundary

Sl. 3: Notranjsko podolje, elementi kraške oblikovanosti
a: Višine nad 800m
b: Višine med 610m in 800m
c: Cona Idrijskega preloma
d: Aluvialna dna večjih zaprtih globeli
e: Robovi ravnega dna večjih zaprtih kraških globeli
f: Odtočni rob kraškega porečja Ljubljanice
g: Activni površinski tokovi
h: Glavne "podolnice" navideznih suhih dolin (Gl. sl. 4)
I: Stranske "podolnice" navideznih suhih dolin
j: Mednarodna meja


NOTRANJSKO PODOLJE
ELEMENTS
OF KARST MORPHOLOGY
N
VRHNIKA
CERKNICA
POSTOJNA
HR
a
b
c
d
e
f
g
h
i
j

2. THE LJUBLJANICA CATCHMENT AREA

The calculated size of the Ljubljanica drainage basin is 1779 km^2, of which about 1100 km^2 are composed of karstic rocks. The location of the water divide is approximate, but bifurcations have been proved at several boundaries by water tracing (Fig. 1). According to studies during the complex water tracing experiments of the nineteen-seventies, the catchment area of the Vrhnika springs, where the main river definitively leaves karst terrain, covers 1108.78 km^2 (K. Žibrik et al, 1976). The mean discharge in the years 1972 to 1975 was 38,60 m^3 sec^{-1}, with a specific run-off of 34.8 l sec^{-1} km^{-2}. I. Gams (1966a) established a mean denudation rate of 65 m^3 km^{-2} a^{-1}.

The karstic rocks are generally micritic, locally oolitic, limestones and dominantly late-diagenetic dolomites, mostly of Mesozoic age. They were formed on the Dinaric platform under conditions of continuous sedimentation. Very uniform shallow sea conditions persisted and were responsible for the extremely high rock purity, generally with less than 5%, but locally as little as 0.1%, insoluble residue. The total thickness of the carbonate sequence is about 6850m (J. Čar, 1996).

Among the non-karstic rocks, only Early Tertiary flysch, deposited directly upon the carbonate sequence, has a significant role. Older Triassic and Permian clastic rocks do not appear to play an important role in karst shaping. Younger sediments are absent, suggesting a final emergence at the end of the Tertiary.

Structurally, the whole of the Ljubljanica basin belongs to the Adriatic sub-plate. The area is composed of several nappes (V. Placer, 1981; U. Premru, 1982) that were overthrust in a NE to SW direction as a result of the collision of the Adriatic sub-plate with the European continent. Gradual change of the movement direction brought about the formation of the Idrija (dextral strike-slip) Fault, which runs through the area in a NW-SE direction. The total displacement on this still-active fault has never been measured systematically, and a widely ranging estimates have been made. However, an apparent displacement of about 12km is evident from the geological map (Fig. 5, inset map).

Examination of satellite imagery gives the impression that the fault is very straight. On the other hand, detailed field observations (J. Čar, 1982; J. Čar and R. Gospodarič, 1984; I. Mlakar, 1969; F. Šušteršič, 1989) revealed that there is not just one fault line. There are at least two main fractures (the Idrija and the Zala faults) and a zone of chaotically displaced blocks between them (Figs. 3, 5), separated by minor faults. Cross correlation of the relief on both sides of the fault zone with that within the central area does not permit the central zone to be attached to any of the blocks on either side. Rather, it displays a unique form and structure, such that the fault zone is best regarded as a separate structural and geomorphic unit in its own right.

Except for the fluvio-denudational relief in the flysch area of the Pivka basin, and some areas on the Permian and Early Triassic clastic rocks (together with the Late Triassic dolomite) most of Ljubljanica basin has a typically karstic surface. In earlier times it was believed that different elevations reflect pre-karstic "levels", and that some lower parts are remnants of pre-karstic superficial drainage. Further research has proved that - with only a few exceptions - this is hardly possible, and that the relief is essentially tectonic (P. Habič, 1981, F. Šušteršič, 1979, 1987 a, b). Basically, the area consists of blocks lifted to different levels, marked by isolated hills (hums) at higher elevations and predominantly flat in the lower areas. (See F. Šušteršič, 1996, photos!)

The highest elevations form a string that runs parallel with the Idrija Fault, in direct contact with the southwestern margin of its main zone (Fig. 3). These are Planinska Gora (1019 m), Javorniki (1293 m) and Snežnik (1796 m). The local base level is at Vrhnika, on the border of the Ljubljansko Barje (Ljubljana Marsh, 294m), where the karst waters finally appear at the surface. Locally the lowest relief is in the Notranjsko podolje, which runs parallel to, and northeast of, the range mentioned before (Fig. 3).

3. THE POLJES OF NOTRANJSKO PODOLJE

In longitudinal section (Fig. 4) the Notranjsko podolje appears to be a string of closed basins (poljes), ranged more or less within the Idrija Fault Zone (Figs. 2, 3):

Table 1, poljes within the Idrija fault zone, crossed by the main stream (Figs. 1, 3):

Label	Name:	Elevation:	Classification	
		(general)	Šerko (1948)	Gams (1994)
B	Babno polje	750 m	uvala	border polje
C	Loško polje	575 m	periodicaly flooded polje	overflow polje
E	Cerkniško polje	550 m	priodical lake	border polje
	Rakov Škocjan	500 m	periodicaly flooded uvala	/
G	Planinsko polje	450 m	periodicaly flooded polje	overflow polje

The latter two poljes (Loški potok and Zadlog) are mentioned because, in the literature, they appear to show some connection with those listed in the main part of the table. They are considered no further. The Postojna basin and Bloke are more closely bound to the main poljes and, where necessary,

Table 1, Appendix (neigbouring poljes, Figs. 1, 2):

Label[1]	Name	Elevation (general)	Classification Gams (1994)	Notes
F	Rakovško polje	520 m	border polje	within the zone, main stream passes by
H	Logaško polje	480 m	border polje	out of the zone, main stream passes by
A	Postojna basin		peripheral polje	flysch area, out of the zone
D	Bloke		border polje	out of the zone
K	Loški potok		/	out of the present Ljubljanica basin
M	Zadlog		/	out of the present Ljubljanica basin

will be included in the discussion. The Rakovško polje lies within the Idrija Fault Zone and cannot simply be omitted, though, from the viewpoint of the present hydrological situation, it could be. Its inclusion necessitates inclusion of the Logaško polje, even though it lies outside the zone, but close to the Ljubljanica final resurgence. It must be stressed again that the Rakov Škocjan is not a karst polje, but it cannot be ignored in this discussion because a great deal of water passes through it.

Despite a century of intensive study the actual mechanism of polje genesis remains obscure. R. Gospodarič and P. Habič (1979, p.25) provide an exhaustive survey of the genetic ideas concerning the Cerkniško polje, which may, without any doubt, also be applied to other poljes in the area. The ideas range from pure tectonic lowering, through fluvial erosion, to corrosion. Though their work (o.c.) is the most extensive to date and they present data

Fig 4: Notranjsko podolje - "talweg". Longitudinal projection on the vertical plane, running through regression line of the Idrija Fault.

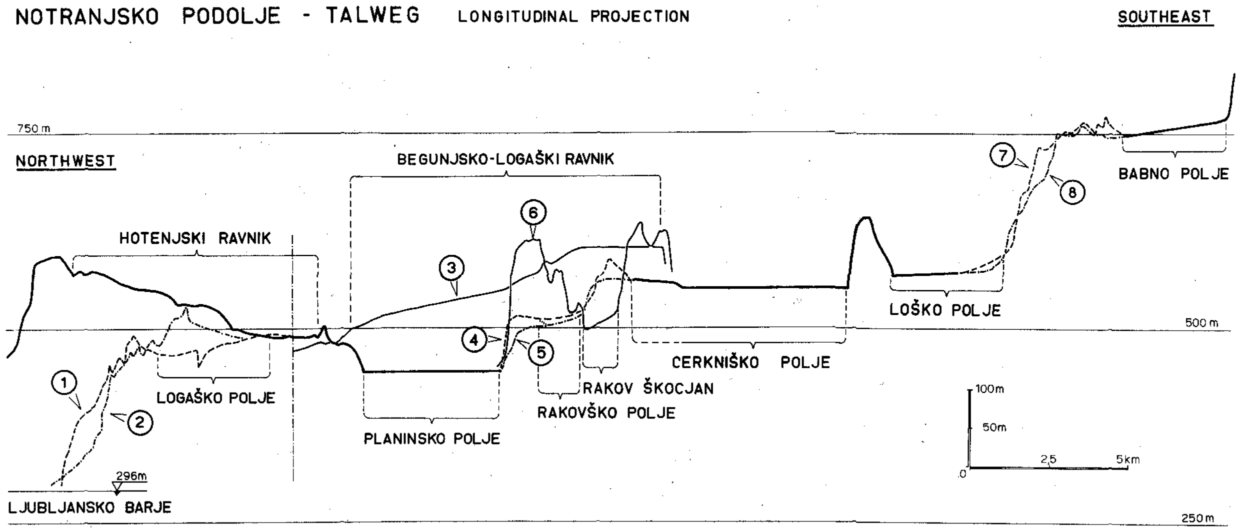
"Talweg" signs identical with Fig. 3.

(Numeration not needed in this context)

Sl. 4: Notranjsko podolje - "podolnica". Vzdolžna projekcija na navpično ravnino, položeno skozi regresijsko premico idrijskega preloma.

Oznake "podolnic " so iste kot na sliki 3.

(Oštevilčenje v tem kontekstu ni potrebno)


NOTRANJSKO PODOLJE - TALWEG LONGITUDINAL PROJECTION
SOUTHEAST
NORTHWEST
750 m
500 m
250 m
BEGUNJSKO-LOGAŠKI RAVNIK
HOTENJSKI RAVNIK
LOGAŠKO POLJE
PLANINSKO POLJE
RAKOV ŠKOCJAN
RAKOVŠKO POLJE
CERKNIŠKO POLJE
LOŠKO POLJE
BABNO POLJE
LJUBLJANSKO BARJE
296m
1
2
3
4
5
6
7
8
100m
50m
0
2,5
5km

partially supporting each of the previous ideas, they appear to remain undecided, and a true synthesis is lacking. Recently M. Vrabec (1994) offered a radically new tectonic explanation, viewing the Cerkniško polje as a rudimentary pull-apart basin.

This is an important indication either that something is fundamentally wrong, or that, in spite of the impressive amount of data collected, the proper conclusions have not yet been drawn. However, some possible mistakes may be indicated:

3.1. Since the very earliest scientific explanations, karst, together with poljes, has been regarded as something transient, and the main relief features were obviously taken as being inherited from some pre-karstic, fluvial phase. Kossmat's (o.c.) analogy between two sectors of the Notranjsko podolje - the Begunjsko-logaški ravnik and Hotenjski ravnik (Figs. 2, 4) - and the evidently trans-environmental dry valley, Čepovanski dol, appeared to support this idea. His followers did not test the idea against the fundamental logic of fluvial systems (longitudinal profiles, sediments etc). Instead they continued hunting for dry valleys, recognising them in any topographic feature that appeared linear in plan (N. Krebs, 1924; J. Rus, 1925; A. Melik, 1928; R. Gospodarič and Habič, 1979).

Poljes have always been viewed as a karst stream piracy phenomenon. The decline of Davisianism and the ascent of climatic geomorphology only changed the postulated mechanisms, without affecting the foundations. F. Šušteršič (1986 a) offered a completely different view of poljes in general, but did not apply it directly to the poljes in this consideration.

3.2. It has always been taken as self-evident that presently visible caves and poljes are intimately related genetically. The idea that their present configuration in a string might be only coincidental has never appeared. This is simpler to understand by considering that, in connection with polje formation, underground transmission systems have always been viewed as tube patterns, basically formed and functioning in epiphreatic (i.e. fluvial-like) conditions. In contrast, water tracing results, not to mention other hydrogeological research, indicated just the opposite. I. Gams (1963) noted that direct relations between the cave "levels" and surface "terraces" simply do not exist. Nevertheless, the necessary conclusions were not drawn, and he appears partly to have turned back to the general opinion (I. Gams, 1973 b).

3.3. Another "axiom" is that processes shaping the slopes around polje basins are fundamentally the same as those forming the closed basins themselves. Consequently, the apparent study of polje genesis turned into a study of their Quaternary transformations (A. Melik, 1955; I. Gams, 1965; R. Gospodarič and P. Habič, 1979). Two facts, self-evident from the viewpoint of the Pure Karst Model (F. Šušteršič, 1986 a, 1996), were neglected (F. Šušteršič, 1986 b): a) the share of slopes that might be specific to poljes is nearly negligible compared to those that appear generally in the neighbourhood (F. Šušteršič, 1987), and they always appear locally, and b) depression positions within the karst are not something exceptional, and depressions generated by any endo-dynamic process (being subsequently filled up within other geomorphic systems) might survive unmodified within the karst. In that case, only the questions of how and why the bottoms became, or possibly remained, flat is relevant.

3.4. Early theories invoking a tectonic origin for poljes failed due to field evidence (R. Gospodarič and P. Habič, 1979, p.25) that did not support contemporary explanations. Further detailed geological mapping (cited above) revealed a different tectonic pattern within the main Idrija Fault Zone. Students were still being influenced by the (otherwise refuted) contractional theory of Earth development, and continued to search for the impossible answer within the context of radial tectonics. They neglected the last decades' comprehension that the dynamics of the continental crust are basically tangential, and offer a number of potential mechanisms for the formation of closed depressions (M. Vrabec, 1994).

3.5. Too much interest has been directed towards the study of a few "important" caves, which are, at first sight, directly connected to the present watering and drainage of the poljes. Far more less spectacular, inactive, caves in the close neighbourhood (i.e. fragments of the same systems) were generally neglected, or at least, misinterpreted. Significant clustering of similar segments at some locations, far from the poljes, was simply overlooked. Consequently, nobody appreciated that the cave systems might have developed according to their own logic, totally unrelated to the poljes, and the present situation might be only coincidental. However, it appears that D. Kuščer (1963) realised that direct interpretation of the active caves together with polje formation might not be reasonable.

3.6. J. Rus (1925) noted that all of the poljes previously listed lie at the contact between limestone and dolomite. He offered an explanation of their genesis, arguing that the actual contact is crucial to polje formation. Today, the processes he listed seem rather naive, but his ideas appeared to receive support from H. Lehmann (1959). I. Gams (1973 b) combined Lehmann's classification with his own findings and the combined view become very popular, but despite being founded partly on field observations and partly upon theoretical calculations, it has never been elaborated into a consistent, convincing system. Nevertheless, the "contact" explanation inhibited further research, and many attempts to understand polje formation were suspended by the belief that *"poljes develop on contacts"*. The field evidence cannot be denied, but this is not the point. In the territory between the poljes, within the zone of the Idrija Fault, geologically completely equivalent contacts exist that display no tendency to evolve into polje-like depressions. As might be expected, many contacts outside the zone did not evolve into poljes either. Even more significantly, the Bloke polje (D) lies completely within dolomite.

4. OVERVIEW OF THE "HORIZONTAL" CAVES

Though the underground karst has been explored intensively for at least 200 years, blank areas still exist. Most of the efforts were directed towards finding presumed underground cave connections between the main poljes, yet no through connection has been explored. It has become clear that the accessible dry caves are just fragments of complex, collapsed and in-filled systems, and the active stream caves - which are relatively unfrequented - are just subaerial sections of basically drowned conduits.

The difference between the caves that have formed as system drains and the vadose caves is very clear. In this paper only the former group is discussed. These caves are referred to as "horizontal caves", though they are generally not horizontal in the true sense of the word. The structure of the 1534 known caves within the Slovenian part of the Ljubljanica catchment area is as follows:

Table 2:

V	Formed exclusively in the unsaturaded (vadose) zone	39.59 %
H	Formed at least partly in the saturated (phreatic or epiphreatic) zone	35.04 %
U	Unsufficient data to recognize the circumstances of formation	6.23 %
C	Transformed to undeterminable shape by collapsing	2.27 %
A	Artificially adapted to indeterminable shape	0.08 %
M	Missing data	16.79 %

Generally, it is believed that the ratio between the bulk frequencies of groups V and H is 2:1, but this figure is based mainly upon cavers' technical experience. Field inspection of many "vertical shafts" reveals that, although steep or really vertical, some of them are phreatic loop channels, and it is possible that if all the caves were re-examined the ratio might change in favour of group H. This paper is intentionally concerned with sub-set H and, unless stated otherwise, all the following considerations deal exclusively with this group.

Detailed study of these caves according to their (penetrable) dimensions revealed that four main classes exist. The least important is the group consisting of caves shorter and shallower than 10m. Because they were registered only exceptionally, their number is highly underestimated, and therefore they are omitted from further consideration.

Among the rest, the greatest frequency is provided by a group that appears to consist predominantly of fragments of longer caves or systems within several tiers. If this is so, an asymptotic approach to the maximum depth of about 300m, as predicted by S.R.H. Worthington (1991), could be expected. However, many such caves are accessible only through vertical vadose shafts, and this dimension becomes blurred, even if the expected dimension is correct.

Another group evidently encompasses "horizontal" caves that are accessible by mere chance, through relatively deep shafts.

In general, caves in the latter two groups are dry. Their walls have been heavily remodelled by collapse or the less extensive spalling of rock slabs, but in many cases it is clear that they were formed under D.C. Ford and R.O. Ewers' (1978) state 2 or 3 conditions. Preserved channels in the bedrock are never horizontal in the proper sense of the word. Phreatic development of the primary passages followed a relatively small number of bedding planes and joints. Most passage cross-sectional areas range between $10m^2$ and $100m^2$. Scallops are generally not preserved or, if preserved, they are barely distinguishable.

Most of these objects are relatively short, one corridor caves and, as a rule, their ends are choked by boulders, loam or, more rarely, by flowstone. Based on the data obtained in extensive excavations during the construction of the motorway between Ljubljana and Postojna, F. Šušteršič (1978 a) calculated that about 95% of the voids in the bedrock had been filled with red soil. More recent detailed mapping of the karst surface confirms this estimate. Thus, the present lengths of these caves are controlled to a great extent by the dynamics of collapse and in-filling/washing of bedrock openings.

The fourth group contains exclusively horizontal active caves, watering or draining some of the poljes. Their present condition matches the Ford and Ewers' (o.c.) states 3 or 4, but it must be stressed that none has really achieved the latter. The general pattern of these caves is a vertical zigzag of phreatic channels, partly incised by canyon-like sections. At some locations, especially in Planinska jama (**748**[2], Fig. 1), the mechanical stability of cave roofs has been surpassed and extensive collapse has occurred to re-establish equilibrium, forming huge, tunnel-like passages. Though some extensions are ended by frontal collapse, the general rule is that even passages some kilometres long end in deep and long "sumps". In the Rak (east) branch of Planinska jama, it is evident that the whole channel is submerged, as branching was discovered several hundred metres from the entrance of the "sump". Shorter caves belonging to the former two groups are common in the close neighbourhood of these caves, indicating that all of them belong to a single tier.

Given the maximum annual discharge and average cross-sectional area of main channels in these caves, and employing S.R.H. Worthington's equation for calculation of the dynamic equilibrium channel dimensions (1991, p.73, Eq. 5.9), it is possible to compute whether the general balance in these systems has been achieved or not. It emerges that "main" channels in the caves of the fourth group, even those that are exceptionally large among the others in the set, have not yet achieved dynamic equilibrium dimensions. On the other hand, if the cross-sectional areas of all the caves in a cluster (tier) are added together, their total area is many times greater than the maximum needed to transmit present drainage. It can be concluded that all these systems were formed in conditions that might differ completely from present ones.

5. SPATIAL DISTRIBUTION OF CAVES

It has already been mentioned that horizontal caves appear in clusters, implying an idea that such concentrations might reflect the positions of abandoned/active flow corridors. In the Ljubljanica catchment area the approximate area of influence of a cave was calculated as 1.38 caves per km^2. However, neglecting caves in the close neighbourhood would introduce great bias due to border effects, and also exclude the possibility of gaining insight into circumstances in areas on the outer side of the watershed. To diminish these effects, a wider area of south-central Slovenia, totalling 5997.27km^2, was taken into consideration, where 2489 caves have been explored and mapped on 4231.39km^2 of karstic rocks. Consideration of this area yields a value of 0.8 caves per km^2 of karstic rocks, and the statistical influence area of a cave becomes 1.25km^2. The absolute values have changed, but the proportions, which are the main interest, remain the same.

Simplified spatial statistics are presented on Fig. 5, which is an adapted cave density map of the Ljubljanica catchment area. Four regions are extracted:

a and b: areas where more than 4 caves of class H and of class V, respectively, appear per influence area (see Table 2), so that relatively stable proportions can be calculated.

- a: count "H" per influence area / count "V" per influence area > 1;
- b: count "H" per influence area / count "V" per influence area ≤ 1;
- c: count "H" per influence area < 4, not regarding the number of caves "V".
- d: no caves of group "H".

Several groupings are evident. In order to facilitate discussion, only those of special interest are numbered, and only the ones ranging along the Notranjsko podolje are discussed. The "H" enriched stripes along the polje borders are considered self-evident, and of no special interest.

No. 1: The "H" enriched zone contains relatively small (less than 20m^2 in cross-section) abandoned phreatic tubes about 300m above the present water-table. F. Šušteršič (1994) interpreted them as the highest tier within the lower Ljubljanica system, between the Planinsko polje and the Ljubljana Marsh, whose upper parts have been removed by denudation.

No. 2: The "H" enriched zone encompasses somewhat larger, highly collapsed dry passages, partly in dolomite, developed within a vertical range of more than 300m.

No. 3 and No. 4: The "H" enriched zones evidently fit together and they are separated only by a "V" enriched stripe. They encompass some of the longest river caves in the area, i.e. Postojnska jama (**747**), Planinska jama (**748**), Tkalca jama (**857**) and Zelške jame (**576**) (Figs. 1, 5). Only a narrow stripe of the "V" enriched zone separates it from the NW corner of the Cerkniško polje, the site of the continuation of the Zelške jame, i.e. Karlovice (**87**, **171**). R. Gospodarič (1976) and F. Šušteršič (1978 b) argued that the present flow direction in part of the system has been reversed with respect to the previous one.

No. 5: The "H" enriched zone is in all aspects similar to No. 2.

No. 10: The "H" enriched zone, containing Križna jama. Though smaller, it is similar to zones Nos. 3 and 4.

No. 11. The "H" enriched zone on the northern slopes of the Snežnik massif. Present conditions give rise exclusively to vadose karstification, if considering accessible caves. Relatively small, predominantly highly reworked passages, are found within a vertical range of nearly 1000m. As neotectonic activity is lifting the core of the Snežnik massif quite rapidly, all the caves might belong to a single tier, subsequently displaced vertically.

The evident similarity of some zones, as well as the sudden end of zone No. 11 just in touch with the Idrija Fault Zone, prompts closer inspection of their relationships. Comparable zones (i.e. Nos. 2 and 5, Nos. 4 and 10) are separated by the Idrija Fault Zone, and the displacements match the dextral strike-slip along the fault. Approximate displacements even match the apparent horizontal displacement along the Idrija Fault. Perhaps this holds true for zone No. 11, too, the counterpart of which might have been moved outside the Ljubljanica catchment area, and even out of Slovenia.

If returned to their, presumably, original positions, the paired zones fuse into single ones, if the narrow stripe of the Idrija Fault Zone is ignored.

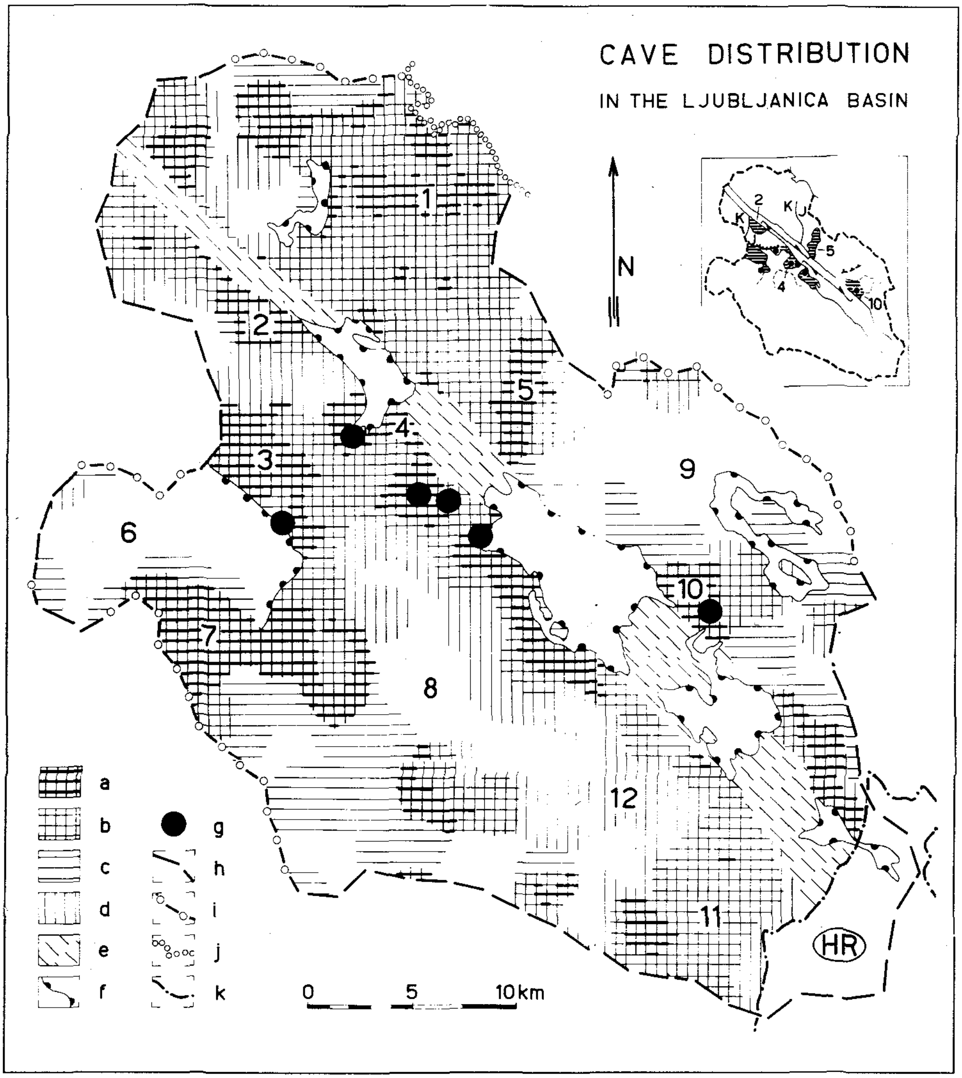

CAVE DISTRIBUTION
IN THE LJUBLJANICA BASIN
N
1
2
3
4
5
6
7
8
9
10
11
12
HR
a
b
c
d
e
f
g
h
i
j
k
0
5
10 km

Fig. 5: Cave distribution in the Ljubljanica basin
a: count H ≥ 4 & count V ≥ 4 : count H / count V > 1
b: count H ≥ 4 & count V ≥ 4 : count H / count V ≤ 1
c: 1 ≤ count H < 4
d: no horizontal caves
e: zone of the Idrija fault
f: borders of the alluvial bottoms of major poljes and lower part of the Pivka basin
g: major river caves
h: approximative border of the karstic Ljubljanica catchment area
I: well determinable border of the karstic Ljubljanica catchment area
j: outflow border of the karstic Ljubljanica catchment area
k: international boundary
Numeration: See text!

Sl. 5: Razporeditev jam v porečju kraške Ljubljanice
a: Število H ≥ 4 & število V ≥ 4 : število H / število V > 1
b: Število H ≥ 4 & število V ≥ 4 : število H / število V ≤ 1
c: 1 ≤ število H < 4
d: Ni vodoravnih (H) jam
e: Cona Idrijskega preloma
f: Robovi večjih kraških polj in Pivške kotline
g: Glavne vodne jame
h: Približno določena razvodnica na kraških ozemljih
I: Jasno opredeljiva razvodnica
j: Odtočni rob kraškega dela porečja Ljubljanice
k: Mednarodna meja
Oštevilčenje: Glej besedilo!

Thus, all the major river caves, i.e. Postojnska (**747**, **472**, Figs. 1, 5), Planinska (**748**), Tkalca (**857**), Zelške (**576**), Karlovice (**87**,**171**) and Križna (**65**, **6286**) form one single string. This "mega" zone is, at the same time, also the richest in shorter, dry caves, i.e. fragments of conduits. The combination of zones Nos. 2 and 5 does not reveal so convincing a result, but the logic is the same. Both reconstructed "corridors" are orientated more or less west-east (however, this was not necessarily the flow direction), as are zones Nos. 1 and 7. Perhaps this indicates that all of them were formed in the same hydrogeological situation, which evidently differed from the present one.

Active stream caves within the string formed by zones 3, 4 and 10 are the largest within the karstic Ljubljanica basin (the caves on the outlet side of the Planinsko polje - Nos. **28**, **259**, **86** - are modest compared to the former ones). They are not situated in the region of the highest discharge between the Planinsko polje and the final Vrhnika springs. Rather, they are located approximately in the middle of the system, and they are arranged approximately at right-angles to the general flow direction. If connections confirmed by dye-test are considered, it becomes clear that, despite many bifurcations, non-accessible connections follow quite direct lines between the inlets and outlets. On the other hand, parts of the main caves string, notably between Cerkniško in Planinsko polje, are situated in quite illogical positions, especially if the geological situation at the inflow part of the Planinsko polje is taken into consideration (F. Šušteršič, 1978 b).

The conclusion that at least part of the transmission system formed under different hydrogeological conditions to those of today becomes the most readily acceptable. What these conditions were remains within the realm of speculation.

Detailed study was done on two locations north and east from the Planinsko polje (F. Šušteršič, 1994, 1996). In the former case a number of horizontal caves are known in the area, and even at first sight they appear to be ranged along the lower and upper contacts of dolomite packages. In Najdena jama (**259**), it is evident that about 3km of its main passages developed along the upper and lower contacts of the stratigraphically higher dolomite package, and along a third bedding plane within the lower Cretaceous limestones, parallel with and about 5m beneath the lower dolomite contact.

The primary tubes are lenticular to ellipsoid but their cross-sections have been altered locally by entrenchment (canyonisation). Apparently the passages are orientated either down/up dip or along the strike, but detailed inspection reveals that this is only an approximation. Passages formed along joints are greatly subordinate and generally they developed at the locations of break-through that provided links from one major bedding plane to another. Phreatic jumps, some more than 50m (downstream) up-wards, are not uncommon. Though some canyonisation has occurred, due to local sources of bedload, most of the system is typically phreatic, with no features suggestive of water-table formation. Later blockfall modification in some passages is evidently related to tectonic injuries of the parent rock.

Among other abandoned dry fragments, Kloka Cave (**3113**, F. Šušteršič, 1994) was studied in detail. Closer inspection of the development revealed three stages of relationship to geological structures:

- initiation along bedding planes;
- penetration into joints;
- expansion by collapsing of crushed zones of faults.

In the location known as Javorjev Grič, an area of about 1km^2 was mapped geologically and geomorphologically at 1:5000 scale. Special care was taken to observe and record all detectable originally underground karst phenomena that now appear at the surface due to denudation. Among the superficial karst phenomena, four types of underground ones were recorded: a/ openings of small phreatic tubes; b/ small collapsed features (<3m) evidently continuing to a choked tube; c/ segments of (sub-)vertical tubes, formed under phreatic conditions; d/ denuded cave passages filled with loam and other sediments. Accessible cave corridors were not found at this location, and true vertical (vadose) shafts were omitted from the previous list.

It appears that around Javorjev Grič an earlier sector of an abandoned tier is exposed. Despite the area being strongly re-worked by denudation, it was possible to observe that most traces of phreatic tubes lie close to either the upper or lower limestone/dolomite contact, which was, again, the most prone to channel formation. The relationship between joints and the channels is less well expressed, however, and more difficult to detect.

6. POLJES AND CAVES

Figs. 4 and 6 show longitudinal sections of the Notranjsko podolje, including the poljes, the caves and the intermediate relief, i.e. the "talwegs" of the previously supposed dry valleys. It becomes clear that the depressions, except for the Planinsko polje and the Loško polje, are relatively shallow. Only those two poljes are without any surficial inflow and it may be that the input of dolomitic gravel must have braked the corrosional (in this case) lowering of the rocky bottoms. The same principle might also be applied to the Babno polje, which has a karstic inflow, but extensive penetration of Pleistocene colluvial material is evident.

On the other hand, caves on the polje borders follow different patterns. Considering the accessibility, and probably origin, too, six basic types may be defined. Interestingly enough, they fit the inflow and outflow caves quite equally, though fundamental differences might have been expected.

CA: Completely inaccessible caves: vertical springs between boulders at the bottoms of funnel-like depressions, springs choked by boulders, "vertical" ponors in the bottoms of poljes. Massive digging has never revealed important cave continuations.

SF: Ascending or descending phreatic, siphon caves, with or without air bubbles.

DS: Short caves, direct extensions from the polje. In the case of springs it appears that they grew backwards, organising inaccessible voids into one main drain. On the outflow side, they appear to disintegrate into smaller tubes, according to Ewers (cf. Ford and Williams, 1989, p.251, Fig. 7.5), and dying out according to Atkinson's (1968) calculations.

PS: Parts of larger systems, open directly to the polje but displaying no direct relation to the polje.

EC: Epiphreatic, tunnel-like, river caves. Their present outlook is due to extensive (especially in the cold periods of the Pleistocene) input of fluvial bed load. Canyonisation is common, though the entrenchment scale is modest

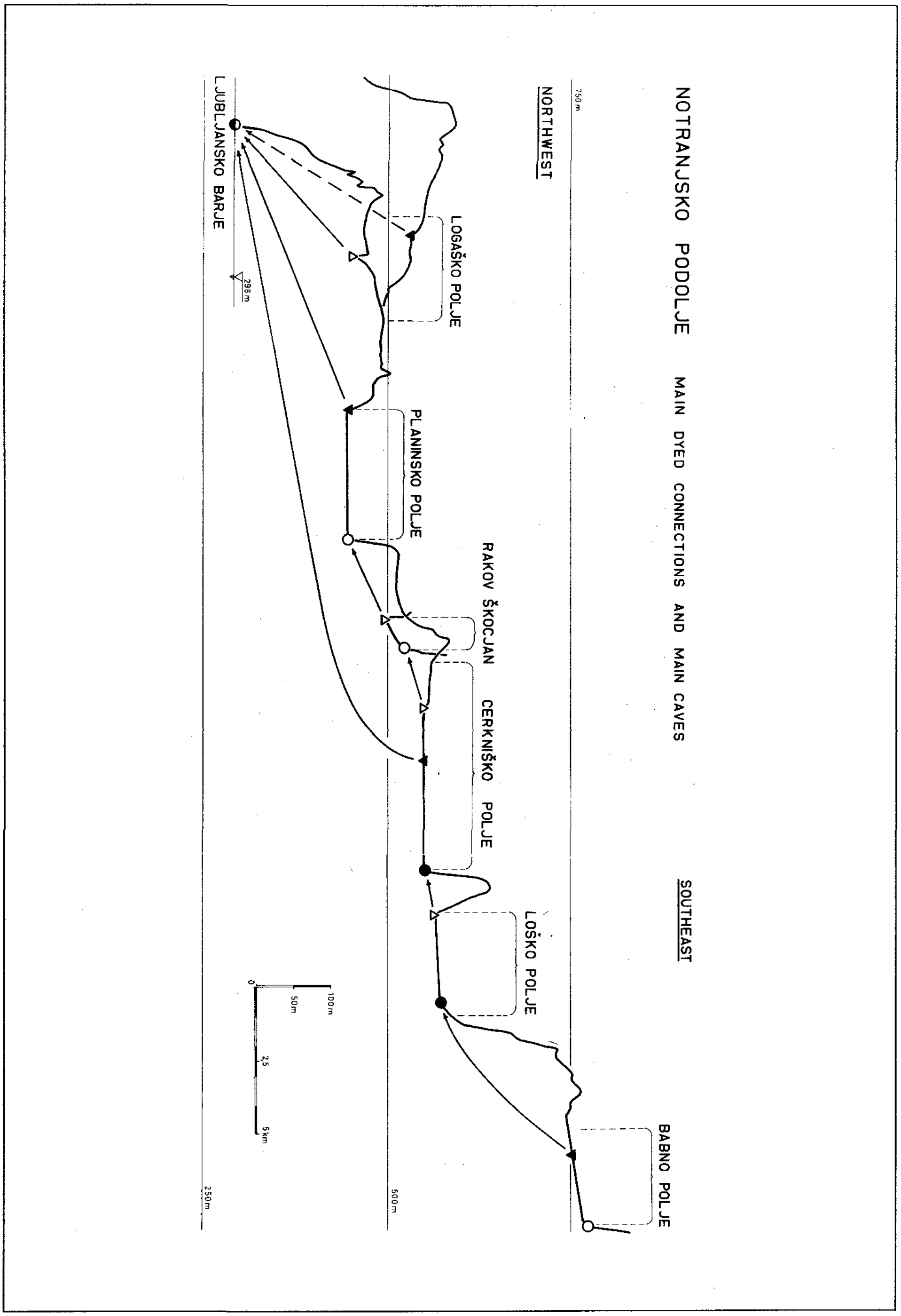

NOTRANJSKO PODOLJE
MAIN DYED CONNECTIONS AND MAIN CAVES
NORTHWEST
SOUTHEAST
750 m
500 m
250 m
LOGAŠKO POLJE
PLANINSKO POLJE
RAKOV ŠKOCJAN
CERKNIŠKO POLJE
LOŠKO POLJE
BABNO POLJE
LJUBLJANSKO BARJE
298 m
0
50m
100m
2,5
5km

Fig. 6. Main dyed connections
Signs identical with Figs. 1 and 4

Sl. 6. Glavne obarvane vodne zveze
Znaki identični s slikama 1 in 4

(generally less than 10m). It is very possible, though difficult to prove, that the passages below the present water-table have been filled with fluvial sediments, and that the present rivers flow close to the top of the tiers. Evidence of "anti-gravitational" erosion is common in these caves, but its true extent is difficult to establish. Anyway, it remains evident that their origin is phreatic, the water-table having been higher than the present polje level.

SH: Swallow holes of surficial water, gathered on the non-karstic surface, and plunging down to the deep water-table directly after crossing the contact. Their appearance resembles many contact caves, or mountain caves, composed of vertical sectors and intermediate meanders.

According to this classification, Table 1 might be continued:

Table 3, poljes within the Ljubljanica basin:

Inflow		Lbl	Name:	Outflow	
Type of cave(s):	Max. len.:			Type of cave(s):	Max. len.:
CA, DS	200 m ?	B	Babno polje	CA, DS	15m
CA		C	Loško polje	CA,PS	722 m
surficial		D	Bloke	CA	
SF, surficial	420 m	E	Cerkniško polje	CA,DS,EC	8760 m
PS,SF	3012 m	L	Rakov Škocjan	PS,CA	2845 m
surficial		F	Rakovško polje	CA	
surficial		A	Pivka basin	EC	19555 m
PS,SF,CA	6156 m	G	Planinsko polje	DS,EC	158 m
surficial		H	Logaško polje	SH	450 m
CA,SF	260 m	J	Ljubljansko Barje	surficial	

Table 3 shows more clearly than detailed discussion that there is no correlation between the polje type, its position within the Ljubljanica basin, and the type and length of the caves there.

However, some other rules become evident. The ES type caves (river caves) are situated where abundant input from the surface, including mechanical load of predominantly Pleistocene origin, appears upstream. This fits quite well with the (disrupted) flow corridor, including the longest caves in the area. Because Križna jama also partly meets this condition, it is not possible to say whether a well developed conduit system was able to transmit larger amounts of mechanical load, or, the opposite, that the load itself served as an abrasive to make the caves larger. In Planinska jama, autochtonous gravel, originating from the present collapse doline of Mala Koleševka (R. Gospodarič, 1976), brought about local entrenchments at least some dozens of metres deep.

Though the direct ponor caves of the Planinsko polje are of DS type (short caves, direct extensions from the polje), some hundreds of metres from the polje flood water appears in Najdena jama (**259**, Fig. 4, 5008+m long, 121m deep), Vranja jama (**88**, 326m long, 90m deep), Logarček (**28**, 2234m long, 83m deep), and some more distant caves such as Gradišnica (**86**, 345m long, 218m deep). There is no direct connection between the polje border and inland caves, as a vertical difference of about 20m between the flood levels on the polje and those within the system remains more or less unchanged regardless of the absolute flood level (F. Šušteršič, 1982). It was concluded (o.c.) that a strong filter must exist between the polje and the inner part of the tier.

Due to the close proximity of the Idrija Fault, the outer part of the system is much modified by collapse and it is impossible to identify the positions of the presumed former main entrances to the system, much less to detect their primary geological structures. Though the inner parts of the tier are clearly recognisable and fully support S.R.H. Worthington's (1991) findings, the sites of initial phreatic descent are completely missing. More importantly, connections between the polje and the karst underground are significantly impeded, and there is no trace of where the entrances to the caves behind might be. This suggests the idea that the cave system is older than the polje, and the present connections are subsequent and unelaborated. Caverns revealed by drilling, at depths down to 100m below the present polje floor, at least do not oppose this conclusion.

The Cerkniško polje lies exactly between the displaced parts of a large stream corridor, and direct connection to the Planinsko polje and its main draining caves is not likely. It may be concluded that the two poljes could be younger than the input/output system, and that the present relationships are coincidental.

7. CONCLUSIONS

Though as yet incomplete, the discussion above permits some conclusions to be drawn:

7.1 The identification criteria for poljes arose primarily as descriptive terms and have related to a popular classification since the very beginning. Later evolution of the polje concept has been bound closely to a single genetic theory, rather than to observed facts and processes.

7.2 The connections between polje formation and Dinaric tectonics must be reconsidered in the light of modern knowledge of tectonics.

7.3 Horizontal caves (or fragments of them) appear in well-expressed clusters, up to several kilometres in length, a few kilometres in width, and some hundreds of metres in depth. This pattern fits the notion of flow corridors within a single tier, as defined by S.R.H. Worthington (o.c.).

7.4 Features of at least two strings of clusters on both sides of the Idrija Fault can be correlated, and their displacements match the apparent displacement along the fault. This means that either the flow corridors were torn apart after formation, or similar structures, highly prone to similar karstification effects, had been established on both sides of a subsequent fault, and later activated.

7.5 The spatial orientation of these clusters only vaguely mirrors the present hydrogeological situation and the polje locations. There is evidence that present water flow makes use - as much as possible - of older voids, inherited from different conditions, and is only partly influenced by the poljes position.

7.6 Caves within a given tier were formed under phreatic conditions and reworked in vadose ones (in the hydrogeological sense). There are no traces of epiphreatic shaping, except in the ponor caves, where fluvial gravel is transported.

7.7 The phreatic passages are concentrated along a small number of bedding planes. In some cases it is evident that their directions do not follow any current structural framework, and that any penetration into joints was secondary. These bedding plane partings play the exact role of inception horizons, as defined by D.J. Lowe (1992). Joints and smaller faults are really important only as master structures to guide the formation of phreatic jumps within a tier, and they play an important role during its adaptation phase. More highly tectonically disrupted zones define areas of significant cavern collapse, or local slab spalling, during the subsequent decay of the cave.

7.8 Except in the direct ponor caves, where water flows on a bed of its own sediment and extensive adaptations by coarse bed load material appeared (I. Gams, 1959), no traces of fluvial organisation of the underground karst exist. Consequently, the input of fluvial bed load, rather than the position within the string of poljes, controls the further development of caves.

7.9 In at least two cases poljes appear to be younger than the presently active draining caves. The cave systems formed according to their own logic, with no influence from the poljes, and the present coincidence has caused only minor adaptations. On the other hand, formation of the poljes followed its own proper logic and the present coexistence and "co-operation" is merely incidental.

7.10 The lack of genetic connection between the poljes and their karst input/output pattern makes the idea of a previous fluvial phase, which should bring about the large mass removal, unneeded. The poljes are just oases of non-karst within the karst (J. Roglić, 1957), in the true sense of the word. Just as the appearance of groundwater at the surface in the desert is unrelated to the arid conditions, the existence of poljes within the karst has nothing to do with the karst itself.

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KRAŠKA POLJA IN JAME NOTRANJSKE

Povzetek

0. PREDGOVOR

E. Silvestru (1995, je zapisal da je kraško polje enkraten primer, kako so strokovni izrazi in njihovo pojmovno ozadje vstopali v krasoslovje. "*Neka... izredno pomembna značilnost je krasoslovju skorajda enkratna: izrazom, ki so kasneje postali temelj krososlovja, je geografija pripisala vsebino že davno prej, kot je krasoslovje postalo samostojna veda, ne da bi na osnovi novih kriterijev kdo kasneje prevetril definicije*" (Prevod F. Š.). Ljudski izraz za (kraško) polje je bil uveden kot strokovni termin, ne da bi kdo natanko premislil kaj pomeni kot tak, seveda pa še manj, kakšna bo odtlej njegova strokovna vsebina.

V svojem prispevku ne želim postavljati nove definicije kraškega polja. Na način, ki bi lahko odškrnil vrata globljemu spoznavanju odnosov med polji in okoliškim krasom, želim soočiti današnje poznavanje poljem bližnjega kraškega podzemlja in sedanje znanje o notranjskih kraških poljih.

1. UVOD

Previdevam, da so slovenskemu bralcu osnovne informacije o krasu Notranjske niso več potrebne in jih zato v povzetku izpuščam (Sl. 1).

Odkrivanje in spoznavanje notranjskih kraških polj se je odvijalo skupaj z vsebinskim razvojem strokovnega termina. Planinsko, Cerkniško in Loško polje (G, E in C kot so označena na sl..1) so bila samoumevna že J. Cvijiću (1893). F. Kossmat (1916) je dodal še Logaško (H) and Rakovško (F) polje, N. Krebs (1924) pa Babno polje. Setavljenka Kossmatove (o.c.) in J. Rusove (1925) karte (Fig. 2) je tedaj povzetek dela prva dobe. Šele A. Šerko (1948) je v svojem sistematičnem pregeldu ovrednotil vse zaprte kotanje, ki bi prišle v poštev in jih obdelal po enotnem kriteriju. Tako se je v naboru znašel tudi Rakov Škocjan, ki pa ga večina avtorjev ne prišteva k kraškim poljem.

F. Kossmat (o.c) je opazil, da se pravkar našteta polja nizajo v skoraj ravni črti vzdolž Idrijskega preloma, znotraj proge znižanega sveta, ki ji danes pravimo Notranjsko podolje (Sl. 2, 3). Navidezne podobnosti s Čepovanskim dolom so ga napeljale k misli, da je nastanek kraških polj v bistvu stopnja v zakrasevanju prvotno površinske reke. Ne glede na to, ali posamezni avtorji to stališče sprejemajo eksplicitno ali ne, in kljub zgodnjim opozorilom, da dejansko stanje ne ustreza šabloni, se je v ozadju razprav o notranjskih kraških poljih ohranilo kot aksiom takorekoč do danes.

2. POREČJE KRAŠKE LJUBLJANICE

Računska ploščina porečja Ljubljanice znaša 1779 km^2. 1100 km^2 od tega je na kraških kamninah, tako da je razvodnica ponekod določena samo približno (Sl. 1). Kraško zaledje vrhniških izvirov meri 1108,78 km^2 (K. Žibrik et al, 1976). Povprečni pretok za leta 1972 do 1975 znaša tam 38,60 m^3 s^{-1}, pri specifičnem odtoku 34,8 l s^{-1} km^{-2}. I. Gams (1966 a) je izmeril povprečen iznos denudacije 65 m^3 km^{-2} a^{-1}.

Kraški kamnini v osnovi sta večinoma mikritni, ponekod oolitni apnenec in dolomit, pretrežno mezozojske starosti. Značilna je njuna velika čistost, saj je netopnega ostanka večinoma manj kot 5%, ponekod celo manj kot 0.1%. Skupna stratigrafska debelina karbonatne skladovnice je okrog 6850m (J. Čar, 1996). Med nekraškimi kamninami se v pomebnejšem obsegu javlja le eocenski fliš.

Za geološko strukturo so značilni številni narivi (V. Placer, 1981; U. Premru, 1982) v smeri od severovzhoda proti jugozahodu, ki so nastali kot posledica kolizije jadranske podplošče z evropskim kontinentom. Postopno spreminjanje smeri potovanja plošč je povzročilo nastanek idrijskega desnega zmika (preloma) (Sl. 5, manjša karta). Terensko kartiranje (J. Čar, 1982; J. Čar and R. Gospodarič, 1984; I. Mlakar, 1969; F. Šušteršič, 1989) je pokazalo, da idrijski prelom ni popolnoma enovit in prem. Gre za več vzporednih prelomev, med katerimi je tektonsko močno poškodovana cona in znotraj katere se posamezni bloki premikajo precej neodvisno.

3. KRAŠKA POLJA NOTRANJSKEGA PODOLJA

V vzdolžnem prerezu (Fig. 4) se kaže Notranjsko podolje kot niz kotanj ob idrijskem prelomu (Sl. 2, 3).

Kljub stoletnim prizadevanjem, da bi pojasnili nastanek kraških polj, pravega odgovora na to vprašanje še nimamo. R. Gospodarič in P. Habič (1979, p.25) sta podala izčrpen pregled tolmačenj nastanka Cerkniškega polja. Misli gredo od čistega tektonskega spusta prek fluvialne erozije do korozije. Četudi je njuno delo doslej najbolj izčrpno, sta se končnemu odgovoru ognila in navajata le dejstva, ki vsako po svoje podpirajo katero izmed prej navedenih

Tabela 1, polja, ki jih prečka glavni tok (Sl. 1, 3):

Oznaka	Ime	Nadm. v.	Klasifikacija	
			Šerko (1948)	Gams (1994)
B	Babno polje	750 m	uvala	border polje
C	Loško polje	575 m	periodično poplav-ljeno polje	prelivno polje
E	Cerkniško polje	550 m	priodično jezero	robno polje
	Rakov Škocjan	500 m	periodično poplav-ljena uvala	/
G	Planinsko polje	450 m	periodično poplav-ljeno polje	prelivno polje

Tabela 1, Dodatek (sosednja polja, Sl. 3):

Oznaka	Ime	Nadm. v.	Klasifikacija Gams (1994)	Opombe
F	Rakovško polje	520 m	robno polje	znotraj cone, glavni tok gre mimo
H	Logaško polje	480 m	robno polje	zunaj cone, glavni tok gre mimo
A	Pivška kotlina		periferno polje	flišno ozemlje, izven cone
D	Bloke		robno polje	izven cone
K	Loški potok		/	izven današnjega porečja Ljubljanice
M	Zadlog		/	izven današnjega porečja Ljubljanice

opcij. To lahko pomeni, da grešimo že v samem pristopu, ali pa da zaključkov še ne znamo potegniti. Vsekakor pa moremo, kot opozorilo za vnaprej, izpostaviti nekaj šibkih točk v dosedanjem znanju.

3.1. Od prvih časov zanstvenega pristopa velja kras, in z njim polja, za nekaj prehodnega. Poglavitne kraške oblike naj bi bile na svoj način preoblikovane podedovane fluvialne. Kossmatovi (o.c.) nasledniki niso preverili njegovega, na analogiji temelječega sklepanja in ugotavljali, ali pričakovano fluvialno logiko lahko odkrijejo kje na terenu, ampak se odpravili na lov za "suhimi dolinami" (N. Krebs, 1924; J. Rus, 1925; A. Melik, 1928; R. Gospodarič in Habič, 1979), kjerkoli se je v tlorisu pokazala vzdolžna reliefna globel. Prodor klimatske geomorfologije je doprinesel le nove možne mehanizme za transformacijo samih kotanj. Zato so polja morala ostati tak ali drugačen produkt kraške piraterije.

3.2. Od začetka velja za samoumevno, da je današnja funkcionalna povezava kraških polj in jam tudi genetska, in misel, da bi bilo sovpadanje lahko naključno, se še ni pojavila. Velik delež takšnjega razmišljanja gre na račun "samoumevnosti", češ da so jame med polji nastale v epifreatičnih pogojih, da so takorekoč rečne struge, ki se jim bregovi stikajo v strop, ob enem pa neogibno navezane na "terase" ki naj bi se ohranile na površju. V slednje je sicer posredno podvomil že I. Gams (1963), vendar misli ni razvijal dalje.

3.3. Nadalnji nedokazani, a vedno prikrito navzoči "aksiom" pravi, da so procesi, ki oblikujejo pobočja okrog kraških polj, identični procesom, ki so izoblikovali samo kotanjo. Tako ni nepričakovano, da se se je preučevanje nastanka kraških polj izrodilo v preučevanje njihovega kvartarnega preoblikovanja (A. Melik, 1955; I. Gams, 1965; R. Gospodarič in P. Habič, 1979). Raziskovalci so spregledali dve dejstvi, samoumevni s stališča Modela čistega krasa (F. Šušteršič, 1986 a, 1996): a) delež pobočij, ki bi jih lahko imeli specifična za polja, je zanemarljiv v primeri z deležem tistih, ki se pojavljajo kjerkoli v okolici, b) položaj "v zaprti globeli"za kras ni nekaj izjemnega, in kakršnakoli zaprta globel, ki jo je izdelala endodinamika, ostane v krasu nezapolnjena. S stališča polij je tedaj pomebno edino vprašanje, zakaj postane v stiku z nihajočo podtalnico dno tako ravno.

3.4. Zgodnje teorije o nastanku polj, ki so jemale tektoniko kot bistveno, so spodrsnile zato, ker se zamišljena struktura ni ujemala s stanjem na terenu (R. Gospodarič in P. Habič, 1979, p.25). Novejše geološko kartiranje (Glej navedke zgoraj!) je postreglo s popolnejšimi podatki, ki odpirajo nove možnosti tolmačenja. V tej zvezi je potrebno poudariti, da se dosedanji raziskovalci nikoli niso povsem otresli logike sicer že davno ovržene kontrakcijske terorije, ki navpične premike izvaja iz radialne tektonike. Spoznanja o tektoniki plošč so pokazala, da zaprte globeli natajajo tudi pri tangencialnih premikih, kar je uspešno uporabil (M. Vrabec, 1994).

3.5. Prevelika pozornost se je usmerjala v majhno število "pomebnih" jam, neposredno povezanih z današnjim navodnjavanjem/odmakanjem polj. Odlomki obsežnih sistemov v neporedni soseščini so ostajali v senci, dlje od polj pa se sploh nihče ni obregnil vanje. Zato se niti ni moglo pokazati, ali se jamski sistemi morda ravnajo po svoji lastni logiki, ki se sploh ne ozira na polja in da je skupno pojavljanje zgolj slučajno.

3.6. J. Rus (1925) je opazil, da ležijo notranjska kraška polja na kontaktih apnenca in dolomita. Mehanizem za nastanek polj, ki ga je izvedel iz te ugotovitve, se nam kaže danes naiven, vendar je osnovno misel nepričakovano podprl H. Lehmann (1959). I. Gams (1973 b) je dopolnil Lehmannovo klasifikacijo z lastnimi opažanji ter jo utemeljil tudi teoretsko. Tako se je, kljub temu da je popolnoma funkcionalna, do danes popolnoma uveljavila in se takorekoč vsaka razprava o nastanku kraških polj razbije ob stavku, da *polja pač nastajajo na kontaktih*. Koincidence se ne da zanikati. Vendar je potrebno dodati, da polja na popolnoma enakih kontaktih v bližnji soseščini niso nastala, niti ne kaže, da kdaj bodo.

4. PREGLED "VODORAVNIH" JAM

Pred nadalnjo obravnavo sem 1534 registriranih jam v porečju Ljubljanice razdelil v naslednje skupine:

Tabela 2:

V	Nastale izključno v neprežeti coni ("navpične jame")	39.59 %
H	Nastale vsaj delno v prežeti coni ("vodoravne jame")	35.04 %
U	Razpoložljivi podatki ne zadoščajo, da bi opredelili pogoje nastanka	6.23 %
C	Podorno popolnoma spremenjene	2.27 %
A	Umetno popolnoma spremenjene	0.08 %
M	Podatki so pomanjkljivi	16.79 %

Kljub splošnemu prepričanju, da je "navpičnih jam" (skupina V) vsaj dvakrat več kot "vodoravnih" (skupina H), je število skoraj enako, zdi pa se, da bi pri se pri boljših podatki lahko celo zasukalo v prid "vodoravnih". V nadaljevanju članka nas zanimajo samo slednje in če ne bo posebej naglašeno, tudi sama besedica "jama" pomeni predstvanika skupine "H".

Podroben študij je pokazal, da jih lahko glede na dolžino in globino razdelimo v štiri skupine.

Posebej izstopa četrta skupina, kjer so zbrane izključno vodne jame, ki napajajo / odvodnjavajo kraška polja. Njihovo današnje stanje odgovarja tretjemu ali četrtemu stanju D.C. Fordovega in R.O. Ewersovega (1978) modela, vendar slednje ni doseženo nikjer. Splošni vzdolžni vzorec teh jam je navpično cikacakanje freatičnih kanalov, v katere se krajevno zajedajo plitva abrazijska korita. Le na nekaterih mestih je bilo vrezovanje tako obilno (Planinska jama, kat. št. **748**, Sl. 1), da je bilo mehansko ravnotežje sten porušeno in je prišlo do podiranja. Potapljanje v "sifone" je pokazalo, da večinoma ne gre za kratka, poplavljena kolena, temveč da so zaliti veliki deli svežnja, tudi če sami kanali ne segajo prav globoko pod gladino podatlnice.

Izračunavanje paragenetskega praga s pomočjo S.R.H. Worthingtonove enačbe (1991, 73, En. 5.9), na osnovi znanih pretokov in prerezov je pokazalo, da današnji prevodniki ne še niso dosegli kritičnih izmer, da pa jih skupni prerezi v vsem svežnju temeljito presegajo. To kaže, da so jamski sistemi nastajali v pogojih ki so se od današnjih temeljito razlikovali.

5. PROSTORSKA RAZMESTITEV JAM

Na osnovi prej navedenih številk lahko izračunamo, da zanaša v porečju Ljubljanice gostota jam 1.38 na km^2. Ker v tem primeru ne upoštevamo jam onstran razvodnice, je tak račun v njeni bližini lahko zelo pristranski. Da bi se temu izognil, sem upošteval 2489 jam južne Slovenije, na 4231.39km^2 ploščine kraških kamnin. Gostota se s tem zmanjša na 0.8 jame na km^2 - statistično vplivno območje jame tedaj pokrije 1,25 km^2 - kar pa razmerij, ki nas prvenstveno zanimajo, ne spremeni. Poenostavljeno prostorsko statistiko prikazuje slika 5. Posamezno šrafirana polja pomenijo:

a in b: območja, kje so znotraj statističnega vplivnega območja najmanj po štiri jame skupine "H" in skupine "V" (glej Tabelo 2!),;

a: število "H" / število "V" > 1;
b: število "H" / število "V" ≤ 1;

c: število "H" < 4, ne glede na število jam skupine "V".

d: ni jam skupine "H".

Posamezna nakopičenja so povsem očitna in da bi olajšali razpravo, so skupine oštevičene. Posebnega pomena so:

Št. 1: Ozemlje Ljubljanskega vrha, ki sem ga že prej spoznal (F. Šušteršič, 1994) kot najvišji, opuščeni sveženj v neposrednem zaledju vrhniških izvirov.

Št. 2: Nakopičenje v območju Grčarevca, kjer so sicer manjši jamski prostori, večinoma zelo poškodovani zaradi podiranja. Navpični razpon svežnja presega 300 m.

Št. 3 in št. 4: Nakopičenji, ki očitno sodita skupaj. Vanju spadajo nekatere najdaljše vodne jame v porečju Ljubljanice: Postojnska jama (**747**), Planinska jama (**748**), Tkalca jama (**857**) in Zelške jame (**576**) (Sl. 1, 5). Le ozek presledek loči to kopico od območja tik ob severozahodnem kotu Cerkniškega polja, kjer se nahajajo Karlovice (**87**, **171**), ki so naravno nadaljevanje Zelških jam. R. Gospodarič (1976) in F. Šušteršič (1978 b) sva mnenja, da je vsaj v delu tega sistema današnja smer vode zasukana glede na predhodno.

Št. 5: Nakopičenje, ki v vseh pogledih spominja na št. 2.

Št. 10: Nakopičenje, ki zajema tudi obe Križni jami. Čeprav manjše, spominja na coni št. 3 in 4.

No. 11. Nakopičenje na severovzhodnem obrobju Snežniškega masiva. Dandanes tu vlada neprežeta cona, kjer lahko nastajajo edino "navpične" jame. "Vodoravne" jame so sorazmerno majhne in drugotno precej spremenjene. Pojavljajo se v višinskem razponu prek 1000 m, kar bi lahko bilo posledica neotektonske aktivnosti na območju Snežnika.

Primerljiva nakopičenja, oštevičena s 2 in 5, pa 4 in 10) deli idrijski prelom. Medsebojhni razmiki se ne krijejo le s smerjo, ampak tudi z iznosom tlorisnega premika. Verjetno velja isto tudi za cono št. 11, katere nadaljevanje bi tedaj ležalo že na Hrvaškem.

Če pomaknemo podobna nakopičenja v njihovo predvideno prvotno lego, tako da izločimo posledice idrijskega zmika, se območja največjih jem zlijejo v en sam niz. Ta "mega" koridor je tudi najbogatejši z krajšimi jamami, to je odlomki sistemov. Verjetno sta oba niza nastala istočasno, v pogojih, ki so se povsem razlikovali od današnjih. Če je temu res tako, potem sta oba niza sterejša od idrijskega preloma.

6. POLJA IN JAME

Danes aktivne jame, ki so v neposrednem stiku s poplavnimi ravnicami polj, lahko razdelime v naslednje skupine:

CA: Popolnoma nedostopne jame: navpični izviri med bloki na dnu lijakastih kotanj; navpični ponori v dnih kraških polij.

SF: Vzpenjajoče se zalite freatične jame z ali brez zračnih mehurjev.

DS: Kratke jame, neposredni podaljški tokov na polju. V primeru izvirov kaže, da se podaljšujejo vzvodno; ponori se po Ewersovi shemi (cf. Ford in Williams, 1989, 251, 7.5) razcepljajo v manjše cevi, katerih prerez upada skladno z Atkinsonovimi (1968) računi.

PS: Deli večjih sistemov, ki jih kraška kotanja gladko seka, ne da bi se kazalo medsebojno učinkovanje s poljem.

EC: Epifreatični, tunelski rovi, preoblikovani kot posledica transporta velikih količin pleistocenskega grušča (I. Gams, 1959). Ne glede na to je freatična zasnova mnogokrat še razvidna.

SH: Požiralniki površinskih voda, zbranih na nekrasu. Voda se skuša po najkrajši poti spustiti do gladine podtalnice, zato so zančilni meandri in skoki, kot jih sicer najdemo v visokogorskih jamah.

Odnose s polji prikažemo tabelarično:

Tabela 3, kraška polja v porečju Ljubljanice:

Vtok			Ime	Odtok	
Tip jam(e)	Max. dlž.			Tip jam(e):	Max. dlž.
CA, DS	200 m ?	B	Babno polje	CA, DS	15m
CA		C	Loško polje	CA,PS	722 m
površinski		D	Bloke	CA	
SF, površinski	420 m	E	Cerkniško polje	CA,DS,EC	8760 m
PS,SF	3012 m	L	Rakov Škocjan	PS,CA	2845 m
površinski		F	Rakovško polje	CA	
površinski		A	Pivška kotlina	EC	19555 m
PS,SF,CA	6156 m	G	Planinsko polje	DS,EC	158 m
površinski		H	Logaško polje	SH	450 m
CA,SF	260 m	J	Ljubljansko Barje	površinski	

Iz Tabele 3 je popolnoma razvidno, da ni nikakršne zveze med položajem polja znotraj porečja Ljubljanice in tipom pritočnih/odtočnih jam.

7. ZAKLJUČKI

7.1 Kriteriji za definicijo polij so nastali kot opisni pojmi. Kasnejši razvoj se je preveč držal ene same genetske teorije in se premalo oziral na drobna terenska opazovanja.

7.2 Zvezo med nastankom polj in tektoniko Dinaridov je potrebno ponovno proučiti s stališča sodobnega pojmovanja tektonike.

7.3 Vodoravne jame, oz. njihovi odlomki, so zbrane v jasno izraženih kopicah, ki so dolge več kilometrov, nekaj kilometrov široke in dosegajo navpični razpon več sto metrov. Ta vzorec se popolnoma sklada z S.R.H. Worthingtonovo (o.c.) zamislijo svežnja.

7.4 Medsebojno primerljiva sta vsaj po dva para nakopičenj jam na obeh straneh idrijskega preloma in njihov razmik se sklada z tlorisnim premikom ob idrijskem prelomu. To pomeni ali da sta dva pretočna koridorja v resnici pretrgana, ali pa da so na obeh straneh preloma že pred premikom nastale strukture, zelo primerne za kasnejši razvoj kanalov, in bile po premiku aktivirane.

7.5 Prostorska orientacija teh nakopičenj se le slabo sklada s sedanjimi hidrogeološkimi razmerami. Zdi se, da današnji tokovi le uporabljajo - kolikor se pač da - starejše kanale.

7.6 Jame znotraj posameznega svežnja so nastale v freatičnih pogojih prežete cone, nato pa bile preoblikovane v neprežeti coni. Sledov preoblikovanja v epifreatičnih pogojih ni, z edinimi izjemami jam, kamor voda vnaša (je vnašala) večje količine proda.

7.7 Freatični rovi so nastali vzdolž manjšega števila lezik. V nekaterih primerih je očitno, da se ne ravnajo po nobenem od tamkajšnjih strukturnih vzorcev, kar pomeni, da so bili vsaj zasnovani pred orogenom. Nosilne lezike imajo v vsem vlogo začetnih horizontov, kot jih je definiral D. J. Lowe (1992). Razpoke in manjši prelomi so mesta, kjer so nastali freatični skoki med začetnimi horizonti znotraj sistema.

7.8 Razen v primerih neposredno ponornih jam, kjer teče voda po lastnem nanosu in je prišlo do obsežnejše mehanske erozije (I. Gams, 1959), nikjer ni sledov fluvialnih vplivov v podzemlje. Oblikovanost ponornih jam torej odreja značaj plavja, ne pa položaj polja v nizu.

7.9 Vsaj v primeru dveh polj kaže, da sta mlajši od sosednjih jamskih sitemov. Jame se oblikujejo po lastni logiki, ne glede na soseščino polj in danjašnja povezava povzroča le manjša prilagajanja. Po drugi plati pa ima tudi nastajanje in oblikovanje polj lastno logiko, sedanja povezava in sodelovanje pa sta predvsem posledica slučaja.

7.10 Ker ni dokazov za genetsko povezavo jam in polj, odpade tudi potreba po "predkraški" fazi. Polja so slučajne "oaze nekrasa v krasu", kar je povedal že J. Roglić (1957).

SOME MINERALS FROM NAJDENA JAMA

NEKAJ MINERALOV IZ NAJDENE JAME

FRANCE ŠUŠTERŠIČ & MIHA MIŠIČ

Izvleček UDK 551.442:553(497.4)

France Šušteršič & Miha Mišič: Nekaj mineralov iz Najdene jame

S pomočjo rentgenske metode sva določila mineralno sestavo osmih vzorcev iz Najdene jame. Poleg kalcita, dolomita, kremena, goethita in splošno razširjenih glinenih mineralov se med karbonati pojavljajo še hidromagnezit, siderit, lansfordit in ankerit, med manganovimi minerali pa todorokit. Kot posebnost sta posamič navzoča še aragonit in variscit.

Ključne besede: Najdena jama, jamski sedimenti, minerali

Abstract UDC 551.442:553(497.4)

France Šušteršič & Miha Mišič: Some minerals from Najdena jama

Mineral composition of eight samples from Najdena jama were determined by X-ray diffraction. Beside calcite, dolomite, quartz and wide-spread clay minerals, among carbonates appear also hydromagnesite, siderite, lansfordite and ankerite, and manganese hydroxide todorokite. As somehow exotic there appears also aragonite in variscite.

Key words: Najdena jama, cave sediments, minerals

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INTRODUCTION

Najdena jama is the most important cave to the north of the Planinsko polje in Slovenia. The main stream of the Planinsko polje, the river Unica, gathers karst waters from higher level karst poljes, as well as collecting allogenic waters that originate on the flysch of the Postojna region and run into the polje through the Postojnska and Planinska jama caves. Najdena jama lies very close to the Pod Stenami group of ponors, which operate only during times of flood. Though some of these ponors are true caves they are choked after a short distance and no directly penetrable connection with the cave exists. This is emphasised during flood events, when water levels in the polje and in the cave remain some 15m vertically apart. Consequently, an effective filter between the polje and the cave must exist. Within the cave the water level itself varies by nearly 30m and during times of flood only a fraction of the normally open passages remain accessible.

There are abundant clay sediments and some relatively poor flowstone in the cave, as well as other mineral deposits. Some of these minerals are amorphous, dark brown to black aggregates, which have not been analysed and have traditionally been interpreted as psilomelane. Others take the form of a delicate white efflorescence, popularly named "cave carbide" by cavers, which has been assumed to be fibrous calcite. In order to check the validity of these conceptions, samples of some deposits were collected and their mineral composition determined by X- ray diffraction.

MINERAL COMPOSITION OF THE SAMPLES

Sample Point: **1**
Location: **Piparski rov 1**
Grid coordinates[1] Y: 5441 762, X: 5081 400, Z: 453

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[1] *The cave survey is based on a high accuracy theodolite polygon, carried out by the Institute for Karst Research, Postojna, Slovenia, completed before the end of the nineteen-seventies (Šušteršič, 1982, 153). The stations of the main polygon are determined to 1cm accuracy, so that the 1m grid references of secondary points are not in doubt.*

Description: The sharp edges of many fallen rocks display a white efflorescence ("cave carbide"); exceptionally these pass into white films that cover the smooth sides of some smaller blocks.

The rock: Like the source bedrock, the fallen blocks are of Lower Cretaceous "dolomite" (see sample point 2), which forms a c. 30m-thick package between the underlying bituminous Lower Cretaceous limestone and very pure Upper Cretaceous limestone above. The dolomite is white to grey and disintegrates on weathering to a coarse dolomite silt.

General situation: The passage cross-section is about 100m^2 and the walls and ceiling are not primary dissolution features, but have been modified by collapse. It is part of a half kilometre section of the cave that is never flooded. No significant draught has ever been felt, yet it is evident that there is always a slow air movement. The mineralization does not appear where the rocks are exposed to dripping water.

Mineral composition[/2]:

Hydromagnesite	$Mg5\ [OH \mid (CO_3)_2]\ .\ 3H_2O$
Siderite	$FeCO_3$
Lansfordite	$MgCO_3\ .\ 5H_2O$
Goethite	$FeOOH$
Ankerite	$CaFe\ [CO_3]_2$

Sample Point: **2**
Location: **Piparski rov 1**
Grid coordinates[/1] Y: 5441 794, X: 5081 458, Z: 451

Description: The sample is bedrock from the same site as Sample 3. See also Sample point 1.

The rock: Coarse-grained late diagenetic calcitic dolomite (Pettijohn, 1975, 360, Fig. 10-43). Even before X-ray diffraction results were available the rock was considered to be "dolomite" by the surveyors, and this term is retained in this text. The percentage composition values are on the limit between dolomite and calcitic dolomite and hence it is acceptable to keep the old terminology.

General situation: The sample was fresh bedrock, from which sample 3 was also collected.

/2 *The percentage values were not determined (except for one sample). The minerals are listed according to apparent proportions in the sample, beginning with the most abundant.*

Mineral composition[/2]:

Dolomite	$CaMg [CO_3]_2$ (89 %)
Calcite	$CaCO_3$ (11 %)

Sample Point: **3**
Location: **Piparski rov 1**
Grid coordinates[/1] Y: 5441 794, X: 5081 458, Z: 451

Description: See sample points 1 and 2. Where the passage walls are permanently wet due to percolation water, and not freshly broken, there are deposits of grey silt. If the generally modest water flow is locally stronger, it can move the particles, arranging the silt into formations, appearing similar to the flowstone. At some points the silt is washed away and redeposited in small pools.

The rock: As described at sample point 2.

General situation: The sampled (silt) material is disintegrated bedrock.

Mineral composition:

Dolomite	$CaMg [CO_3]_2$
Calcite	$CaCO_3$

Sample Point: **4**
Location: **Platke**
Grid coordinates[/1] Y: 5441 829, X: 5081 477, Z: 442

Description: Dark brown to black crusts covering ledges on the wall below an aven appear to have originated from a single point or a very limited location, and then spilt like a very viscous liquid. The deposits are some centimetres thick, with an earthy consistency and a brittle rather than plastic texture, probably due to secondary cementation. Traditionally the material was dismissed as either psilomelane, or bat excrement, even though the location is wet, and not close to the cave entrance.

The rock: Bituminous Lower Cretaceous limestone. The beds are about 30cm thick, and many are rich in fossil shells, possibly *Requienia ammonia sp.* The base of the dolomite package (see sample points 1 to 3) is some 10m higher.

General situation: A chamber about 8m wide and 10m high has been enlarged from an oblique phreatic tube of modest dimensions by dripping water originating from two avens. The mineral deposit appears much younger than the passage. At the top of the chamber is a squeeze with a very strong draught, but the draught is not felt close to the deposit. Due to the permanent dripping from the avens the air is generally saturated with water, and passage floor becomes a lake during normal floods, while the sample location remains without the reach of normal floods.

Mineral composition:

Quartz	SiO_2
Illite[/3]	$(K,H_2O)Al_2\,[(H_2O,OH)_2\,|AlSi_3O_{10}]$
and/or Paragonite[/3]	$NaAl_2\,[(OH,F)_2\,|AlSi_3O_{10}]$
Goethite	FeOOH
Todorokite	$(H_2O,..)_{\leq 2}\,(Mn,..)_{\leq 8}\,(O,OH)_{16}$

Sample Point: **5**
Location: **Velika Štirna**
Grid coordinates[/1]: Y: 5441 808, X: 5081 442, Z: 420

Description: Dark brown to black stained coarse flowstone on the wall and floor below a small aven with a permanent water drip.

The rock: Bituminous Lower Cretaceous limestone. The beds are about 30cm thick, and some are rich in fossil shells, possibly *Requienia ammonia sp.* The base of the dolomite package (see sample points 1 to 3) is some 20m higher.

General situation: The sample site is on a ledge in the wall of a large chamber some tens of metres high and wide. It lies within the reach of normal flooods and all the neighbourhood is covered by thick layers of loam, but the actual site is completely washed by a small, permanent and relatively intense water drip. The chemical composition of the water has not yet been studied, but it appears that water is neither calcite precipitating nor aggressive at present. During normal floods, i.e. for several months each year, the site is completely submerged.

Mineral composition:

Quartz	SiO_2
Calcite	$CaCO_3$
Illite	$(K,H_2O)Al_2\,[(H_2O,OH)_2\,|\,AlSi_3O_{10}]$
Dolomite	$CaMg\,[CO_3]_2$

Sample point: **6**
Location: **Medvedji rov (Cave Bear's Passage), roof**
Grid coordinates[/1] Y: 5441 876, X: 5081 378, Z: 458

Description: Dark brown to black loamy infill between coarse gravel choking the passage continuation. Locally the sediment appears to be laminated.

/3 *It was not possible to determine definitively whether the mineral in question is illite or paragonite.*

The rock: Bituminous Lower Cretaceous limestone. The beds are about 30cm thick and many of them are rich in fossil shells, possibly *Requienia ammonia sp.* The base of the dolomite package (see sample points 1 to 3) is some 5m higher.

General situation: The location is at the blind end of a 1m-wide and high passage, choked by coarse limestone cobbles. The passage appears to be a secondary development, parallel to the main passage of Vranja and Najdena jama. In the floor, very close to the sample point, are bones of the cave bear, *Ursus spelaeus sp.* Conditions in the passage appear to have remained effectively unchanged since the bear's body was washed in by flood water. Currently the passage is about 15m above flood level and is never flooded. Because of the blind end to the passage the air is static.

Mineral composition:

Quartz	SiO_2
Illite	$(K,H_2O)Al_2\ [(H_2O,OH)_2\ \vert AlSi_3O_{10}]$
Goethite	FeOOH
Calcite	$CaCO_3$

Sample point: **7**
Location: **Medvedji rov (Cave Bear's Passage), floor**
Grid coordinates/[1] Y: 5441 876, X: 5081 378, Z: 457

Description: Dark brown to black loamy to sandy infill between the coarse gravel choking the continuation of the passage. At some places the sediment appears to be laminated.

The rock: As described at sample point 6.

General situation: See sample point 6. The sample was taken on the floor, about one metre below sample 6, close to the bones of the cave bear, which have partly disintegrated into a silty mass.

Mineral composition:

Quartz	SiO_2
Calcite	$CaCO_3$
Illite	$(K,H_2O)Al_2\ [(H_2O,OH)_2\ \vert AlSi_3O_{10}]$
Variscite	$Al\ [PO_4]\ .\ 2H_2O$
Todorokite ?	$(H_2O,..)_{\leq 2}\ (Mn,..)_{\leq 8}\ (O,OH)_{16}$

Sample point: **8**
Location: **Medvedji rov (Cave Bear's Passage), floor**
Grid coordinates/[1] Y: 5441 876, X: 5081 378, Z: 457

Description: White needles in "sea-urchin-like" structures on dark brown to black stained coarse cobbles, lying within the material described at sample point 6.

The rock: As described at sample point 6.

General situation: See sample points 6 and 7. When discovered (November 1964), parts of the wall and several cobbles on the floor were covered with clusters of white, 0.5 - 1 cm - long needles. By analogy with deposits in neigbouring caves, the explorers assumed that the needles were aragonite, without carrying out tests. During the following years the material progressively disappeared. The final surviving example was taken by the authors in summer, 1972, and is part of the mineral collection in the Department of Geology, University of Ljubljana.

Mineral composition:

Aragonite	$CaCO_3$

DISCUSSION

This paper is a presentation of the results of analyses of well-known mineral occurences, rather than a study of cave mineralogy. X-ray diffraction analysis confirmed only one "naked-eye" determination, that of aragonite. If psilomelane ($(Ba,Mn^{2+}...)_3\ (O,OH)_6Mn_8O_{16}$) is accepted as a general term for mixed manganese hydroxides, then two of the guessed determinations of the dark, amorphous masses were also reasonably close. However, two of the guesses missed completely, and the nature of the white amorphous mineral was also misdetermined. Thus, one broad conclusion is that the use of analogy led to "geofantasy". However, other, more serious, conclusions can be drawn.

The mineral composition of Sample 1 is dominated by hydrated magnesium carbonates (hydromagnesite and lansfordite). It is possible that they are derived from the dolomite that forms a significant proportion of the bedrock, and the hydrated magnesium carbonates crystallized probably due to evaporation. It must be noted that "cave carbide" is not common in Najdena and neighbouring caves, but where present it occupies positions affected by slight air movement.

The iron minerals detected (goethite, siderite and ankerite) might be of similar origin, as some ankerite is normal in dolomitic rocks. In this case goethite and siderite might originate from disintegrated ankerite. However, it must be noted that analysis of the bedrock (Sample 2) did not reveal ankerite. If its presence was not simply obscured by the other two carbonates, it is possible that iron was washed from the red soil on the surface and brought into localised parts of the cave by percolation water.

The complex hydrated oxide of manganese (todorokite) was found at two locations in the cave. The accumulations are relatively young, though not recent or sub-recent. It is evident that at the time of deposition the todorokite was part of a viscous, loamy fluid that moved down the walls and/or penetrated between the cobbles. In both situations it was mixed with quartz and illite, both of which are characteristic of recent (and some older) Unica river sediments. It appears that some time after the upper parts of the cave tier had been abandoned, manganese was added to clayey material that was being washed down from older cave fillings. It must be added that manganese is not present in the cave loams in general, but has been transported downwards by percolating water recently at some localities.

In the other dark sediment in the Cave Bear's Passage, goethite appears to be responsible for the staining, while in the Velika Štirna, where the sample point is exposed to regular floods, the staining might be due to organic matter.

That variscite might appear close to the bones of the cave bear is self-evident, though it is fair to ask why no other phosphates are present. It may be simply because the sample was not taken from the mass that obviously includes weathered bones, but from about 30 cm away. Perhaps variscite is just the most mobile among a number of possible bone-decay minerals.

The common occurrence of illite and quartz has been mentioned as characteristic for sediments derived from flysch. In Najdena jama these minerals appear in samples that either originate in old Unica river sediments, or are exposed to present floods. However, similar sediment is also found on the surface, evidently released from denuded old caves, and its appearance is not very informative. On the other hand, its non-appearance in some samples indicates that the sample site was not "polluted" with such material and that the mineralization is only locally controlled.

The question of aragonite appears to be more interesting. In Slovenia, aragonite needles were first described in Ravenska jama (F. Hochenwart, 1832, cit. D. Kuščer et al., 1959, p. 21), about 60 km NW of Planinsko polje. Our further (unpublished) explorations have revealed other cave aragonite occurrences in the wide area between Idrija and Ljubljana (See also T. Petek, 1995). All of them belong to the region of isolated karst (P. Habič, 1982) of west-central Slovenia, which is characterized by interchange of clastic and carbonate sediments (at times intercalated with pyroclastic material), and very complicated tectonics.

Najdena jama lies a few kilometers south of the southern limit of this geological region, in the Dinaric karst of southern Slovenia, which is characterized by different (exclusively carbonate) rocks and a different tectonic setting. Thus, though a regional link appears evident, there is no obvious geological connection.

Detailed study of the Ravenska jama aragonites was first performed by D. Kuščer et al. (1959), and later extended by P. Placer et al. (1989). They agreed that aragonite was deposited due to temporary very high concentrations of magnesium in percolating water, and not due to higher temperatures.

In this case, the probable source of magnesium was in nearby pyroclastic rocks.

In the case of Najdena jama such a source is missing. However, a 30 m-thick dolomite layer directly above the location might play a similar role. On the other hand, all the described localities lie below or within this dolomite layer, but aragonite was deposited only in the Cave Bear's Passage. Only one difference is evident at first glance. The aragonite locality is in a remote, dead, corner of a blind passage, where air movement is virtually absent, and the compact roof permits only minute dripping. The other localities lie in relatively open space, everywhere exposed to abundant wetting, and significant draughts.

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[/4] *The given pagination includes the whole text. In order to make the reference list more understandable, the titles quoted are of summaries/abstract.*

NEKAJ MINERALOV IZ NAJDENE JAME

Povzetek

UVOD

Najdena jama je najpomebnejša med jamami severno od Planinskega polja, od koder se napaja. Vodna gladina v njej niha za okrog 30 m in ob poplavah ostane dostopen le majhen del njenih prostorov. Zato je zelo bogata z ilovnatimi odkladninami. Sige je sorazmerno zelo malo, še manj pa drugih mineralov, ki jih najdemo le posamič. Netaketeri od njih se pojavljajo v obliki brezobličnih temno rjavih do črnih skupkov, ki smo jih doslej "na oko" imeli za psilomelan. Druge najdemo v obliki belega oprha oz. nekoliko bolj kompatnih skupkov, ki jim jamarji pravimo "jamski karbid", zraven pa si mislimo, da gre za vlaknati kalcit. Redke pojave belih iglic smo vedno imeli za aragonit, to pa je bil verjetno vzrok, da so kmalu "dobili noge". Da bi dognala, za kaj v resnici gre, sva vzorčila nekaj najpomebnejših nahajlišč in vzorce preiskala z rentgensko metodo.

MINERALNA SESTAVA VZORCEV

Vzorčno mesto:	**1**
Kraj:	**Piparski rov 1**
Gauss-Krügerjeve koordinate	Y: 5441 762, X: 5081 400, Z: 453

Opis: Ostre robove mnogih podornih blokov prerašča bel oprh ali kompaktnejši skupki ("jamski karbid"). Izjemoma se pojavlja tudi bela prevleka na gladkih straneh manjših kosov.

Mineralna sestava:

Hidromagnezit	$Mg_5\ [OH\ \vert(CO_3)_2]\ .\ 3H_2O$
Siderit	$FeCO_3$
Lansfordit	$MgCO_3\ .\ 5H_2O$
Goethit	FeOOH
Ankerit	$CaFe\ [CO_3]_2$

Vzorčno mesto	**2**
Kraj:	**Piparski rov 1**
Gauss-Krügerjeve koordinate:	Y: 5441 794, X: 5081 458, Z: 451

Opis: Vzorec je vzet z matične kamnine vzorca 1. Glej tam!

Mineralna sestava:

Dolomit	CaMg $[CO_3]_2$ (89 %)
Kalcit	$CaCO_3$ (11 %)

Vzorčno mesto: **3**
Kraj: **Piparski rov 1**
Gauss-Krügerjeve koordinate: Y: 5441 794, X: 5081 458, Z: 451

Opis: Glej vorčni mesti 1 in 2. Kjer je jamska stena stalno mokra in ni svežih odlomov, nastaja siv melj. Če komaj zaznavno polzenje vode lahko krajevno premika posamezne delce, nastanejo tvorbe, podobne stalaktitom. Če je tok še močnejši, melj odnaša in ga odlaga v manjših lužah.

Mineralna sestava:

Dolomit	CaMg $[CO_3]_2$
Kalcit	$CaCO_3$

Vzorčno mesto: **4**
Kraj: **Platke**
Gauss-Krügerjeve koordinate: Y: 5441 829, X: 5081 477, Z: 442

Opis: Temno rjave do črne skorje pokrivajo poličke na steni pod kaminom. Kaže, da izvirajo iz enega samega mesta in da so se šele kasneje razlezle v obliki zelo židke tekočine. Skorje so debele do nekaj centimetrov, bolj prstene kot plastične, zelo verjetno zaradi rahle cementacije. Doslej smo to snov "na oko" ocenjevali kot psilomelan ali iztrebke netopirjev, čeprav je kraj kar daleč od vhoda in precej vlažen.

Mineralna sestava:

Kremen	SiO_2
Illit	$(K,H_2O)Al_2\,[(H_2O,OH)_2\,|AlSi_3O_{10}]$
in/ali Paragonit	$NaAl_2\,[(OH,F)_2\,|AlSi_3O_{10}]$
Goethit	FeOOH
Todorokit	$(H_2O,..)_{\leq 2}\,(Mn,..)_{\leq 8}\,(O,OH)_{16}$

Vzorčno mesto: **5**
Kraj: **Velika Štirna**
Gauss-Krügerjeve koordinate: Y: 5441 808, X: 5081 442, Z: 420

Opis: Temnorjavo do črno obarvana siga na steni ali dnu rova pod majhnim kaminom. Kapljanje je sorazmerno intenzivno tudi ob najhujši suši, ob poplavah je vzorčno mesto zalito.

Mineralna sestava:

Kremen	SiO_2
Kalcite	$CaCO_3$
Illit	$(K,H_2O)Al_2\ [(H_2O,OH)_2\ \vert AlSi_3O_{10}]$
Dolomit	$CaMg\ [CO_3]_2$

Vzorčno mesto: **6**
Kraj: **Medvedji rov, strop**
Gauss-Krügerjeve koordinate: Y: 5441 876, X: 5081 378, Z: 458

Opis: Temnorjavo do črno obarvana gmota ilovnatega izgleda med grobimi prodniki, ki zapirajo nadaljevanje rova. Sem in tja sediment izgleda laminiran.

Mineralna sestava:

Kremen	SiO_2
Illit	$(K,H_2O)Al_2\ [(H_2O,OH)_2\ \vert\ AlSi_3O_{10}]$
Goethit	FeOOH
Kalcit	$CaCO_3$

Vzorčno mesto: **7**
Kraj: **Medvedji rov, dno**
Gauss-Krügerjeve koordinate: Y: 5441 876, X: 5081 378, Z: 457

Opis: Temnorjavo do črno obarvana gmota ilovnatega izgleda med grobimi prodniki, ki zapirajo nadaljevanje rova. Sem in tja izgleda sediment laminiran. Vzorec je bil vzet v neposredni bližini ostankov kosti jamskega medveda, si so razpadle v meljasto kašo.

Mineralna sestava:

Kremen	SiO_2
Kalcit	$CaCO_3$
Illit	$(K,H_2O)Al_2\ [(H_2O,OH)_2\ \vert AlSi_3O_{10}]$
Variscit	$Al\ [PO_4]\ .\ 2H_2O$
Todorokit ?	$(H_2O,..)_{\leq 2}\ (Mn,..)_{\leq 8}\ (O,OH)_{16}$

Vzorčno mesto: **8**
Kraj: **Medvedji rov, dno**
Gauss-Krügerjeve koordinate: Y: 5441 876, X: 5081 378, Z: 457

Opis: Bele iglice zbrane v skupkih, ki spominjajo na hišico morskega ježka. Podlaga so temnorjavo ali črno obarvani debeli prodniki, ki ležijo med materialom, opisanim pri vzorčnem mestu 6.

Opomba: V času odkritja (November 1964), so tudi stene delno prekrivali skupki belih iglic, ki smo jih takoj imeli za aragonit. V naslednjih letih so zbiralci opravili svoje početje tako temeljito, da sva poleti 1972 podpisana komajda rešila poslednji kos. Ta se danes nahaja v Mineraloški zbirki Oddelka za geologijo, NTF, Univerze v Ljubljani.

Mineralna sestava:

Aragonit $CaCO_3$

RAZPRAVA

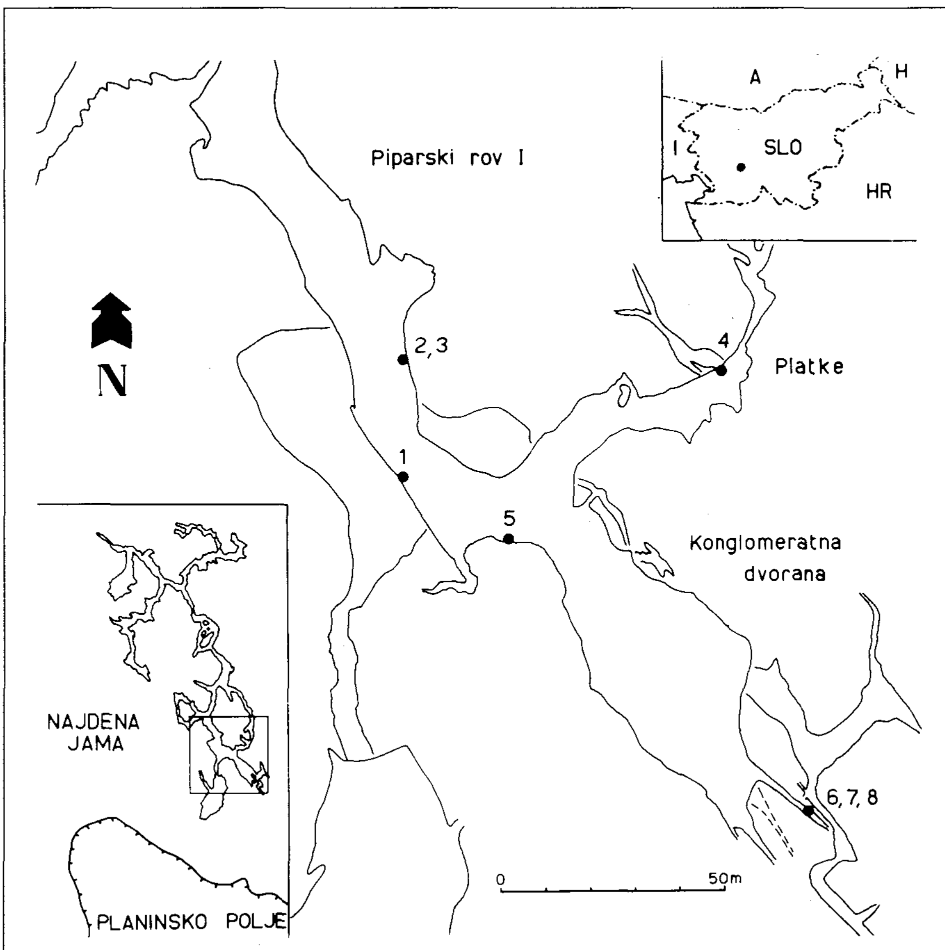
Članek predstavlja rezultate rentgenskih ananliz mineralov z nekaterih dobro znanih nahajališč v Najdeni jami - nima pa namena biti krajevna študija jamske mineralogije. Analiza je potrdila le eno oceno "na oko", namreč aragonit. Če vzamemo psilomelan $((Ba,Mn^{2+}...)_3\ (O,OH)_6Mn_8O_{16})$ kot streho za manganove hidrokside na sploh, sta sorazmerno pravilni še dve oceni. Dve pa sta popolnoma zgrešeni, tako kot je javno mnenje napačno presodilo o tudi "jamskem karbidu".

Razprava o podrobnosti posameznih mineralov oz. nahajališč ne prinaša posebnih novosti. Širši javnosti bolj zanimivo je vprašanje aragonita. V Sloveniji je bil prvič opisan v Ravenski jami (F. Hochenwart, 1832, cit. D. Kuščer et al., 1959, p. 21), okrog 60 km severozahodno od Planinskega polja. Najino še neobjavljeno raziskovanje (Glej tudi T. Petek, 1995), kaže, da na širšem ozemlju med Ljubljano in Idrijo aragonit ni posebnost, le da so iglice praviloma velike le nekaj milimetrov.

To območje spada k osamelemu krasu severozahodne Slovenija (P. Habič, 1982), za katerega je značilno izmenjavanje klastičnih in karbonatnih sedimentov, med katere se včasih vrivajo tudi piroklastiti. Posebej Idrijsko ozemlje s širšo okolico pa je znano tudi po zelo zapleteni tektoniki.

Najdena jama leži v Dinarskem krasu južne Slovenije, le nekaj kilometrov južno od severne meje te geološke enote. Značilna je skoraj 7 km debela izključno karbonatna skladovnica in popolnom drugačna tektonska zgradba. Zato o ožji geološki povezanosti obeh ozemelj govorimo le stežka, čeprav se zdi prostorska zveza nujna.

Prvi so aragonit Ravenske jame podrobneje preučili D. Kuščer et al. (1959), njihovo delo pa so nadgradili L. Placer et al. (1989). Raziskovalci se strinjajo, da se je aragonit odlagal zaradi občasno zelo visoke koncentracije magnezija v prenikli vodi in ne zaradi povišanih temperatur. V konkretnem primeru je bila vir magnezija neposredna soseščina piroklastitov. V primeru Najdene jame tak vir manjka, morda pa bi podobno vlogo lahko igrala okrog 30m debela dolomitna skladovnica tik nad nahajališčem. Po drugi plati ležijo nahajališča vseh analiziranih vzorcev iz Najdene jame pod navedeno dolomitno skladovnico, ali pa prav v njej - argonit pa smo našli edino v Medvedjem rovu. Na prvi pogled je razvidna le ena razlika med nahajlišči: aragonit najdemo le v oddaljenem, mrtvem kotu slepega rova, kjer premikov zraka skoraj ni in kompakten strop prepušča komaj zaznavno količino vode. Preostala nahajališča so na sorazmerno precej namočenih krajih in so bolj ali manj izpostavljena stalnemu prepihu.



OTHER PAPERS

OSTALI ČLANKI

ANALYSES OF SOME MICROELEMENTS IN THE TISSUES OF *Proteus anguinus* (Amphibia, Caudata) AND IN ITS HABITAT

ANALIZE NEKATERIH MIKROELEMENTOV V TKIVIH MOČERILA (*Proteus anguinus*, Amphibia, Caudata) IN V NJEGOVEM HABITATU

BORIS BULOG

Izvleček: UDK 574.2:597.9(497.4)

Boris Bulog: Analize nekaterih mikroelementov v tkivih močerila (*Proteus anguinus*, Amphibia, Caudata) in v njegovem habitatu

Članek predstavlja preliminarne ekološke raziskave na endemični jamski dvoživki. V dosedanjih analizah so določali koncentracije As, Cu, Zn, Hg, Cd in Se v tkivih in koncentracije Cu, Zn, Hg, As in Cd v vodi in sedimentih v Planinski jami. Koncentracije Hg v rečnih sedimentih so štirikrat manjše kot v tkivih. Hg v tkivih močerila ni dosegel vrednosti pri drugih dvoživkah iz nekontaminiranih habitatov. Močeril bi lahko akumuliral znatne količine posameznih mikroelementov, če upoštevamo dolgo življenjsko dobo, v onesnaženih vodah pa celo letalne doze.

Ključne besede: biologija, speleobiologija, jamska favna, Amphibia, Proteus anguinus, mikroelementi

Abstract: UDC 574.2:597.9(497.4)

Boris Bulog: Analyses of some microelements in the tissues of *Proteus anguinus* (Amphibia, Caudata) and in its habitat

This article presents preliminary ecological studies of endemic cave salamander *Proteus anguinus*. Recently we also determined the concentrations of As, Cu, Zn, Hg, Cd and Se in the tissues and the concentrations of Cu, Zn, Hg, As and Cd in the water and sediments in the Planina Cave. The concentrations of Hg in river sediments are four times smaller than in their tissues. Hg in tissues of Proteus did not reach the values of other amphibians from the uncontaminated habitats. Owing to its long life span, Proteus could accumulate a considerable quantity of the individual microelementss and in polluted waters even a lethal dose of these elements.

Key words: biology, speleobiology, cave fauna, Amphibia, Prouteus anguinus, microelements

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INTRODUCTION

Proteus anguinus is the only species of the European cave salamander and the most famous troglobiont of our underground waters in the Dinaric Karst. Christiansen introduced the phrase troglomorphy to specify those phenotypic features which were typical for cave animal evolution and served to distinguish a cave adapted organisms (Christiansen 1992). A large part of the Slovenian territory situated between the Ljubljana Marsh and the Adriatic sea is a classical Karstic area. Caves and underground rivers are features of the karst topography. It is worth mentioning that three thousands caves exist in this area, of considerable geographic and biological interest (Cave register).

The purpose of this paper is to present our recent ecological studies of the endemic cave salamander and, particularly, to report on the preliminary studies of accumulation of the individual metals and other microelements as potential toxic substances in its tissues. The water resources in the Karst area are extremely sensitive to all kind of pollution. Our Karstic areas have relatively rare sources of useful water. During the dry seasons the surface streams may often disappear completely and the underground waters may be limited or not quite accessible. Consequences of this may be also higher concentrations of pollutants in the underground waters. Self purification processes in the underground waters are not clear enough and are quite different from these in the surface waters (Sket and Velkovrh 1981).

Among the most serious chemical pollutants are the chlorinated hydrocarbon pesticides (DDT), aldrin, and dieldrin; the polychlorinated biphenyls (PCBs), which are used in a variety of industrial processes and in the manufacture of many kinds of materials; and such metals as mercury, lead, cadmium, arsenic, and beryllium. All of these substances persist in the environment, being slowly, if at all, degraded by natural processes; in addition, all are toxic to life if they accumulate in any substantial quantity. Minerals essential for animal life include common salt (sodium chloride), calcium, phosphorus, sulfur, potassium, magnesium, manganese, iron, copper, cobalt, iodine, zinc, molybdenum, and selenium. The last six of these are toxic to animals if excessive amounts are eaten.

The ultimate control of pollution will presumably involve the decision not to allow the escape into the environment of the substances that are harmful to life, the decision to contain and recycle those substances that could be harmful if released into the environment in excessive quantities, and the decision not to release into the environment substances that persist and are toxic to living things. Essentially, therefore, pollution control does not mean an abandonment of existing productive human activities but their reordering so as to guarantee that their side effects do not outweigh their advantages.

MATERIALS AND METHODS

We used a small number of specimens for our studies owing to the very strict enforcement of natural conservation laws. We established these studies on ten specimens that we captured in the Pivka branch of the Planina Cave near the sampling point three and four. Animal tissue metal contents were measured by neutron activation analysis. Planina Cave waters and sediments have been sampled since 1994 on sampling points one and two (Rak branch) and on sampling points three and four (Pivka branch).

Metal levels in water and sediment samples were determined by one of the following methods: neutron activation analysis, cold vapour atomic absorption spectrometry, atomic fluorescence spectrometry, or X-ray fluorescence (Byrne and Kosta 1974, Horvat et al. 1989, Fajgelj 1993, Wobrauschek 1993). Metal contents have been determined on Institute "Jožef Stefan" - The laboratory for the environmental chemistry.

RESULTS

We have established the contents of the copper, zinc, arsenic, selenium cadmium, and mercury in the liver, kidneys, integument, and muscles of Proteus. The metal contents of animal tissue were measured by neutron activation analysis. They were also established in the rivers Pivka and Rak, both streaming through the cave, and their sediments (Dermelj et al. 1984, Bulog in prep.).

Recent preliminary studies showed that the concentration of Hg in the individual tissues did not exceed a mean value of approximately 0.7 $\mu g/g$ of fresh tissue (Table 1.). The largest concentrations of mercury and arsenic were found in the liver of Proteus, a smaller one in muscle, and the smallest in the kidneys and the integument (Table 1, Figs. 1-4). The largest concentrations of Cd were established in the integument and the largest concentrations of Cu, Zn and Se were determined in the liver.

The concentrations of As, Sb, Cu, Zn, Cd, and Co in the river sediments exceed these in the tissues of Proteus. The concentrations of Hg in the river sediments are four times smaller than in tissues.

Table 1 presents the recent analyses of concentrations of six microelements in the tissues of Proteus and Table 2 the concentrations of five microelemnts in the water and sediment of its habitat.

	LIVER						MUSCLES						KIDNEY						INTEGUMENT					
	As	Cu	Zn	Hg	Cd	Se	As	Cu	Zn	Hg	Cd	Se	As	Cu	Zn	Hg	Cd	Se	As	Cu	Zn	Hg	Cd	Se
1	/	1.4	10.9	0.19	/	6.6	/	0.13	6.0	0.10	/	1.0	/	0.42	10.5	0.05	/	2.6	/	0.23	9.1	0.04		1.3
2	/	3.4	10.5	0.54	/	7.0	/	0.11	4.1	0.17	/	0.6	/	0.40	10.5	0.07	/	1.6	/	0.23	5.7	0.17		0.6
3	/	14.6	16.6	1.30	/	7.7	/	/	/	/	/	/	/	2.80	/	0.09	/	/	/	0.40	16.7	0.01		1.7
4	/	1.8	9.3	0.44	/	2.7	/	0.60	6.2	0.48	/	0.5	/	0.70	16.6	0.11	/	2.0	/	0.30	14.3	0.06		0.2
5	/	1.5	9.5	0.29	/	2.4	/	0.30	6.9	0.37	/	0.4	/	0.50	12.7	0.13	/	1.2	/	0.60	9.3	0.06		3.5
6	/	18.7	8.1	0.60	/	5.2	/	0.35	6.2	0.40	/	0.5	/	0.50	14.5	0.13	/	1.4	/	0.45	13.1	0.06		0.5
7	/	3.0	8.5	0.75	/	4.9	/	0.13	3.3	0.54	/	0.4	/	0.69	12.8	0.22	/	1.0	/	0.19	8.0	0.11		0.5
8	/	3.3	10.9	0.81	/	6.4	/	0.23	3.7	0.38	/	0.8	/	0.72	8.9	0.14	/	2.9	/	0.49	10.5	0.07		0.5
9	0.34	2.6	12.9	0.43	0.25	6.4	0.13	0.47	7.3	0.40	$<10^{-2}$*	0.6	0.05	0.77	15.6	0.06	$<10^{-2}$*	1.6	0.09	0.32	6.8	0.13	0.67	0.5
10	/	2.8	7.3	1.21	0.07	8.8	/	2.43	4.3	0.46	$<10^{-2}$*	0.7	/	/	/	0.20	/	4.2		0.15	7.6	0.09	$<10^{-2}$*	0.8
x	**0.34**	**5.31**	**10.5**	**0.66**	**0.16**	**5.81**	**0.13**	**0.53**	**5.33**	**0.37**	**$<10^{-2}$***	**0.61**	**0.05**	**0.83**	**12.8**	**0.12**	**$<10^{-2}$**	**2.06**	**0.09**	**0.34**	**10.1**	**0.08**	**<0.67**	**1.01**

*Table 1. Microelement concentrations in the organs of ten specimens of Proteus and their mean values, in μg / g and *ng / g of fresh tissue.*
*Tabela 1. Koncentracije mikroelementov v organih 10 primerkov močerila in njihove srednje vrednosti, v μg / g in *ng / g svežega tkiva.*

	Cu		Zn		Hg		As		Cd	
Sampling points in Planina Cave	**water**	**sediment**	**water**	**sediment**	**water**	**sediment**	**water**	**sediment**	**water**	**sediment**
1	1.35	36	6.08	107	0.27	0.11	0.13	9.5		0.65
2	1.44	41	8.40	140		0.16	0.14	11,3		0.64
3	2.23	28	13.70	100	0.29	0.04	0.12	6.5		0.31
4	2.27	20	14.80	76	0.29	0.03	0.15	4.3		0.12
x	**1.82**	**31.25**	**10.75**	**105.75**	**0.28**	**0.085**	**0,14**	**7.9**		**0.43**

Table 2. Microelement concentrations in water and sediments from the Planina Cave, in μg/l (in water) and in μg/g of dry sample (in sediments) and their mean values.
Tabela 2. Koncentracija mikroelementov v vodi in sedimentih Planinske jame, v μg/l (v vodi) in v μg/g suhe mase vzorca (v sedimentih) ter njihove srednje vrednosti.

Fig. 1. Microelements concentrations in the liver of ten specimens of *Proteus* and their mean values
Sl. 1. Koncentracije mikroelementov v jetrih desetih primerkov močerila in njihove srednje vrednosti

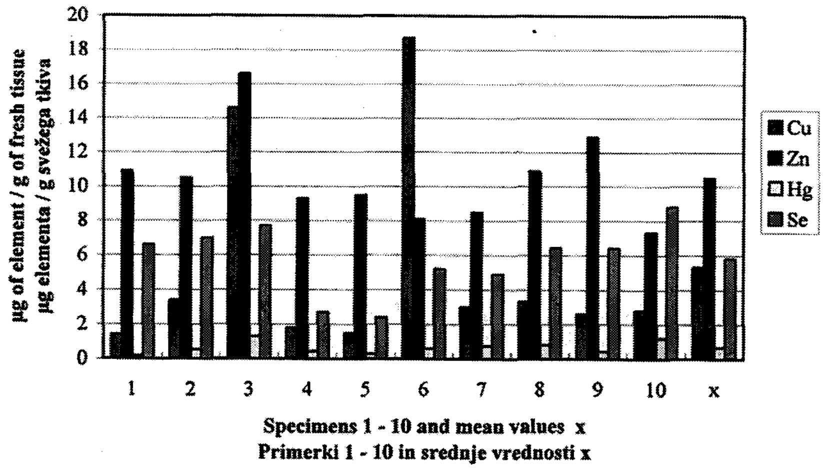


Fig. 2. Microelements concentrations in the muscles of ten specimens of *Proteus* and their mean values
Sl. 2. Koncentracije mikroelementov v mišicaah desetih primerkov močerila in njihove srednje vrednosti

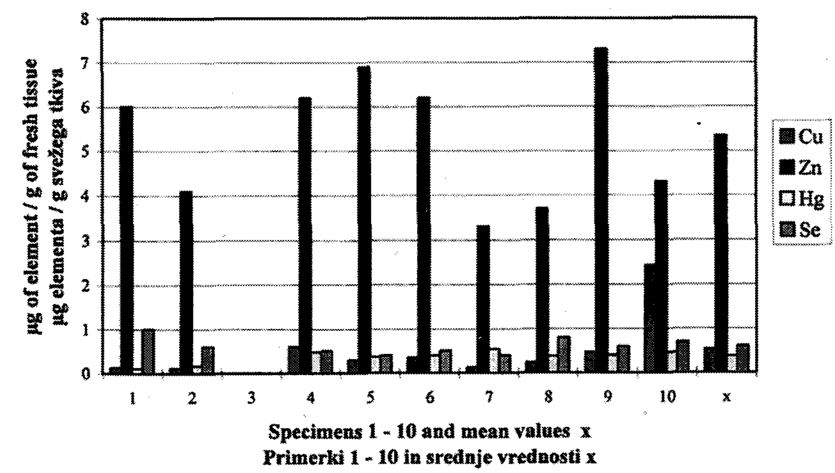


Fig. 3. Metals concentrations in the kidneys of ten specimens of *Proteus* and their mean values
Sl. 3. Koncentracije mikroelementov v ledvicah desetih primerkov močerila in njihove srednje vrednosti

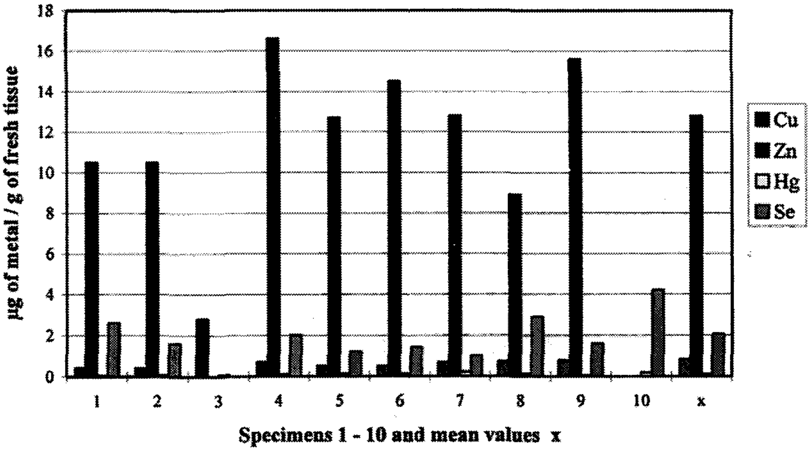
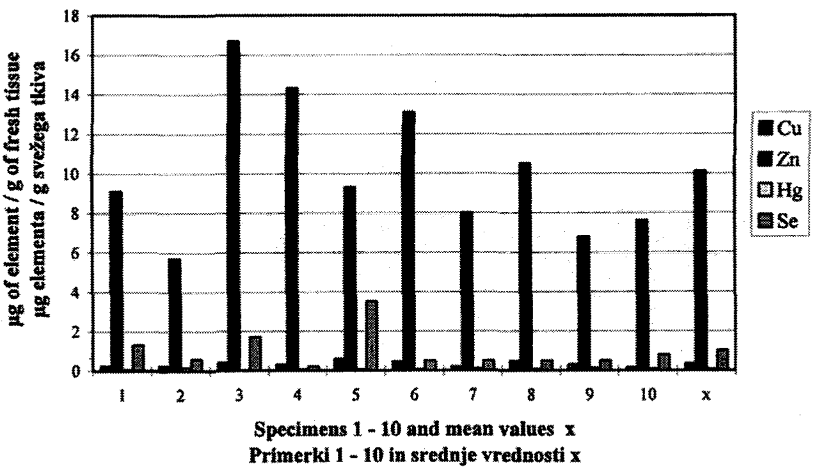


Fig. 4. Microelements concentrations in the integument of ten specimens of *Proteus* and their mean values
Sl. 4. Koncentracije mikroelementov v koži desetih primerkov močerila in njihove srednje vrednosti



DISCUSSION

The possible pathways of metals through the body of Proteus are not known. We may expect the ingestion of metals: **1.**) With the consumption of the prey, sediment particles or with water consumption. **2.**) With the direct absorption from the surrounding water by the integument and through the gills. **3.**) With the absorption from the air during the lung respiration. The absorption of Hg in amphibians could take place with the food consumption through the skin and with the absorption through the air (Bryne et al. 1975). Simkiss and Taylor (1989) discussed about the cellular mechanisms of the metal obtainment in the aquatic animals. They supposed this may be passive process or connected with the active ionic channels for the transport of important ions. Further analyses in Proteus will deal with the control of accumulation of microelements, their uptake and transport through the animal.

The maximal end value of Hg concentrations in fishes recommended for their and our protection is 0.5 μg/g of fresh tissue (Saiki et al. 1992). The reproductive sterility in fishes was described in cases where the concentration of Se reached values > 12 μg/g of fresh tissue (Saiki et al. 1992).

Proteus' proportion of Hg in individual tissues was also found in other amphibians (Byrne et al. 1975). They measured the largest concentrations of Hg in the tissues of amphibians overall in uncontaminated waters in the liver (2 μg/g of fresh tissue), in the kidney (1.5 μg/g of fresh tissue), and in the muscles (0.5 μg/g of fresh tissue). The concentrations of Hg in tissues of amphibians in contaminated waters are much larger (about 20 μg/g of fresh tissue in the liver and kidney and 2-3 μg/g of fresh tissue in muscles and integument). Obviously, the concentrations of Hg in tissues of Proteus did not reach the values of other amphibians from the uncontaminated habitats. Preliminary studies suggest that the liver of Proteus accumulates the largest amounts of microelements and may be considered as the target organ (Table 1, Cijan 1994, Bulog 1994). Owing to its long life span, Proteus could accumulate a large quantity of the individual metals and in polluted waters even a lethal dose of these elements.

The comparison of metal concentrations in the river sediments with their natural values (after Turkeian and Wadepohtl 1961) showed that analysed microelements accumulate in the sediments of Planina Cave.

Certain modern industrial and biological processes concentrate mercury compounds to dangerous levels. Besides the danger from many consumer goods that contain potentially harmful levels of mercury, the air may be contaminated by mercury vapours, fumes, and dusts and the waters by effluent wastes containing mercury in various forms. The latter may then be converted by bacteria in the muddy sediments into organic mercurial, which may in turn be concentrated by the fishes, amphibians and other aquatic forms of life. The exact mechanism by which mercury enters the food chain remains largely unknown, and probably vary among ecosystems. We do know, however, that certain bacteria play an important early role. Studies have shown that bacteria that process sulfate in the environment take up mercury in its inorganic form, and through metabolic processes convert it to methylmercury. The conversion of inorganic mercury to methylmercury is important for two reasons: (1) methylmercury is much more toxic than inorganic mercury, and (2) organisms require considerably longer to eliminate methylmercury. At this point, the methylmercury-containing bacteria may be consumed by the next higher level in the food chain, or the bacteria may release the methylmercury to the water and then to the next level in the food chain (Miller, D.R. 1979). Depending on the type of mercury compound and the mode of contact, the symptoms of intoxication vary.

Arsenic is very widely distributed in the environment, and all animals are exposed to low levels of this element. For most people, food constitutes the largest source of arsenic intake (about 25 to 50 micrograms per day), with lower amounts coming from drinking water and air. Some edible fish and shellfish contain elevated levels of arsenic, but this is predominantly in an organic form that has low toxicity. Above-average levels of exposure are usually associated with one or more of the following situations: Arsenic is believed to exert its toxicity by combining with certain enzymes (the organic catalysts of the cell), thereby interfering with cellular metabolism. The amount of arsenic intake that is required to cause a harmful effect depends on the chemical and physical form of the arsenic. In general, inorganic forms of arsenic are more toxic than organic forms, and forms that dissolve easily in water (soluble forms of arsenic) tend to be more toxic than those that dissolve poorly in water. Also, toxicity depends somewhat on the electric charge (the oxidation state or valence) of the arsenic.

Zinc is an essential trace element in the vertebrate body, where it is found in high concentration in the red blood cells as an essential part of the enzyme carbonic anhydrase, which promotes many reactions relating to carbon dioxide metabolism. It is the component of numerous proteins. Zinc present in the pancreas may aid in the storage and excretion of insulin and other hormones (Hambridge et al. 1986). Zinc is a component of some enzymes that digest protein in the gastrointestinal tract. The toxicity of the metals increases sharply in the order zinc, cadmium, mercury. The toxicity of zinc is low. In drinking water zinc can be detected by taste only when it reaches a concentration of 15 parts per million (ppm); water containing 40 parts per million zinc has a definite metallic taste. Cases of fatal poisoning have resulted through the ingestion of zinc chloride or sulfide, but these are rare.

Compared with those of zinc, the toxic hazards of cadmium are quite high. It is soluble in the organic acids found in food and forms salts that are converted into cadmium chloride by the gastric juices. Even small quantities can cause poisoning, with the symptoms of increased salivation, persistent vomiting, abdominal pain, and diarrhea. Fatal cases have been reported. Cadmium has its most serious effect as a respiratory poison: a number of fatalities have resulted from breathing the fumes or dusts that arise when cadmium is heated. Symptoms are difficult or laboured breathing, a severe cough, and violent gastrointestinal disturbance.

Copper is important in synthesis of haemoglobin. It is the component of many enzymes. Excess of copper in the biological systems changes individual biochemical processes (Fajgelj, 1993). Wilson's disease, also called hepatolenticular degeneration is a hereditary defect associated with the metabolism of copper and characterized by the progressive degeneration of the basal ganglia of the brain, the development of a brownish ring at the margin of the cornea, and the gradual replacement of liver cells with fibrous tissue.

Among organic compounds, the most toxic are derivatives that contain the halogen elements (fluorine, chlorine, bromine and iodine), sulfur, selenium, tellurium, nitrogen, phosphorus, arsenic, lead, and mercury. Most organometallic compounds are toxic, while oxygen-containing derivatives of the hydrocarbons are usually less toxic.

In all biologic systems the dose of an added substance, including nutrients, determines the effect. The level at which the nutrient may exert toxic effects varies, and for some nutrients, such as vitamins A and D, iron, fluoride, selenium, and iodine, the level is much lower than for others.

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ANALIZE NEKATERIH MIKROELEMENTOV V TKIVIH MOČERILA (*Proteus anguinus*, Amphibia, Caudata) IN V NJEGOVEM HABITATU

Povzetek

Kraški svet zavzema skoraj polovico ozemlja naše domovine, zaradi česar nosi Slovenija pečat ene najbolj kraških dežel na svetu. Močeril ali človeška ribica naseljuje podzemske vode Dinarskega krasa in je edini jamski vretenčar v Evropi. Razširjen je v podzemlju Dinarskega krasa od reke Isonzo-Soča v Italiji na severozahodu do reke Trebišnjica v Hercegovini na jugovzhodu. Ta neotenična dvoživka ohranja celo življenje nekatere larvalne znake v odraslem stanju. *Neotenija* je fenomen, pri katerem osebki dosežejo reproduktivno zrelost in ohranjajo zunanje znake ličinke. Po vsej verjetnosti pride do upočasnjenega razvoja somatičnih organov pri relativno normalni hitrosti dozorevanja spolnih organov. Pri rednih neotenih (*Proteus, Necturus* in *Amphiuma*) je razlog za nepovratno neotenijo v neobčutljivosti tkiv na tireoidne hormone.

V okviru naših ekoloških raziskav poteka tudi proučevanje kopičenja mikroelementov v naravnem okolju in tkivih močerila. Vodni viri na kraškem območju so zaradi specifičnosti zgradbe kraškega sveta izjemno občutljivi na enkratne in trajne oblike onesnaževanja. V sušnih obdobjih lahko površinski tokovi povsem presahnejo in ena izmed nevarnih posledic sušnosti je sorazmerno blago razredčenje odpadnih voda in povišane koncentracije škodljivih snovi. Samoočiščevalni procesi v podzemskih vodah niso povsem jasni in v večji meri tudi nepredvidljivi (Sket in Velkovrh 1981).

Namen prispevka je predvsem predstaviti predhodne analize kopičenja posameznih težkih kovin in drugih mikroelementov kot potencialno strupenih substanc v močerilovih tkivih. Vsebnost mikroelementov je bila merjena v podzemskih tokovih rek Pivka in Rak. in v rečnih sedimentih. Analizirana je bila vsebnost, bakra, cinka, arzena in živega srebra, v rečnih usedlinah pa še kadmija. Pri tem smo uporabili različne analitične metode (atomska absorpcijska spektrometrija hladnih par, nevtronska aktivacijska analiza, X-žarkovna fluorescenca).

Rezultati analiz vsebnosti kovin v vodah iz Planinske jame kažejo, da so njihovi koncentracijski nivoji pod maksimalnimi dovoljenimi koncentracijami (MDK - Pristov 1992). Izmerjene vrednosti v Pivki in Raku so dokaj izenačene, kljub temu, da ju napaja voda iz različnega hidrografskega zaledja. Rečne usedline kopičijo precejšnje količine mikroelementov zaradi adsorpcije, hidrolize,... in se z desorbcijo ponovno sproščajo v vodo. Primerjava koncentracij kovin v jamskih rečnih usedlinah z naravnimi vrednostmi le teh (po Turekian in Wedepohl 1961) kaže, da se analizirane kovine kopičijo v rečnih usedlinah. Kopičenje kovin v rečnih usedlinah iz Planinske jame je sicer precejšnje, vendar pa vsebnosti kovin niso tako visoke, da bi lahko govorili o močnem onesnaženju. Za realno sliko vsebnosti kovin v vodi in usedlinah bomo v naslednjih letih redno odvzemali vzorce.

V dosedanjih študijah je bila določena tudi vsebnost bakra, cinka, arzena, selena, kadmija in živega srebra v jetrih, ledvicah, koži in mišicah močerila (Tabela 1, Slike 1 - 4). Vsebnost teh mikroelementov je bila merjena z nevtronsko aktivacijsko analizo. Predhodni rezultati kažejo, da jetra kopičijo največjo količino mikroelementov (Bulog 1994).

Privzem kovin v telo močerila bi lahko potekal na več načinov: 1.) z zaužitjem plena, usedline ali vode, 2.) z absorbcijo direktno iz vodnega okolja skozi kožo in škrge in 3.) z absorbcijo iz zraka skozi pljuča in kožo. Privzem živega srebra pri dvoživkah naj bi potekal s konzumacijo hrane, preko kože in z zračno absorbcijo (Byrne et al. 1975). Upoštevajoč način prehranjevanja močerila lahko predvidevamo, da močeril sprejema precejšen del mikroelementov nakopičenih v rečnih sedimentih. Simkiss in Taylor (1989) razpravljata o načinih privzema kovin na celičnem nivoju pri vodnih organizmih in menita, da je v mnogih primerih privzem kovine v telo pasiven proces. Lahko pa je povezan z aktivnimi ionskimi črpalkami (npr. kadmij), ki služijo transportu pomembnih ionov (npr. za kalcij).

V nadaljnjih raziskavah nameravamo vključiti redno kontrolo kopičenja kovin v tkivih in naravnem okolju močerila, proučevanje možnih poti privzema v telo močerila, transporta, porazdelitve, biotransformacij in izločanja mikroelementov.

PALEOEKOLOŠKE ZNAČILNOSTI KOZINSKIH PLASTI V OKOLICI ŠKOCJANSKIH JAM

PALEOECOLOGICAL PROPERTIES OF KOZINA BEDS NEAR ŠKOCJANSKE JAME CAVES

MARTIN KNEZ

Izvleček UDK 564.02(118)(497.4)

Martin Knez: Paleoekološke značilnosti kozinskih plasti v okolici Škocjanskih jam

Polži in haraceje se pojavljajo v horizontih, ki predstavljajo eno ali več plasti. V profilu Divača je 16 horizontov s polži in 13 s haracejami. V šestih horizontih so haraceje bolj ali manj pomešane s polži. Poudariti pa moram, da je od 23 horizontov 10 horizontov v katerih so samo polži in 7 horizontov, v katerih najdemo le haraceje. Samo 6 horizontov je, kjer so polži pomešani s haracejami. Polži iz rodu Stomatopsis kot tudi tankolupinasti polži so dobro ohranjeni. Prav taki so krhki rastlinski ostanki haracej, ki še v fosilnem stanju vključujejo oogonije v njihovem življenjskem položaju. To dokazuje, da niti polži niti haraceje niso pretrpeli transporta. Zato obe skupini organizmov najverjetneje predstavljata paleobiocenozo.

Ključne besede: geologija, paleoekologija, biostratigrafija, kozinske plasti, haraceje, Škocjanske jame, Slovenija

Abstract UDC 564.02(118)(497.4)

Martin Knez: Paleoecological properties of Kozina Beds near Škocjanske Jame Caves

Mollusca and Haracea occur within horizons that represent one or more layers. In the Divača profile there are 16 horizons with Mollusca and 13 with Haracea. In six horizons Haracea are more or less mixed with Mollusca. However it must be stressed that out of 23 horizons there are 10 horizons where only Mollusca and 7 horizons where only Haracea can be found. There are only 6 horizons where Mollusca are mixed with Haracea. Mollusca of genus Stomatopsis and also thin shelled snails are well preserved. Fragile vegetational remains of Haracea include oogonia in their living position are also well preserved. It proves that most probably neither Mollusca nor Haracea endured transport. Thus both groups most probably represent a paleobiocenose.

Key words: geology, paleoecology, biostratigraphy, Kozina beds, Haracea, Škocjanske Jame Caves, Slovenia

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UVOD

V profilu Divača sem v kozinskih plasteh proučeval horizonte z izredno številnimi haracejami in polži. Med obema skupinama sem iskal morebitno povezavo v pojavljanju. S temi in z nekaterimi drugimi fosili sem želel spoznati paleoekološke razmere v času sedimentacije.

Profil Divača leži v useku magistralne ceste Senožeče - Divača, približno 800 m pred odcepom ceste za Divačo (slika 1). Vsek je severovzhodno od vasi, nekako med odcepom stare ceste in zadnjim klancem pred Divačo. To območje je na jugovzhodnem delu Osnovne geološke karte SFRJ, list Gorica (S. Buser, 1968).

DOSEDANJE RAZISKAVE KOZINSKIH PLASTI

G. Stache (1859) je v skladovnici plasti, ki jo imenujemo liburnijska formacija, prvotno poznal samo njen srednji del, čeprav je ločil še spodnje in zgornjeforaminiferne apnence. Kozinske plasti je razdelil na stomatopsidne apnence v nižjih in haracejske apnence v višjih nivojih. Kasneje je (G. Stache, 1889) srednji del poimenoval po vasi Kozina kozinske plasti. Do danes se ime kozinske plasti ni več spreminjalo (K. Drobne & R. Pavlovec, 1991). M. Hamrla (1959; 1960) meni, da ne bi bilo primerno obdržati tega imena le za spodnji paleocenski del liburnijske formacije, temveč da bi ga razširili na vse bituminozne apnenčeve plasti s premogom, favno kozinij, stomatopsisov, haracej in drugih.

M. Pleničar (1961) je spodnji terciar označil kot "zgornji del kozinskih plasti" oziroma "glavni haracejski apnenec". Stachejev (1889) spodnji del kozinskih plasti, je M. Pleničar uvrstil v 17. (sladkovodni) in 18. (morski) horizont.

Nekateri avtorji (G. Bignot & L. Grambast, 1969) ločijo v kozinskih plasteh dva stratigrafsko ločena nivoja s haracejami. V spodnjem delu so

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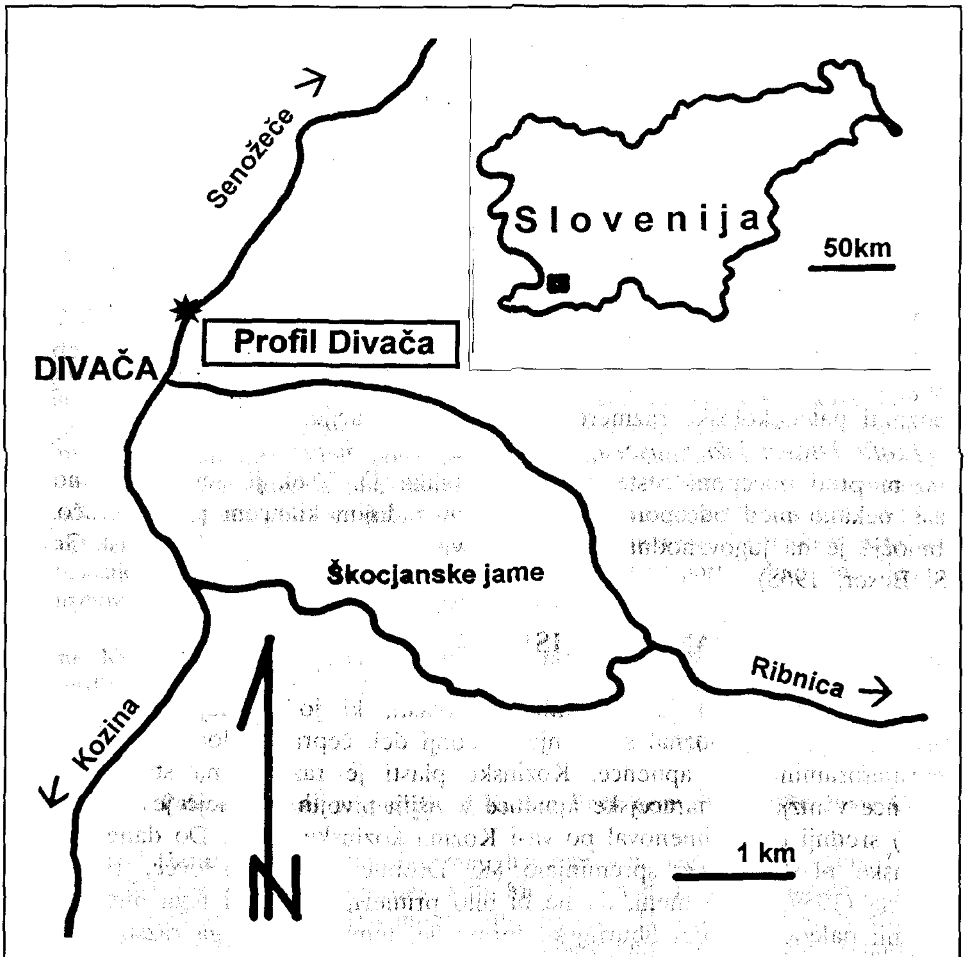


Sl. 1: Položaj profila Divača
Fig. 1: The situation of the Divača profile

apnenci z oogoniji haracej (Porochara stacheana), v zgornjem apnenci z oogoniji haracej in drugimi deli steljk (Lagynophora liburnica). Oboje navadno spremljajo polži, drobne foraminifere (Discorbidae) in Microcodium elegans.

Čeprav najdemo v spodnjem nivoju kozinskih plasti skoraj vedno samo oogonije iz rodu Porochara jih v vznožju Slavnika dobimo skupaj z rodom Lagynophora (G. Bignot & L. Grambast, 1969).

Spodnji del kozinskih apnencev definirata J. Pavšič in M. Pleničar (1981) kot brečaste apnence z rodovoma Microcodium in Discorbis, s polži iz rodov

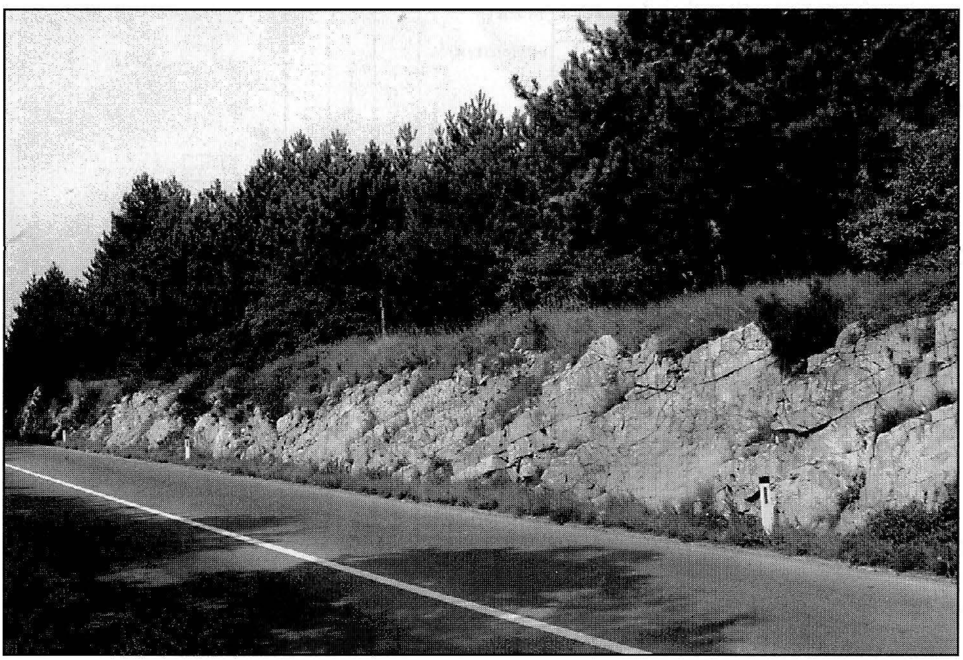
Stomatopsis in Cosinia, ostrakodi in koralami. Mlajši del kozinskih plasti pa obsega bituminoze apnence z miliolidami in haracejami.

G. Stache (1864, 1867, 1872, 1875, 1880, 1889) je haracejske apnence uvrščal v paleocen Italijanski raziskovalci so kozinske apnence šteli v eocen (C. d'Ambrosi, 1931, 1942, 1955; B. Martinis, 1962). Na podlagi haracej meni M. Feist (1979), da spadajo kozinske plasti v najstarejši paleocen ali v najmlajšo kredo. Danes uvrščamo kozinske apnence v danij (K. Drobne & R. Pavlovec, 1991).

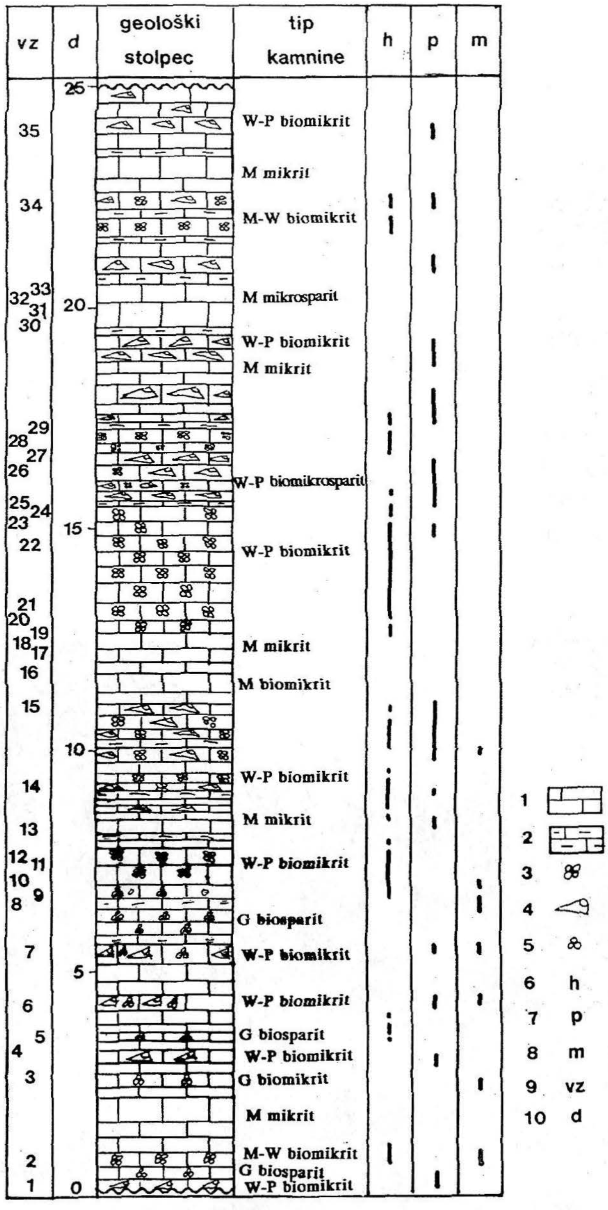
PROFIL DIVAČA

Kozinske plasti sem proučeval med Divačo in Vremskim Britofom ter severno od Divače (profil Divača, slika 2). Na teh mestih sem namreč našel bogate ostanke haracej, ob katerih lahko razmišljamo o paleoekoloških in drugih vprašanjih.

Čeprav so o pomembnosti haracej pisali številni avtorji (G. Bignot, 1972; L. Grambast, 1962, 1965 in drugi), ki so raziskovali na področju Divače in Škocjanskih jam, ni profila Divača še nihče podrobno opisal.



Sl. 2: Profil Divača
Fig. 2: Divača profile



Sl. 3: Geološki stolpec profila Divača. 1-apnenec, 2-laporni apnenec, 3-haraceje, 4- polži, 5-miliolide, 6-haraceje, 7-polži, 8-miliolide, 9-vzorec, 10-debelina (cm)

Fig. 3: Geological column of the Divača profile. 1-limestone, 2-marly limestone, 3-Haracea, 4-Mollusca, 5-Milliolides, 6-Haracea, 7-Mollusca, 8-Milliolides, 9-sample, 10-thickness (in cm)

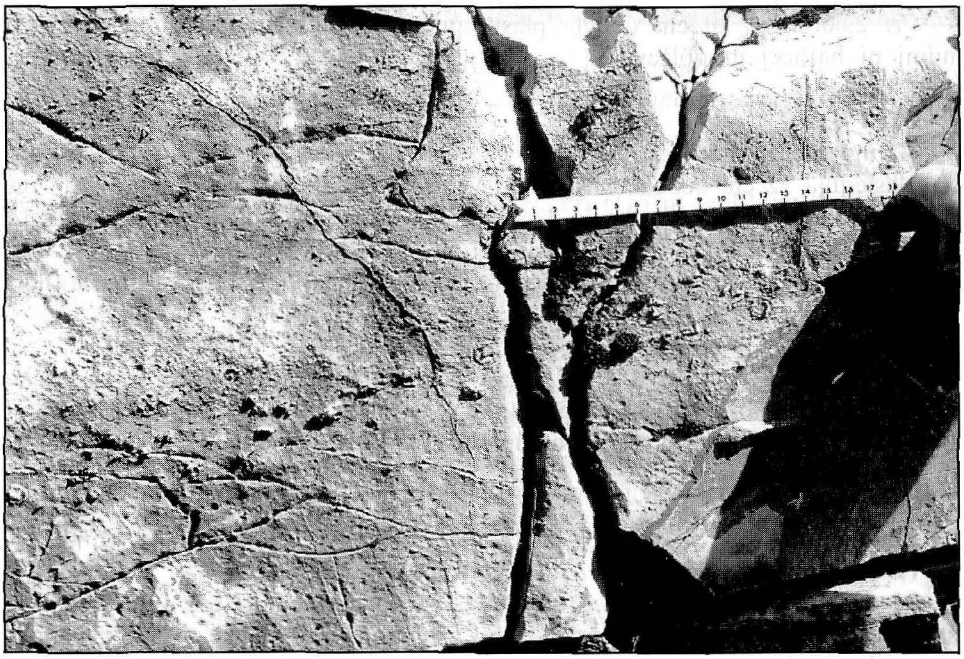
OPIS PROFILA DIVAČA

Plasti z bogato haracejsko favno ter horizonti s polži so v profilu Divača debele nekaj metrov. Pregledal sem profil v dolžini 86 m. Debelina pregledanega litološkega stolpca plasti pri Divači zanaša 25 m (slika 3). Vpad plasti 180/20 je večinoma enakomeren v celotnem profilu.

V apnencih iz profila Divača dobimo oogonije haracej z drugimi deli rastline. Po G. Stacheju (1889) je to Lagynophora liburnica. Poleg nekaj drugih nahajališč v Evropi so v kozinskih plasteh južne Slovenije haraceje iz rodu Lagynophora najštevilčnejše (G. Bignot & L. Grambast, 1969).

Profil sem začel opisovati tam, kjer se začno v večjih množinah pojavljati polži. Hkrati sem iskal čim več horizontov s haracejami. Največ haracej je v srednjem delu profila.

V profilu Divača sem natančneje opisal 42 plasti. V opisih plasti so vključeni vsi horizonti s polži in vsi s haracejami ter vmesne plasti, v katerih sem opazil spremembo v sedimentaciji in vzel vzorce. Zaradi večinoma slabe ohranjenosti polžev in težavnega izluščenja iz kamnine, sem določil le tri rodove: Stomatopsis sp., Cosinia sp.? in Kallomastoma sp.?.



Sl. 4: Prvi horizont s polži
Fig. 4: The first horizon with Mollusca

Plast 1
(Prvi horizont s polži)
Prvi polži iz rodu Stomatopsis sp. so v horizontu, debelem 35 cm. Pojavijo se naenkrat v veliki množini. Daljša os hišic je vzporedna s plastmi. V prvih desetih centimetrih horizonta so hišice polžev večinoma visoke do 4 cm in široke do 1,2 cm. V naslednjih desetih centimetrih so hišice visoke do treh centimetrov in imajo premer manjši od enega centimetra. V apnencu nad tem horizontom tudi manjših polžev ni več. Polži enako hitro, kot se pojavijo, tudi izginejo. Nekaj centimetrov nad plastmi z zadnjimi polži so različni odlomki fosilov. V teh plasteh ni haracej in miliolid (slika 4).

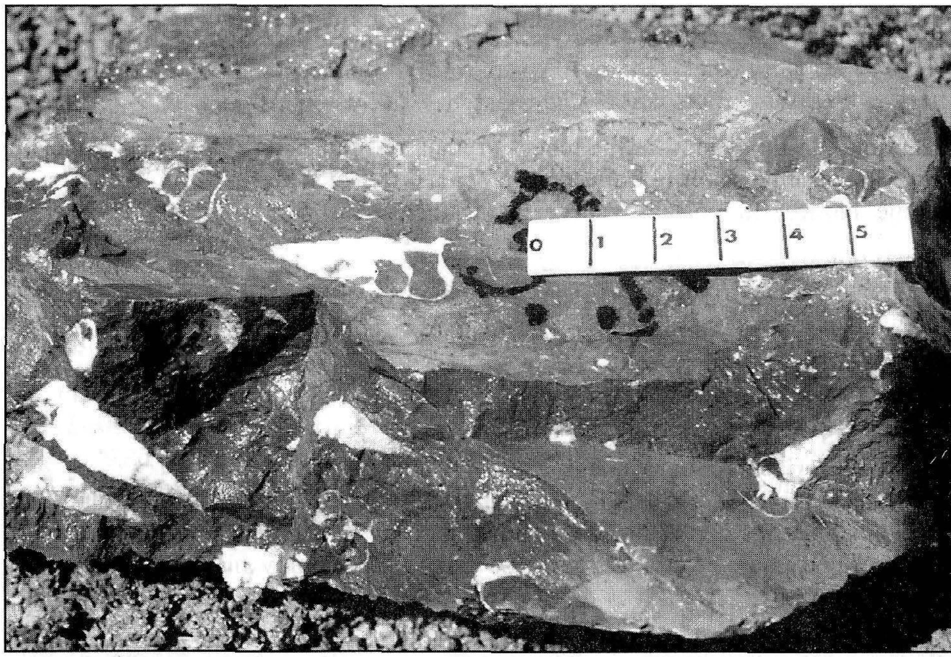
Plast 2
(Prvi horizont s haracejami)
Nad horizontom s polži je 10 cm debel apnenec z miliolidami. Najpogostejša rodova sta Quinqueloculina in Triloculina. Nad miliolidami se pri 45 cm pojavijo v 2 cm debelem horizontu prve haraceje.
Navzgor sledi apnenec mikritnega tipa brez fosilov. Do 1,20 m je debeloplastnat, nato so do 2,60 m plasti debele od 30 do 40 cm.

Plast 3
Pri 2,60 m je 30 cm debela plast apnenca s številnimi miliolidami. Med njimi ni haracej in polžev.

Plast 4
(Drugi horizont s polži)
Naslednja 12 cm debela plast sivorjavega apnenca s polži Stomatopsis je pri 3,40 m. Hišice polžev so visoke 3 cm, široke okrog 7 mm. Vmes so nekatere manjše od 1 cm. Med polži ni haracej.
Pri 3,75 m je med plastmi apnenca 4 do 5 cm debela laporna plast brez fosilov.

Plasti 5 in 6
Apnenec postane pri 3,80 m (plast 5) bolj temnorjav. V njem so redke miliolide. Pri 4,40 m (plast 6) najdemo v apnencu poleg posameznih miliolid tudi polže. V pretrtem apnencu med 4,70 m in 5,40 m miliolid ni več. Pri 4,90 m so posamezne haraceje.

Plast 7
(Tretji horizont s polži)
Med 5,40 m in 5,70 m je tretja plast s polži, med katerimi so ponekod številne miliolide. Hišice polžev iz rodu Stomatopsis so visoke večinoma okrog 4 cm in široke 1 cm. Precej pogosti so tudi manjši polži (Cosinia sp.? in Kallomastoma sp.?), visoki okrog 1 cm. Polži imajo notranjost hišic zapolnjene z debelokristalnim sparitom (slika 5).



Sl. 5: Številni polži so zapolnjeni z debelokristalnim sparitom
Fig. 5: Numerous Mollusca are filled by coarse-crystalline sparite

Pri 5,80 m so v nekaj milimetrov debelem horizontu v mikritnem apnencu do 2 mm velike zapolnitve železovih oksidov. Pri 6,15 m je 12 cm debela plast tankoplastnatega, lapornatega apnenca. Naslednja laporno plast je pri 6,80 m. Vmes je apnenec s številnimi miliolidami, katerega plasti so debele od 5 do 10 cm. Miliolide se v lapornih plasteh ne pojavljajo. Med 6,80 m in 6,85 m je 5 cm drobnolameliranega lapornatega apnenca.

Plasti 8, 9, 10 in 11
(Drugi horizont s haracejami)

Plasti med 6,85 m (plast 8) in 7,70 m (plast 11) vsebujejo številne dobro ohranjene haraceje. Na površini plasti so posamezni izluženi oogoniji haracej. Haraceje so najpogostejše v zgornjih 30 cm-tih drugega horizonta s haracejami med 7,40 m in 7,70 m.

Plast 12

Vzorec sem v plasti 12 vzel tik nad drugim horizontom s haracejami pri 7,80 m. Tu je apnenec še zelo homogen in neplastnat. Od 7,80 m do 7,90 m je apnenec lapornat in drobnoplastnat ter močno bituminozen. Debelina posameznih plasti je od približno enega do nekaj milimetrov. V teh plasteh so posamezne, zaradi pritiskov stisnjene, vendar ohranjene haraceje. Polžev v tej plasti ni.

Plast 13

Drobnoplastnati laporni apnenec prehaja v neplastnati apnenec trinajste plasti. Neplastnat, svetlo do temnorjav apnenec med 7,90 m in 8,50 m ne vsebuje haracej in polžev. Vzorec iz plasti 13 sem vzel pri 8,10 m.

Plast 14
(Četrti horizont s polži)

Pri 8,50 m je 30 cm debel apnenec s posameznimi majhnimi polži s hišicami, velikimi nekaj milimetrov.

Plast 15
(Tretji horizont s haracejami)

Pri 8,80 m je 3 cm debela laporna plast (slika 6). Ta plast prehaja v 10 cm debel horizont neplastnatega apnenca z redkejšimi haracejami. Haraceje pri 9 m skoraj izginejo. Nato so zopet vse pogostejše, čeprav ni vidnih sprememb v sedimentu.

Sl. 6: Ena od lapornih plasti, nad katerimi se pojavljajo haraceje
Fig. 6: One of marl layers above which Haracea appear

Plast 16
(Četri horizont s haracejami in peti horizont s polži)
Nad devetim debelinskim metrom so v 30 cm debelem apnencu svetlosive barve pogostejši polži, pomešani s haracejami. Hišice polžev (Stomatopsis) so večinoma prekristaljene, notranjost je zapolnjena z debelokristalnim sparitom. Haraceje so dobro ohranjene. Apnenec je bituminozen.
Plast 17
(Peti horizont s haracejami)
Drugi najbogatejši horizont s haracejami je pri 9,35 m. Izredno številni oogoniji in drugi deli rastlin - predvsem talusi, so v 10 cm debelem apnencu. V tem horizontu polžev nisem našel. Pri 9,45 m haraceje nenadoma izginejo.

Plast 18
(Šesti horizont s polži)
Pri 9,80 m se v laminiranem apnencu pojavijo posamezni polži. Kakih 20 cm više so v temnorjavem apnencu redke miliolide. Temu apnencu sledi pri 10,20 m 3 do 5 cm debela laporna plast.

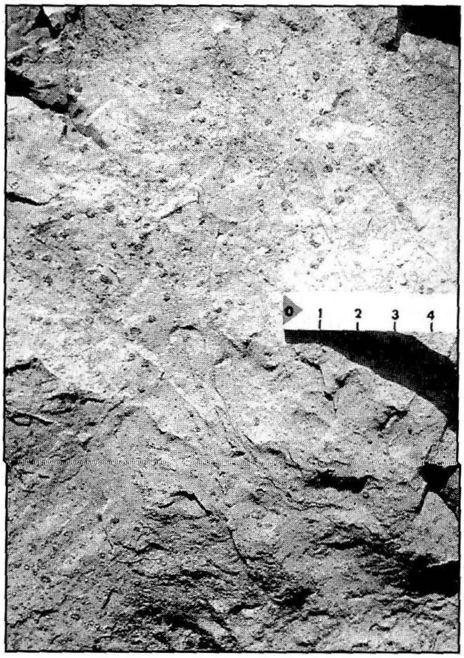
Plast 19
(Šesti horizont s haracejami in sedmi horizont s polži)
Naslednjih 50 cm profila do 10,75 m je horizont s haracejami in ter tankolupinastimi, do 1 cm visokimi polži (Cosinia?). Haraceje so zelo dobro ohranjene in so pri večini poleg oogonijev tudi ostali deli rastlin.

Plast 20
(Sedmi horizont s haracejami in osmi horizont s polži)
Med 10,80 m in 11 m je apnenec s posameznimi haracejami in večjimi polžjimi hišicami, visokimi in širokimi 1,5 cm. Pri 11,00 m polži in haraceje izginejo.

Plast 21
Pri 11,20 m je mikritni apnenec brez polžev in haracej.

Plast 22
Pri 12 m so v bituminoznem apnencu rjave do črne lise, razporejene v smeri plastovitosti. V njem ni polžev in haracej. Podobno je pri 12,25 m in 12,90 m.

Plast 23
(Osmi horizont s haracejami)
Pri 12,70 m se začne osmi in hkrati najdebelejši horizont s številnimi haracejami (slika 7). Poleg oogonijev dobimo še druge dele alg. Debelina pretrtih plasti apnenca je okrog 10 do 20 cm. Posamezni, do 1 cm visoki polži, se pojavijo prav na vrhu osmega horizonta s haracejami.



Sl. 7: Osmi horizont s haracejami
Fig. 7: Horizon with Haracea and Mollusca

Plasti 24, 25 in 26

Podobno kot pri prejšnjih plasteh je tudi v vzorcih 24 (na 12,90 m), 25 (na 13,50 m) in 26 (na 14,80 m). Med 14 in 15 m so haraceje dobro ohranjene in večkrat zelo številne. Posamezni deli rastlin so večinoma veliki med 4 in 5 mm, nekajkrat tudi večji.

Pri 15 m se med haracejami pojavljajo posamezni polži, katerih hišice so visoke do 5 cm.

Plasti 27 in 28

Pri 15,20 m (plast 27) je v apnencu še vedno veliko bolj ali manj nepoškodovanih delov haracej (oogoniji, preseki talusov in drugo).

Pri 15,45 m (plast 28) haracej ni več. Tu se zaključi osmi horizont s haracejami. Najdebelejši in najbogatejši horizont s haracejami v profilu Divača je debel torej 2,75 m.

Zgornji nivo osmega horizonta s haracejami je od apnenca brez polžev in haracej, ki je nad osmim horizontom s haracejami, ločen z 2 cm debelo plastjo drobnoplastnatega lapornega apnenca. Zanimivo je, da se v skoraj tri metre debelem horizontu s haracejami polži pojavljajo le izjemoma.

Med plastema 28 in 29 se haraceje in polži pojavljajo le posamično. Drugih fosilov v mikritni osnovi ni.

Plast 29
(Deveti horizont s haracejami in deveti horizont s polži)

V spodnjem delu devetega horizonta s haracejami in polži je pri 15,70 m (plast 29) 3 do 4 cm debel horizont z zelo številnimi polži (Kallomastoma sp.?). Hišice polžev so visoke do 2 cm in imajo tanke stene.

Proti vrhu devetega horizonta s haracejami med 15,80 m in 16,20 m opazimo postopno upadanje števila haracej in hkrati rast števila polžev. Haraceje pri 16,20 m pod 3 do 5 cm debelo plastjo tankoplastnatega lapornega apnenca popolnoma izginejo. Dva centimetra nad laporno plastjo so v svetlorjavem apnencu posamezne haraceje.

Plast 30
(Deseti horizont s polži)
Med 16,50 m in 16,70 m so s številnimi drobnimi polži (Cosinia sp.?), manjšimi od 1 cm. Izjemoma so posamezni polži veliki do 2 cm. Tu ni haracej.

Plast 31
(Deseti horizont s haracejami)
Od 16,70 m (vzorec 31) do 17,20 m je veliko haracej. Polžev ni ali so zelo redki. Pri 17,10 m je sredi apnenca s haracejami 8 do 10 cm debela plast lapornega apnenca.

Plast 32
(Enajsti horizont s haracejami in enajsti horizont s polži)
Pri 17,15 m so v 8 do 10 cm debelem lapornem apnencu številne haraceje. Razporejene so vzporedno s plastnatostjo. Tudi na površini plasti je videti številne predvsem oogonije skupaj z okrog 2 cm visokimi polži. Kamnina je temnosiva in bituminozna, ponekod vsebuje velike koncentracije haracej in polžev.

Plast 33
(Dvanajsti horizont s polži)
Pri 17,50 m (plast 33) je podobno kot v plasti 32, le da so tu številni majhni polži (pod 1 cm). Pri 18,20 m polžev ni več. Apnenec je temnorjav in gost.

Plast 34
(Trinajsti horizont s polži)
Polži se pojavijo tudi med 18,80 m in 19,45 m. Njihove hišice so visoke od 3 do 4 cm. V tem horizontu ni haracej. Nad trinajstim horizontom s polži je 5 cm debela plast lapornatega apnenca.

Plast 35
V apnencu pri 19,70 m ni niti haracej niti polžev. Plasti so od 19 m do konca profila debele večinoma do 1 m.
Plast 36
Od 20,00 m (plast 36) do 20,60 m je v profilu svetlosiv apnenec s številnimi, do 1 mm velikimi, nepravilno oblikovanimi fenestrami, ki so zapolnjene s sparitom. V tem delu profila ni haracej in polžev. Pri 20,60 m je tanka (2 do 3 cm debela) laporna plast.

Plast 37
Apenčeva plast se začne pri 20,60 m tik nad 2 do 3 cm debelo laporno plastjo. V apnencu ni polžev in haracej.

Plast 38
(Štirinajsti horizont s polži)

Pri 20,65 m je 20 cm debel horizont s številnimi velikimi polži (Stomatopsis) z višino hišic od 4 do 5 cm ter širino tudi preko 2 cm, vendar brez haracej. Štirinajsti horizont s polži se hitro zaključi in preide v apnenec brez fosilov.

Pri 21,50 m je 5 do 10 cm debela laporna pola.

Plast 39
(Dvanajsti horizont s haracejami)

Takoj nad laporno plastjo se v črnem bituminoznem apnencu zopet pojavijo haraceje. Horizont s haracejami je debel 40 cm in sega do 22,00 m. Haraceje so po celotnem horizontu enakomerno razporejene. Polžev ni skupaj s haracejami. Dvanajstemu horizontu s haracejami sledi 10 cm debela plast temnega apnenca brez polžev in haracej.

Plast 40
(Trinajsti horizont s haracejmi in petnajsti horizont s polži)

Pri 22,00 m je 0,5 cm debela plast lapornatega apnenca. Med 22,00 m in 22,20 m so v apnencu s haracejami in polži številčnejše haraceje (slika 8). Posamezni polži (Kallomastoma sp.?) med haracejami so visoki do 2 cm. Pri 22,55 m v apnencu haracej in polžev ni več.

Sl. 8: Horizont s haracejami in polži
Fig. 8: Horizon with Haracea and Mollusca

Plast 41

Pri 22,60 m je apnenec temen, skoraj črn. Pri 23,20 m se začne 60 cm debel horizont svetlo sivorjavega, gostega apnenca. Na 23,60 m je v opisanem profilu zadnja laporno apnenčeva plast, debela 5 cm. V teh plasteh polžev in haracej ni.

Plast 42
(Šestnajsti horizont s polži)

Pri 24 m je zadnji horizont s polži (Kallomastoma sp.?), debel 20 cm. Polži imajo do okrog 4 cm visoke hišice (slika 9). Večinoma niso koničasti, temveč imajo zaokrožene hišice. Do 25 m najdemo ponekod še posamezne polže.

Sl. 9: Šestnajsti horizont s polži
Fig. 9: The 16th horizon with Mollusca

PALEOGEOGRAFSKE IN PALEOEKOLOŠKE ZNAČILNOSTI

LIBURNIJSKA FORMACIJA

Sedimenti liburnijske formacije naj bi se po G. Stachejeveih (1872) predstavah usedale v bližini zelo razčlenjene obale. Morje naj bi bilo deloma brakično, med lagunami pa naj bi bili estuariji in ločena obalna jezera (G. Stache, 1889). Z upoštevanjem pojavljanja koskinolin in miliolid se M. B. Cita (1955) bolj navdušuje za epikontinentalni kot kontinentalni nastanek liburnijskih plasti.

Pri sladkovodnih plasteh liburnijske formacije se je G. Stache (1889) opiral na polže, plasti premoga in haraceje. Vse tri značilnosti vremskih in kozinskih plasti se v številnih plasteh in horizontih pojavljajo v raziskanih profilih. Za polže je R. Pavlovec (1963a, 1963b) izrazil dvom, da bi bili sladkovodni. M. Hamrla (1959) je prišel do zaključka, da so premogi nastajali tudi v limnično-brakičnem okolju. Nekateri mislijo, da je bil kras v času odlaganja liburnijske formacije že dobro razvit (M. Hamrla, 1959; 1960) in da zato ne moremo pričakovati številnih tekočih voda, ki bi polnile obalna jezera (R. Pavlovec, 1963a).

Podobno opisuje zgodovino nastajanja tega dela ozemlja S. Buser (1973, 1989). V zgornjem senoniju so se nekateri deli Tržaško - Komenske planote dvignili iz morja. V senoniju in paleocenu so se pogosto menjavali morski, brakični in sladkovodni pogoji sedimentacije.

Po novejših raziskavah niso plasti liburnijske formacije v celoti morske ali v celoti sladkovodne. Nad vremskimi plastmi so apnenci s številnimi haracejami. Ti apnenci kažejo na bližino sladkovodnega ali brakičnega okolja (R. Pavlovec, 1981).

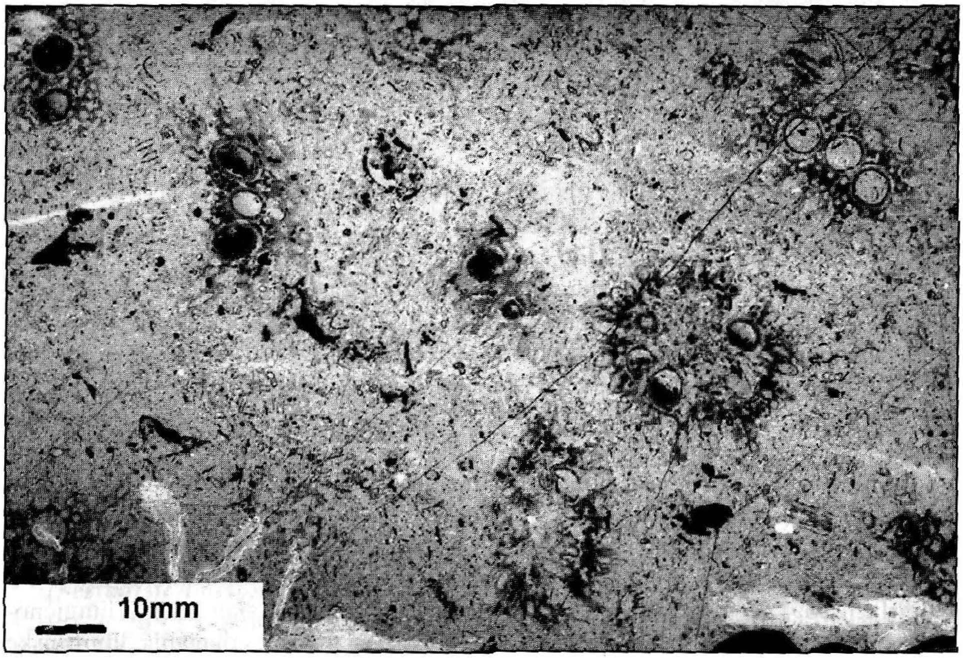
KOZINSKE PLASTI

Tipi horizontov s haracejami in polži

V profilih, ki sem jih pregledal v kozinskih plasteh, izstopajo trije tipi horizontov po katerih sklepam na paleoekološke razmere med njihovo sedimentacijo. Pri tem se mi zdijo najbolj uporabni ostanki haracej.

Tip A: horizonti s haracejami (haracejski travniki po G. Stacheju).

Tu združujem horizonte s haracejami, ki ne kažejo znakov vsaj večjega transporta. To pomeni, da so poleg oogonijev v sedimentu ohranjeni tudi drugi deli steljk alg (slika 10).



Sl. 10: Haraceje ne kažejo znakov daljšega transporta
Fig. 10: Haracea do not display signs of longer transport

Tip B: horizonti z oogoniji.
Tip B označuje horizonte s haracejami, ki kažejo znake transporta. Od celotne rastline so ohranjeni le oogoniji.
Tip C: horizonti s haracejami in polži.
Tip C označuje horizonte, v katerih se pojavljajo haraceje in polži (slika 11).
Tip D: horizonti s polži.
Tip D označuje horizonte, v katerih se pojavljajo samo polži (slika 12).

Sl. 11: Del nekdanjega haracejskega "travnika"
Fig. 11: In some horizons only Mollusca appear

Sl. 12: V nekaterih horizontih se pojavljajo samo polži
Fig. 12: A part of former "Haracea meadow"

INTERPRETACIJA HORIZONTOV S HARACEJAMI IN POLŽI

Pri haracejah je potrebno upoštevati, da jih vodni tokovi in valovi z lahkoto prenašajo. Zaradi tega najdemo v večini apnencev kozinskih plasti le presedimentirane haraceje (tip B). Zaradi krhkosti se deli steljke med transportom zdrobijo in porazgubijo v sedimentu. Na sekundarnem mestu se zato največkrat ohranijo samo njihovi oogoniji. A. Carozzi (1953) meni, da imamo lahko za avtohtone le tiste horizonte, v katerih so poleg oogonijev tudi deli celih rastlin. Podobno razmišlja R. Pavlovec (1963a), ki pravi, da je večina ostankov haracej v liburnijskih sedimentih na sekundarnem mestu. Ostanki haracejskih travnikov so samo tisti horizonti s haracejami, v katerih so poleg oogonijev ohranjeni še številni drugi deli rastlin. Zato sklepa, da tudi haracej ne moremo imeti za zanesljiv znak sladkovodnega okolja sedimentacije. To domnevo podkrepi z ugotovitvijo, ki sta jo podala A. Remane in C. Schlieper (1958), da se haracejski travniki pojavljajo ob ustjih obrežnih jezer, ki niso sladka. Omenjena avtorja zatrjujeta, da se ponekod pojavljajo v sladki in brakični vodi celo iste vrste. C. A. Davis (1900) je ugotovil, da se recentni harofiti pojavljajo v "tratah", debelih od 10 do 20 cm, kjer je na kvadratnem decimetru našel 50 do 80 osebkov. Isti avtor je iz petih primerkov rodu Chara dobil 3,0518 g kalcijevega karbonata, kar pomeni, da eni rastlini pripada 0,61036 g. L. Cayeux (1935) ugotavlja, da so haraceje važen vir kalcijevega karbonata pri nastanku sladkovodnih sedimentov, saj haraceje neposredno vežejo kalcijev karbonat (M. Hamrla, 1959).

Številni horizonti s haracejami iz profila Divača (tip A) so glede na zgoraj navedene podatke nedvomnno del nekdanjega haracejskega "travnika", saj sicer ne bi bilo ohranjenih toliko celih delov rastlin. Zato je možna ideja G. Stacheja (1889), ki je predvideval, da so haraceje iz liburnijskih plasti živele v zaprtih sladkovodnih jezerih, v katerih naj bi se menjavala višina vode (R. Pavlovec, 1963a, 1963b). Ostanki haracej so v nekaterih horizontih v profilu Divača tako številni, da si je tolikšno produkcijo težko predstavljati v majhnih lokalnih haracejskih naseljih, kot jih imenuje R. Pavlovec (1963a). Zato se je isti avtor (1963a) navduševal za brakično okolje sedimentacije horizontov z haracejami.

Različni avtorji navajajo predvsem tri področja, v katerih živijo oziroma naj bi živele haraceje. To je sladkovodno okolje, morsko okolje ter brakično okolje. Mnogi se izognejo točnejši opredelitvi in govorijo o "nemorskem" življenskem okolju haracej.

1) Sladkovodno okolje

Številni avtorji (G. Stache, 1889; M. Hamrla, 1959; 1960; N. K. Pantič, 1960; M. Herak, 1963; M. Bilotte, 1980 in drugi) pišejo da so haraceje živele v mirnem sladkem vodnem okolju.

Danes so haraceje po nekaterih avtorjih (N. K. Pantič, 1960) izključno vodne rastline, ki navadno žive v sladkih in brakičnih vodah bogatih s kalcijevim karbonatom. Po drugih avtorjih (C. A. Davis, 1900) dobimo haraceje danes tako na površju kot v globljih delih močvirij in jezer.

2) Morsko okolje

S. Olsen (1944) navaja, da je našel vrsto Chara baltica, ki jo najpogosteje navajajo kot morsko vrsto, v Baltiškem morju, kjer je slanost le 18 promilov.

Ugotovil je, da večina vrst harofitov lahko obvladuje znaten razpon v množini kalcijevega karbonata v vodi, odločilnega pomena pa so pH pogoji. Prišel je do zaključka, da se harofiti ne pojavljajo v zelo kislih vodah, nekaj jih je možno dobiti v prehodnih kislo-alkalnih vodah, večina pa jih živi v alkalnem okolju.

Spiralno oblikovane kalcitizirane dele oogonijev (girokonit) najdemo tudi v recentnih morskih sedimentih kot tudi v "Ocala" apnencih na Floridi (R. E. Peck & C. C. Reker, 1948; C. S. Chen, 1965).

3) Brakično okolje

G. Stache (1889) je mneja, da se haraceje lahko prilagodijo tudi na brakični način življenja. Podobno zatrjuje tudi M. Hamrla (1959; 1960). Po drugih avtorjih (W. N. Croft, 1952) recentne haraceje žive popolnoma potopljene v plitvo, bolj ali manj gibajočo sladko ali brakično vodo. V takšnih pogojih so živele tudi fosilne alge od devonija naprej.

R. E. Peck (1957) meni, da se pojavljajo harofiti v morskih sedimentih zaradi transporta drobnih oogonijev iz njihovega izvornega prostora in trdi, da niso nikoli živeli v pravem morskem okolju. Glede na raziskave v severni Ameriki R. A. Peck (1957) zatrjuje, da predstavlja skupina Charophyta nemorske vodne rastline. Predstavnike teh organizmov najdemo po vsem svetu v nemorskih apnenčastih sedimentih kamninah. L. Rakosi (1989) navaja, da so živeli vsi paleogenski primeri harofitov v limnični ali brakični vodi.

M. Herak (1963) omenja možnost, da so harofiti najprej živeli v morskem okolju, nato brakičnem in nazadnje v sladkovodnem vodnem okolju. G. Bignot (1966, 1972, 1987), G. Bignot in L. Grambast (1969) ter M. Cousin (1964) menijo, da rodova Porochara in Lagynophora kažeta pri nas na zelo malo slano lagunsko do jezersko okolje. Podobno meni tudi R. Goldring (1991).

R. Pavlovec in M. Pleničar pišeta (1981), da je srednji del liburnijske formacije (kozinske plasti) nastajal v lagunskem, jezerskem in brakičnem okolju. Opozarjata na premogove vložke. Zaradi številnih haracej se za lagunaren razvoj kozinskih plasti zavzemata tudi J. Pavšič in M. Pleničar (1981). Na drugi strani pa R. Pavlovec (1981) piše, da je srednji del liburnijske formacije s številnimi ostanki haracej, s sladkovodnimi polži in ostanki premoga najmanj morski, čeprav tudi ni povsem sladkovoden. Iz teh plasti omenja tudi apnenec s koralami, ki govori za morski sediment.

Tudi podatki o globini, v kateri naj bi živeli harofiti, niso enotni. M. Hamrla (1959; 1960) meni, da so haraceje najverjetneje živele do globine 15 m. L. Rakosi (1989) pravi, da recentni harofiti živijo do globine 30 m, C. A. Davis (1900) piše, da haraceje navadno žive v globinah od 10 do 15 metrov. Po drugih podatkih recentne haraceje žive v vodi globoki le do 6 metrov (N. K. Pantič, 1960).

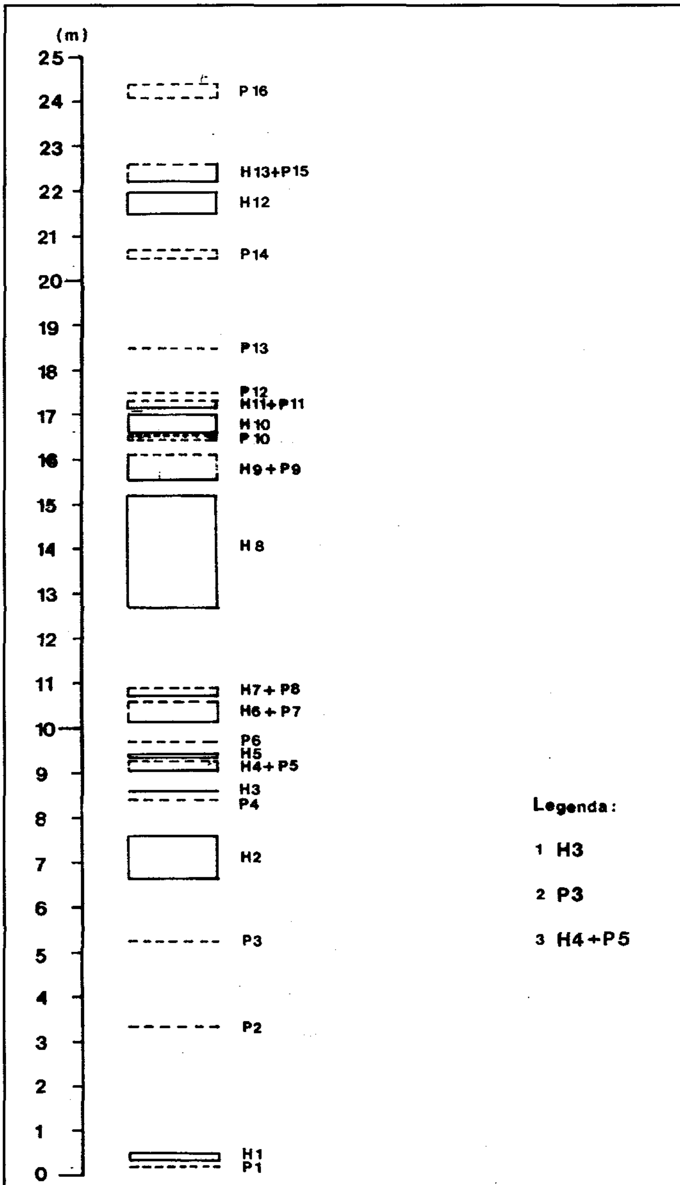
Predvsem v profilu Divača se vidi, da je med vsedanjem kozinskih plasti morska gladina večkrat malenkostno nihala in je lahko prišlo celo do okopnitev.

Na nihanje vodne gladine kažejo tanke laporne plasti med plastmi apnenca. Laporne plasti med plastmi apnenca so najverjetneje znak zelo plitve vode, katere vodna gladina je lahko nihala le za približno pol metra. Material, iz katerih so laporne plasti, naj bi prinesle v plitvo morje vode s kopnega med občasnimi okopnitvami. Večkraten vpliv sladke vode kažejo tudi rezultati raziskav izotopske sestave kisika in ogljika, ki jih je naredil U. Herlec. Takoj nad lapornimi plastmi so v večini primerov horizonti s haracejami. Tudi stromatolitni apnenci in številni znaki bioturbacije v nekaterih plasteh potrjujejo zelo plitvo vodo z bujno favno in floro. Vsekakor je zelo verjetno, da so se haraceje intenzivneje razvijale v nekoliko plitvejši vodi kot miliolide. Na občasno plitvejše okolje kažejo tudi ponekod številni debelolupinasti polži (Stomatopsis sp.), ki jih najdemo v neposredni bližini horizontov s haracejami.

G. Stache (1889) se je pri sklepanju o številnih sladkovodnih plasteh opiral na t.i. sladkovodne polže (Stomatopsis sp., Cosinia sp.?). Rod Stomatopsis ima močne navpične stebričke na površini hišice. Ustje je obdano s širokim, močnim robom. R. Pavlovec (1963a) je glede sladkovodnega življenjskega okolja stomatopsisov izrazil dvom, saj meni, da za življenje v sladki vodi ne bi pričakovali tako debelih hišic in na površini močnih grebenov. Večina recentnih sladkovodnih polžev ima znatno tanjše hišice, na površini pa mnogo šibkejša navpična ali radialna rebra. Močni grebeni in hišice so pogoste predvsem pri morskih ali vsaj brakičnih polžih, kot na primer pri rodi Cerithium sp. (R. Pavlovec, 1963a). Vendar najdemo v nekaterih horizontih v profilu Divača tudi tankolupinaste polže iz rodov Cosinia sp.? in Kallomastoma sp.?.

V nekaterih plasteh iz profila Divača, kjer se pojavljajo polži iz rodu Stomatopsis sp., najdemo poleg oogonijev haracej tudi številne druge dele haracej, ki zaradi dobre ohranjenosti in s tem nepresedimentiranosti kažejo na skupno življenje s polži. Večkrat sem v neposredni bližini horizontov z rodom Stomatopsis sp. dobil tudi številne miliolide, ki so morski organizmi. Torej je možno, da polži niso povsem ali samo sladkovodni. M. Hamrla (1959) navaja podatek, da se haraceje in miliolide pogosto pojavljajo skupaj. Podobno pišeta tudi J. Pavšič in M. Pleničar (1981).

Glede na vse povedano soglašam z R. Pavlovcem (1963a), ki dvomi v trditev G. Stacheja (1889), da bi bili polži iz rodu Stomatopsis značilni sladkovodni predstavniki. Zaradi spremlajočih horizontov z miliolidami tudi ne moremo z gotovostjo trditi, da so se vse kozinske plasti odlagale v sladki vodi. Kljub temu, da moramo pri paleoekološki interpretaciji upoštevati tudi haraceje, sem mnenja, da organizmi, ki sestavljajo biocenozo v profilu Divača niso značilni predstavniki sladke vode in so najverjetneje živeli v brakičnem do slanem okolju.



Sl. 13: Skica horizontov s haracejami in polži v profilu Divača: 1-horizont s haracejami, 2-horizont s polži, 3-horizont s haracejami in polži

Fig. 13: A sketch of horizons with Haracea and Mollusca in the Divača profile: 1-horizon with Haracea, 2-horizon with Mollusca, 3-horizon with Haracea and Mollusca

RAZMERJE MED HORIZONTI S HARACEJAMI IN HORIZONTI S POLŽI

Večina avtorjev ni ločeno obravnavalo posameznih horizontov s polži oziroma s haracejami. Med raziskovalci, ki so jih ločili je bil G. Stache (1859), ki je v okviru kozinskih plasti ločil spodaj ležeče stomatopsidne apnence, ki jih prekrivajo haracejski apnenci. Tudi M. M. Komatina (1967) je v kozinskih plasteh opisal v nekaterih horizontih številčnejše polže, v drugih haraceje. M. Hamrla (1959) je prišel je do zaključka, da so haraceje v plasteh pomešane s polži.

Polži in haraceje se ne pojavljajo v okviru ene ali več plasti temveč v horizontih, ki predstavljajo eno ali več plasti. V profilu Divača je 16 horizontov s polži in 13 s haracejami. V šestih horizontih so haraceje bolj ali manj pomešane s polži. Poudariti pa moram, da je od 23 horizontov, (kjer so polži ali haraceje ločene, oziroma so polži in haraceje v istem horizontu) 10 horizontov v katerih so samo polži in 7 horizontov, v katerih najdemo le haraceje. Samo 6 horizontov je, kjer so polži pomešani s haracejami (tip C, slika 13).

Polži iz rodu Stomatopsis sp. kot tudi tankolupinasti polži (Kallomastoma sp.?), ki so predvsem v zgornjem delu profila Divača, so dobro ohranjeni. Prav tako so odlično ohranjeni krhki rastlinski ostanki haracej, ki še v fosilnem stanju vključujejo oogonije v njihovem življenjskem položaju. To dokazuje, da najverjetneje niti polži niti haraceje niso pretrpeli transporta. Iz teh opazovanj sklepamo, da sta obe skupini organizmov živeli skupaj in nista bili združeni po smrti. Zato obe skupini organizmov najverjetneje predstavljata paleobiocenozo.

SKLEP

Osnovni namen naloge je bil proučevanje okolja sedimentacije tistega dela kozinskih plasti, kjer se pojavljajo haraceje in polži. Pri tem sem prišel do naslednjih ugotovitev.

1. Pri haracejah iz kozinskih plasti imamo primere, kjer so alge živele na mestu (Stachejevi haracejski "travniki").
2. Skupaj z nepresedimentiranimi haracejami se pogosto pojavljajo tudi polži.
3. Številne laporne pole in sledovi bioturbacije kažejo na večkratno nihanje vodne gladine in verjetno tudi na občasne okopnitve.
4. S kemično analizo kisikovih in ogljikovih izotopov v vzorcih je U. Herlec ugotovil večkraten vpliv sladke vode na morsko okolje ter s tem mešanje slane in sladke vode.

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PALEOECOLOGICAL PROPERTIES OF KOZINA BEDS NEAR ŠKOCJANSKE JAME CAVES

Summary

The study was carried out within the project Karst in Slovenia I, financed by the Ministry of Science and Technology of Republic of Slovenia.

In the Divača profile in the Kozina beds I studied the horizons with extremely large number of Haracea and Mollusca. I investigated the eventual relationship of appearance of these two groups. By these and some other fossils I tried to recognize paleoecological conditions during the sedimentation. The Divača profile lies in a road cutting of the main road Senožeče - Divača, about 800 m from the exit of the old road and the last incline before Divača. The area may be found on the southeastern part of Basic Geological Map SFRJ, sheet Gorica.

In the limestones of the Divača profile we get the oogonia of Haracea and other parts of the plant and sometimes numerous Mollusca. As at some other finding sites in Europe also the Kozina beds in southern Slovenia contain a

large number of Haracea belonging to Lagynophora genus. Within the Divača profile I described 42 layers with Haracea and Mollusca in detail.

In the profiles that I examined in the Kozina beds there are three outstanding horizons after which one may deduce the paleoecological conditions during their sedimentation. The remains of Haracea seem the most appropriate:

Type A: horizons with Haracea (according to Stache Haracea meadows). Here I joined the horizons with Haracea that were not affected by transport. It means that besides oogonia there are other parts of algae preserved in a sediment;

Type B: horizons with oogonia. These are horizons that show the traces of transport. From the entire plant, only oogonia are preserved;

Type C: horizons with Mollusca. Horizons consisting Mollusca only are considered.

In studying Haracae one must take into account that water curents and waves transport them easily. This is why only resedimented Haracea (Type B) are found in most of limestones of the Kozina beds. Due to fragility, parts of a plant are easily broken and lost among the sediment during the transport. Thus at the secondary place their oogonia only are preserved. Several authors think that most of the Haracea remains in Liburnian sediments are found in their secondary location. The remains of Haracea meadows are only those horizons with Haracea where there are numerous other parts of plants preserved, not only oogonia. This is why Haracea may not be a reliable proof freshwater sedimentation environment.

Numerous horizons containing Haracea in the Divača profile (Type A) undoubtedly belong, according to the above data, to former "Haracea meadows" as there are many parts of whole plants preserved. Thus the idea of G. Stache, presuming that Haracea of Liburnian beds lived in closed freshwater lakes where the water level varied, may be probable. In some horizons of the Divača profile the remains of Haracea are so numerous that such a production is difficult to imagine in small local Haracea settlements as they are called by R. Pavlovec. This is why the same author justified the brackish environment of Haracea horizon sedimentation. Various authors quote three enviroments where Haracea lived or are supposed to have lived. This is either fresh water environment, marine environment or brackish environment. Many of them avoid a precise definition and they speak of "non-marine" living environment of Haracea.

Most of authors did not study separately the horizons with Haracea and those with Mollusca. Mollusca and Haracea do not appear in one or several layers but in horizons that represent one or more layers. In the Divača profile there are 16 horizons with Mollusca and 13 with Haracea. In six horizons Haracea are more or less mixed with Mollusca. However it must be stressed that out of 23 horizons (where Mollusca and Haracea are separated, or in the same horizon) there are 10 horizons containing only Mollusca and 7 horizons where only Haracea can be found. Only 6 horizons contain Mollusca mixed with Haracea.

Especially in the upper part of the Divača profile the thin-shelled Mollusca are well preserved. Also well preserved are fragile plant remains of Haracea that even in a fossil state include oogonia in their living position. It proves that most probably neither Mollusca nor Haracea suffered transport. The conclusion from these observations can be, that these two groups of organisms lived together and were not mixed after their death. This is why both groups of these organisms probably represent a paleobiocenose.

The basic aim of this contribution is a study of sedimentation environment of that part of the Kozina beds where Haracea and Mollusca appear. I came to following conclusions:

1. In the Kozina beds we have cases of flora on the spots where algae lived (Stache's Haracea meadows) and cases of resedimented parts of Haracea (oogonia).
2. We presume that oogonia were transported by water currents towards deeper parts of a sedimentation basin.
3. Mollusca often appear together with not-resedimented Haracea.
4. Numerous patches of marl and traces of bioturbation record that water level oscillated and sometimes even disappeared.
5. By chemical analysis of oxygen and carbon isotopes in the samples a repeated influence of fresh water to saline environment was determined and hence mixing of marine and fresh water.

DIET OF THE TAWNY OWL (*STRIX ALUCO*) IN THE KARST ENVIRONMENT NEAR ŠKOCJANSKE JAME (SW SLOVENIA)

PREHRANA LESNE SOVE *(STRIX ALUCO)* V KRAŠKEM PREDELU BLIZU ŠKOCJANSKIH JAM (JZ SLOVENIJA)

LOVRENC LIPEJ & MIRAN GJERKEŠ

Izvleček UDK 598.88:591.13

Lovrenc Lipej & Miran Gjerkeš: Prehrana lesne sove (*Strix aluco*) v kraškem predelu blizu Škocjanskih jam (JZ Slovenija)

V kraškem predelu blizu Škocjanskih jam (jugozahodna Slovenija) smo raziskali prehrano lesne sove (*Strix aluco*). Njene izbljuvke smo pobirali na počivališču ob vhodu v jamo v obdobju 1992-1993. Najpomembnejša vrsta plena je bil polh (*Myoxus glis*), ki je sestavljal 37,7% celotnega plena in 83,5% biomase vsega plena. Žuželke so bile pomembna skupina nadomestnega plena. V članku podajamo tudi spremembe v prehrani v različnih letnih časih.

Ključne besede: lesna sova, *Strix aluco*, prehrana, polh, *Myoxus glis*, Slovenija, Kras, Škocjanske jame

Abstract UDC 598.88:591.13

Lovrenc Lipej & Miran Gjerkeš: Diet of the Tawny Owl (*Strix aluco*) in the karst environment near Škocjanske Jame (SW Slovenia)

The diet of the Tawny Owl (*Strix aluco*) was studied in karst area near Škocjanske Jame (Škocjan Caves) in the southwestern part of Slovenia. Pellets were collected during the 1992-1993 period in the cave entrance in the submediterranean forest belt. The dominant prey group was the Fat Dormouse (*Myoxus glis*), 37.7% by number and 83.5% by weight. Insects were the most important alternative prey. Seasonal variations in the diet are also discussed.

Key words: Tawny Owl, *Strix aluco*, diet, Fat Dormouse, *Myoxus glis*, Slovenia, Kras, Škocjanske Jame

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INTRODUCTION

The Tawny Owl (*Strix aluco*) feeds on a wide range of prey, mainly on small mammals but also on other vertebrates and invertebrates. The diet of this nocturnal raptor has been investigated extensively in most parts of Europe (Southern, 1954; Delmee *et al.,* 1982; Mikolla, 1983; Sara & Massa, 1985; Bochensky, 1990; Kirk, 1992;. Zalewski, 1994). Although the Tawny Owl (*Strix aluco)* is a common owl species throughout Slovenia (Geister, 1995), there is only a scarce number of studies on the diet of this nocturnal bird. Reports on its diet have come from the NE part of Slovenia (Janžekovič, 1986; Šorgo & Janžekovič, 1995) and from the Slovene part of Istria (Lipej, 1988).

This paper presents information about the diet of the Tawny Owl in the submediterranean karst environment near Škocjanske Jame, which are, as an internationally important site, listed in the UNESCO List of World Natural Heritage.

METHODS

Whole and partially broken pellets were collected in a rocky limestone habitat located near doline of Sokolak near Škocjanske Jame. They had accumulated under the nest in the cave entrance. In order to study the seasonal variation in the diet, samples were gathered 4 times in 1992 and once in 1993.

Pellets were broken by hand and all undigested prey remains were sorted and separated. Small mammals were identified from cranial remains by diagnostic features according to Kryštufek (1985, 1991). Birds were determined on the basis of skull remains and humeri, while insects and other invertebrates were identified as to order from chitinous fragments of wings, elitrae and heads. For the abundance assessment of mammal remains, the minimum number of individual prey was counted. The mean prey weight of small mammals for biomass calculations were obtained from Lipej (1988). The mean prey weight of birds (thrushes) and invertebrates was roughly estimated.

STUDY AREA

Breeding site of the Tawny Owl is situated in the rocky habitat near the dolina of Sokolak (Fig. 1), which is covered with dense forest vegetation. The

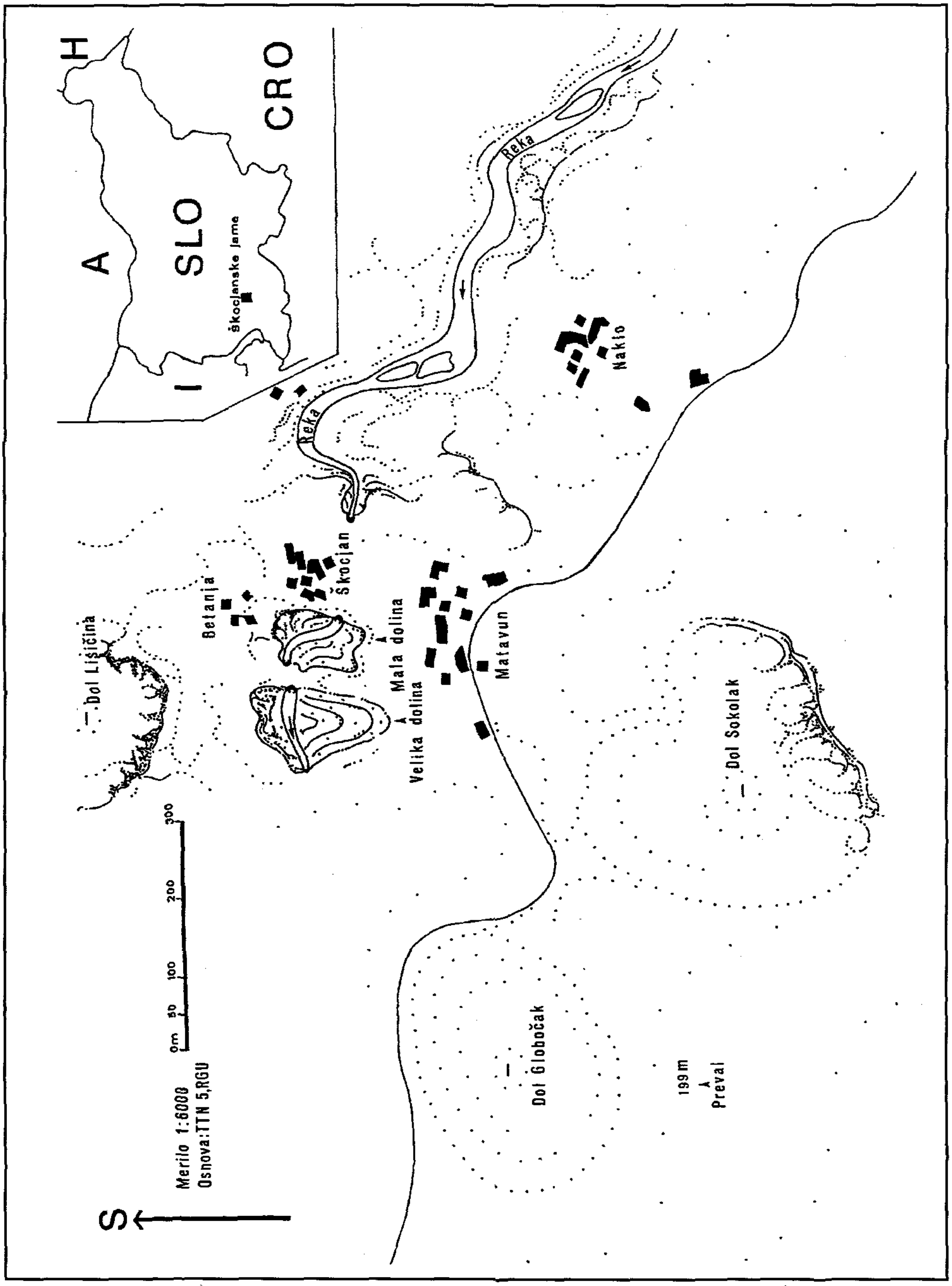

Fig. 1: The study area
Sl. 1: Zemljevid obravnavanega območja

owl's nest is oriented towards doline with a large field in its central part, surrounded by a forest belt. The study area is located in the submediterranean phytogeographic area according to M. Wraber's phytogeographical vegetational map of Slovenia. The background is typically karstic. The forest vegetation is constituted of thermophilous forest association *Ostryo-Quercetum pubescentis* and karst meadows in phase of succession (Kaligarič, pers. comm.).

RESULTS

A total of 321 prey specimens were recovered from 144 whole and some partially broken pellets during the period from 1992 to 1994. Five brown pellets also contained earthworms (Oligochaeta), sand grains and vegetable

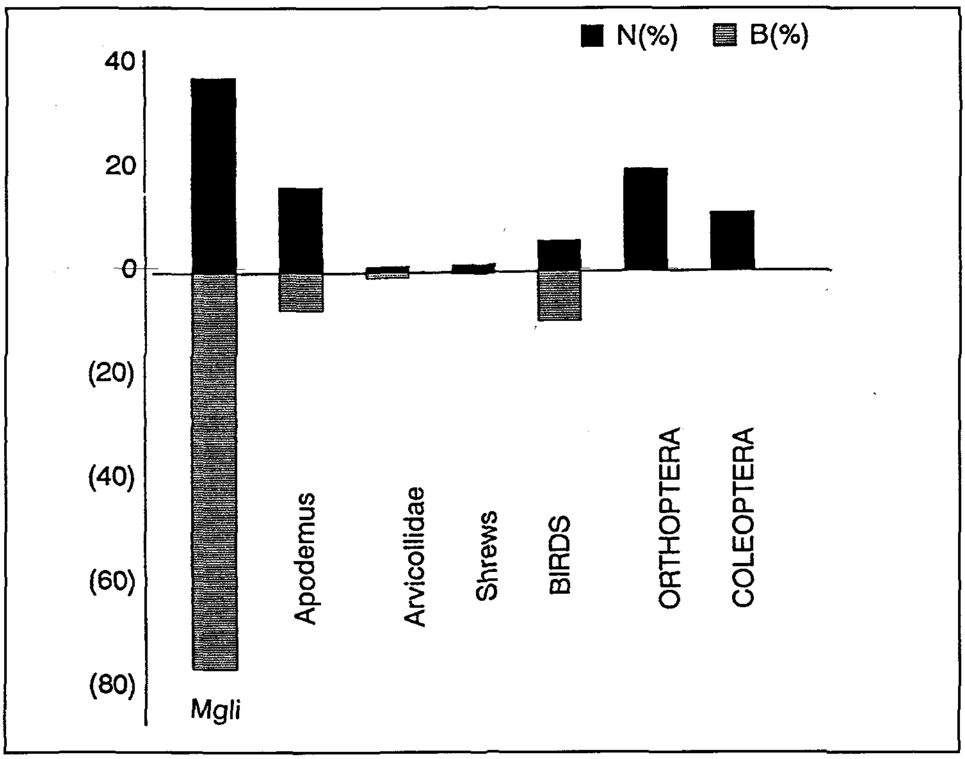

Fig. 2: The proportions of important prey groups in the diet of the Tawny Owl in terms of abundance (N) and biomass (B). Mgli is abbreviation for the Fat Dormouse (Myoxus glis).

*Sl. 2: Deleži najpomembnejših skupin v celotni abundanci (N) in biomasi (B) plena v prehrani lesne sove. Kratica Mgli označuje polha (*Myoxus glis*).*

prey species	**N**	**N(%)**	**B(%)**	**W(g)**
Myoxus glis	121	37.7	76.2	125
Muscardinus avellanarius	4	1.2	0.6	27.5
Apodemus agrarius	1	0.3	0.1	20.5
Apodemus flavicollis	16	5.0	2.8	35
Apodemus sylvaticus	8	2.5	1.0	24.5
Apodemus spp.	28	8.7	3.5	24.5
Rattus spp.	2	0.6	0.7	72
Pitymys liechtensteini	1	0.3	0.1	20
Chionomys nivalis	3	0.9	0.7	49
Talpa europea	8	2.5	3.8	95
Sorex minutus	1	0.3	< 0.1	4.5
Crocidura suaveolens	2	0.6	< 0.1	5
Crocidura leucodon	2	0.6	0.1	10
Myotis sp.	1	0.3	0.2	20
PASSERIFORMES	19	5.9	9.6	100
DIPLOPODA	1	0.3	< 0.1	1
ORTHOPTERA	65	19.6	> 0.1	1
COLEOPTERA	36	11.2	> 0.1	3
LEPIDOPTERA	1	0.3	> 0.1	1
sum	321	100	100	

*Table 1: The diet of the Tawny Owl (*Strix aluco*) at Sokolak near Škocjanske Jame. The columns represent the number of each prey group in the diet (N) and its percentage (N(%)), the percentage of each prey group in terms of biomass (B(%)) and the mean prey weight in grams of each prey group (W).*

Tabela 1: Prehrana lesne sove v Sokolaku pri Škocjanskih jamah. Kolone ponazarjajo število osebkov posamezne skupine plena (N) in njegov delež (N(%)), delež posamezne skupine v celotni biomasi plena in povprečno težo posamezne skupine plena v gramih (W).

prey species	**winter 92**	**spring 92**	**summer 92**	**winter 93**	**summer 93**
Myoxus glis	47 (50)	13 (24.5)	30 (47.6)	20 (50)	11 (15.5)
Muscardinus avellanarius		3 (5.7)		1 (1.6)	
Apodemus agrarius				1 (2.5)	
Apodemus flavicollis	4 (4.3)	3 (5.7)			9 (12.7)
Apodemus sylvaticus	1 (1.1)			2 (5.0)	5 (7.0)
Apodemus spp.	8 (8.5)	4 (7.5)	1 (1.6)	2 (5)	13 (18.3)
Rattus spp.		1 (1.9)		1 (2.5)	
Pitymys liechtensteini	1 (1.1)				
Chionomys nivalis	1 (1.1)	2 (3.8)			
Talpa europea	6 (6.4)	2 (3.8)			
Sorex minutus					1 (1.4)
Crocidura suaveolens	1 (1.1)	1 (1.9)			
Crocidura leucodon	2 (2.1)				
Myotis sp.		2 (3.8)			
PASSERIFORMES	5 (5.3)	7 (13.2)	2 (3.2)	2 (5.0)	3 (4.2)
DIPLOPODA		1 (1.9)			
ORTHOPTERA	7 (7.4)	3 (5.7)	29 (46.0)	10 (25.0)	16 (22.5)
COLEOPTERA	11	10	1 (1.6)	1 (2.5)	14
	(11.8)	(18.9)			(19.7)
LEPIDOPTERA		1 (1.9)			
sum	94	53	63	40	71

Table 2: Seasonal variations in the diet of the Tawny Owl at Sokolak (near Škocjanske Jame). The proportions of each prey group are given in parentheses.

Tabela 2: Sezonske spremembe v prehrani lesne sove v Sokolaku pri Škocjanskih jamah. Deleži posameznih skupin plena so podani v oklepajih.

fibres. All brown pellets were found in the winter months, probably due to the wet conditions. Since we were not able to determine the accurate number of earthworms, this prey group was not taken in consideration. Small mammals were the main prey, constituiting 62% by abundance and 90.4% by biomass (Fig. 2). At least 13 species of small mammals were identified in the diet of the Tawny Owl. Among them the Fat Dormouse *(Myoxus glis)* was the dominant prey species, constituting 37.7% of the bird's total prey (Table 1). Other important mammal species were *Talpa europaea*, *Apodemus flavicollis* and *A. sylvaticus*. Only 4 specimens of woles were found in the Tawny Owl's pellets; three of *Chionomys nivalis* and one of *Pitymys liechtensteini*. Shrews were taken only rarely. Birds comprised 5.9% of total prey and 9.6% by weight (Fig. 2). The great majority of birds taken by the Owl were thrushes (family Turdidae). Numerically, invertebrates represented 31.4% of total prey. Proportion of invertebrates by weight was almost negligible. The predominant insect groups taken by the Tawny Owl were Orthoptera and Coleoptera. In the spring period the dominant Coleoptera were cockchafers (*Melolontha melolontha*). The prey taken by the Tawny Owl ranged from less than 1 g (insects and other invertebrates) to 125 g (*Glis Myoxus*).

Seasonal variations in the diet were not very obvious (Fig. 3). The Fat Dormouse was dominant in all sample collections, except in the summer 1993, when Wood Mice of the genus *Apodemus* were taken in higher proportion. The proportion of the Fat Dormouse ranged from 15.5% to 50% of total prey and from 53.6% to 93.7% by weight. The invertebrates were preyed most often in the summer period, particularly grasshopers and cockchafers.

DISCUSSION

In the greatest part of Europe, the Tawny Owl feeds principally on small vertebrates (summarized in Mikolla, 1983). In rural areas the dominant prey species are mostly small rodents, especially voles (Arvicollidae) and mice (Muridae) (summarized in Mikkola, 1983), while in urban and suburban areas birds prevail in its diet (Manganaro *et al.*, 1990; Zalewski, 1994). In our study, the Fat Dormouse was taken by owls throughout the year. The proportion of this species ranged from 15.5% to 50% of total prey and from 54% to 94% by weight. We should point out that we used the mean prey weight of 125g from Lipej (1988). This mean weight is probably overestimated, and for this reason we should rather determine the prey weight from mandible lenght *versus* weight ratio. However, even if such corrections were made, the importance of the Fat Dormouse in the diet of the Tawny Owl would be still great.

High proportions of the Fat Dormouse were recorded also for the Eagle Owl (*Bubo bubo*) from the Slovene part of Istria - 36.4% of the total prey number (Lipej, 1988) and from Karst Edge near Črni kal - 33.3% of the total prey number (Lipej, 1995). The Fat Dormouse was found also in the pellets and in the nest of the Golden Eagle *(Aquilla chrysaetos)* in Istria (Lipej & Gjerkeš, not published). Šorgo and Janžekovič (1995) reported that the Fat Dormouse represented 12.4% by number and 29.4% by weight in the Tawny Owl's diet from the Pohorje Mountais. However, in other European countries the Fat Dormouse was always recorded in negligible proportions (> 1%) in the diet of European owls (Mikolla, 1983).

The high proportion of the Fat Dormouse in the diet of the Tawny Owl is probably reflected in the high abundance of this species in the owl's hunting territory. The population density of the Fat Dormouse was assessed to be very high in the area around Divaška Jama (B. Kryštufek, personal communication). On the other hand, this tree-living species was probably easier to catch than other species. Since we did not practice any trapping sampling of this arboreal species, we are not able to evaluate the hunting pressure of the Tawny Owl on these mammals. On the other hand, we still lack a simple and relatively exact technique for the assessment of the Fat Dormouse's density.

Generally, the voles of the genus *Microtus* represent the most common prey of owls throughout Europe (summarized in Mikolla, 1983). However, microtines are considered to be rare in the study area (Kryštufek, 1991), as it was reported also for the Istrian region (Lipej & Gjerkeš, 1994). Only two microtine species were preyed by the Tawny Owl. *Pitymys liectensteini* is a fossorial vole, inhabiting open habitats. *Chionomys nivalis* is considered a rock-dwelling species (Kryštufek, 1991) and yet less vulnerable to owl predation.

In Istria, shrews are the most important prey group in the diets of the Tawny and Barn Owls (*Tyto alba*) (Lipej, 1988; Lipej & Gjerkeš, 1994). At the studied site, shrews were rarely taken by the Tawny Owl. The dominant White Toothed Shrews of the genus *Crocidura* inhabit mainly open habitats (Kryštufek, 1991). The presence of the non-forest species in the diet, such as shrews of the genus *Crocidura*, moles and the vole *Pitymys liechtensteini,* indicate that the Tawny Owl hunts also in open habitats like those in dolines. Probably, the Tawny Owl would catch more shrews if the density of the Fat Dormouse declined.

Birds were of minor importance in its diet. The most common prey were species of the thrush family (fam. Turdidae). It seems that these birds are preyed in the vicinity of the Tawny Owl's breeding site, where these birds breed as well. On one ocassion in winter 1993, we found a dropping of the Tawny Owl. From feather remains we identified *Tichodroma muraria*, a bird regularly wintering in the area.

The majority of small mamals preyed by the Tawny Owl are considered forest species (i.e. *Myoxus glis*, *Apodemus flavicollis, A. sylvaticus*). It is evident that the Tawny Owl caught its prey in the forest belt which surrounds the breeding site, as previously confirmed by other authors (Southern, 1954; 1970;

Mikolla, 1983; Bochensky, 1990). Other species, such as moles and shrews, were caught in the doline of Sokolak.

Insects were frequently taken by the owl as an alternative prey. According to the optimal foraging theory, which predicts that a predator should maximize the difference between the energy spent for catching and the energy obtained (Pianka, 1974; Stephen & Krebs, 1986), insects are not a convenient prey group. They are probably preyed by the owl because of reduced availability of the main prey - the Fat Dormouse. On the other hand, invertebrates were preyed mostly in summer period, when the dense vegetation cover reduces the availability of ground small mammals, as previously suggested by various authors (Southern, 1954; Shrubb, 1980).

PREHRANA LESNE SOVE (*STRIX ALUCO*) V KRAŠKEM PREDELU BLIZU ŠKOCJANSKIH JAM (JZ SLOVENIJA)

Povzetek

Čeprav je lesna sova ena izmed najpogostejših slovenskih sov, je bilo opravljenih presenetljivo malo ekoloških in bioloških raziskav o tje ptici. V tem prispevku podajava rezultate preiskave sovjih izbljuvkov iz Sokolaka pri Škocjanskih jamah, kjer lesna sova redno gnezdi. Počivališče lesne sove sva odkrila v skalnem biotopu, ki ga obdaja submediteranski gozd črnega gabra in hrasta puhovca *Ostryo-Querceto pubescentis.* Na dnu doline se odpirajo travišča in manjša polja.

Preiskava izbljuvkov lesne sove je pokazala, da je polh (*Myoxus glis*) najpomembnejša vrsta plena. Njegov delež je v letih 1992-1993 znašal od 15.5% do 50% celotnega plena. Od drugih vrst malih sesalcev so bile plenjene predvsem gozdne miši (rod *Apodemus)* in krti (*Talpa europea)* Delež rovk in voluharic je bil presenetljivo majhen. Od drugih vretenčarjev je lesna sova občasno plenila tudi ptice. Žuželke so bile pomembna skupina nadomestnega plena. Še posebej v poletnem obdobju so bili pogosto plenjeni ravnokrilci in hrošči, predvsem majski hrošči *(Melolontha melolontha).* V petih rjavih izbljuvkih smo našli ostanke deževnikov, ki pa jih zaradi praktičnih razlogov (neprimerljivosti metode z drugimi metodami štetja plena) nismo vključili v obravnavo.

O vlogi polha v prehranjevalni verigi evropskih gozdov skorajda ni podatkov. Edini primerljivi deleži polha v prehrani lesne sove so znani s Pohorja (Šorgo & Janžekovič, 1995), sicer pa je, sklicujoč se na razpoložljive podatke v literaturi, delež te vrste povsod v Evropi neznaten. Polh je pomembna vrsta plena tudi v prehrani velike uharice in planinskega orla iz podobnih habitatov v Istri.

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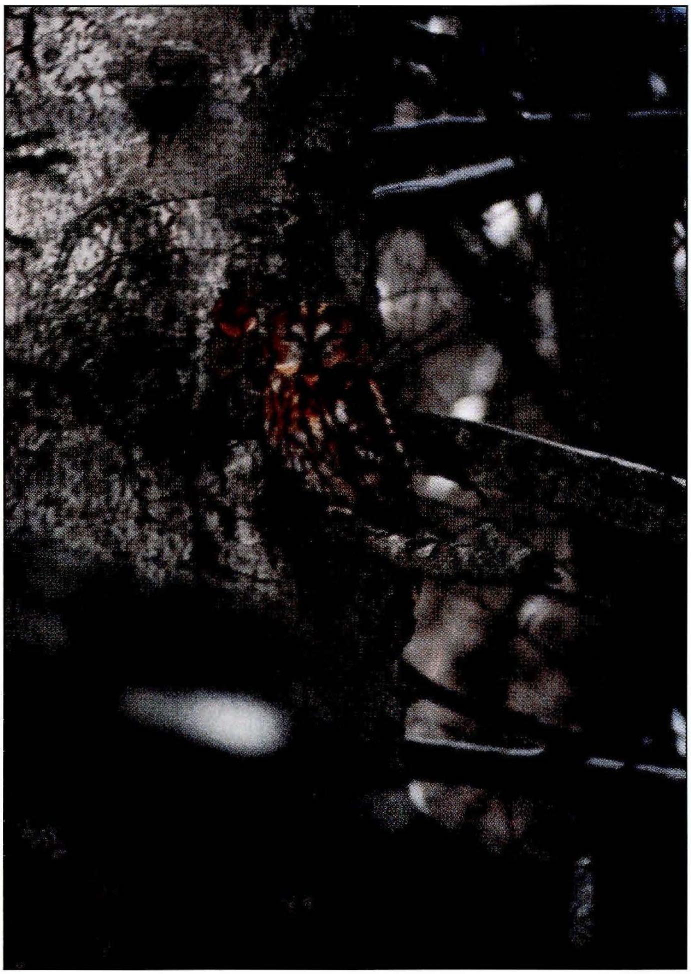

*Tawny Owl (*Strix aluco*) (Photo by T. Makovec)*
*Lesna sova (*Strix aluco*) (Foto T. Makovec)*

OCENA EFEKTIVNE INFILTRACIJE V ŠTUDIJSKEM POLIGONU TIČNICE

ESTIMATION OF THE EFFECTIVE INFILTRATION IN THE TIČNICA EXPERIMENTAL BASIN

METKA PETRIČ

Izvleček UDK 556.33(497.4 Idrija)

Metka Petrič: Ocena efektivne infiltracije v študijskem poligonu Tičnice

Efektivna infiltracija je podana z deležem padavinske vode, ki neposredno napaja podzemni odtok. Ker se pogoji infiltracije spreminjajo v odvisnosti od reliefnih, klimatskih, vegetacijskih in hidrogeoloških razmer, je njeno vrednost težko natančno določiti. V članku je predstavljena ena izmed možnih metod ocene tega parametra, ki temelji na preučevanju odnosov med padavinami in pretoki v eksprimentalnem bazenu. Za študijski poligon je bil izbran mali karbonatni vodonosnik Tičnice pri Idriji. S primerjavo količin vode je bila določena karakteristična vrednost efektivne infiltracije za območja s podobnimi značilnostmi.

Ključne besede: efektivna infiltracija, eksperimentalni bazen, karbonatni vodonosnik, Tičnica, Idrija, Slovenija

Abstract UDC 556.33(497.4 Idrija)

Metka Petrič: Estimation of the effective infiltration in the Tičnica experimental basin

The effective infiltration is given with the portion of rainfall water which directly feeds the underground discharge. As the infiltration conditions change due to relief, climate, vegetation and hydrogeological conditions, it is very difficult to determine its value accurately. In the article one of the possible methods to evaluate this parameter is presented. It is based on the study of relations between precipitation and discharge in an experimental basin. As experimental basin a small carbonate aquifer of the Tičnica near Idrija was chosen. Comparing the amounts of water the characteristic value of the effective infiltration for areas with similar characteristics was determined.

Key words: effective infiltration, experimental basin, carbonate aquifer, Tičnica, Idrija, Slovenia

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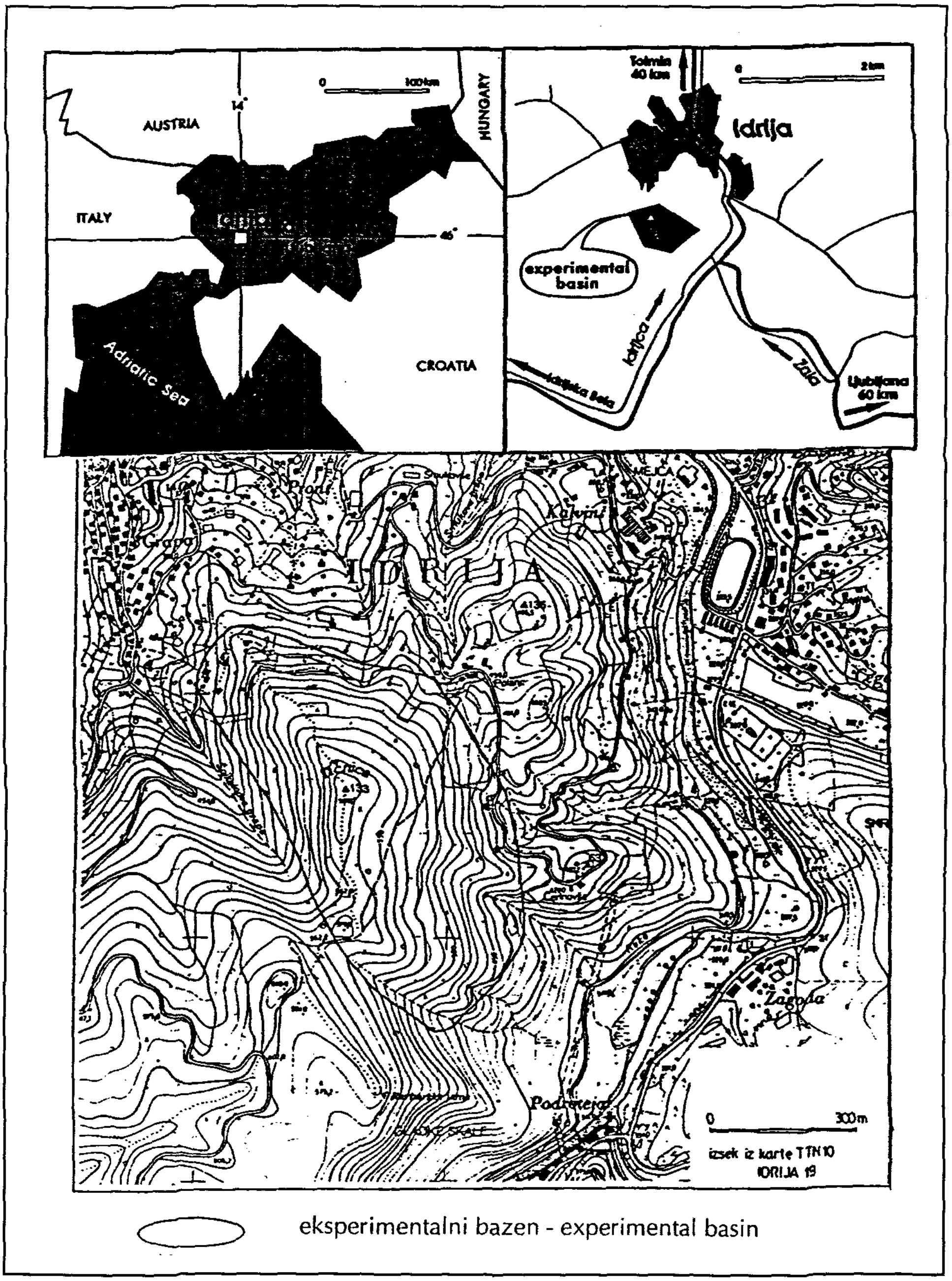
Pri preučevanju hidrogeoloških bazenov se pogosto srečujemo s problemom postavitve ustreznih odnosov med padavinami in pretoki izvirov. Eno izmed osnovnih vprašanj, ki si jih zastavljamo, se nanaša na efektivno infiltracijo, oz. na delež padavin, ki neposredno napajajo podzemni odtok. Čeprav je vprašanje na videz enostavno, pa lahko nanj le redko natančno odgovorimo. Problem se pojavlja predvsem pri velikih bazenih, saj točne dimenzije običajno niso znane in ni možno spremljanje celotnega odtoka. Tudi splošne empirične enačbe upoštevajo samo nekatere izmed pogojev, ki vplivajo na vodno bilanco in zato ne dajejo realnih rezultatov.

Možna rešitev se ponuja z uporabo manjših eksperimentalnih bazenov, kjer lahko direktno primerjamo padavine in pretoke. Karbonatni vodonosnik Tičnice pri Idriji v severozahodni Sloveniji ima vse lastnosti takega študijskega poligona, saj so znani njegove dimenzije, sestava tal, geološka zgradba, relief in stanje vegetacije, za enoletno obdobje pa sem zbrala tudi dnevne podatke o padavinah in pretokih vseh izvirov na tem območju. S primerjavo med količino vode, ki je v času opazovanja padla na površino bazena v obliki padavin in količine vode, ki je medtem odtekla skozi vse izvire, sem lahko ocenila karakteristično vrednost efektivne infiltracije za območja s podobnimi značilnostmi.

OSNOVNI PODATKI O VODONOSNIKU

GEOGRAFSKI POLOŽAJ IN TOPOGRAFSKE ZNAČILNOSTI

Hrib Tičnica se dviguje na južnem robu mesta Idrije, ki leži 35 km zahodno od Ljubljane na vzporedniku 46 severne širine in poldnevniku 14 vzhodne dolžine (slika 1). Na severni in vzhodni strani se spušča proti mestu, na jugu proti Podroteji, na zahodni strani pa je omejena s Špikelnovo grapo. Študijski poligon obsega karbonatni vodonosnik v zgornjem delu hriba med kmetijami Čerinovše, Polanc in Kosmač. Tičnica predstavlja mikroenoto v predalpskem hribovju zahodne Slovenije, zato je obravnavani vodonosnik primeren poligon za študij hidrodinamičnih zakonitosti na tem območju.

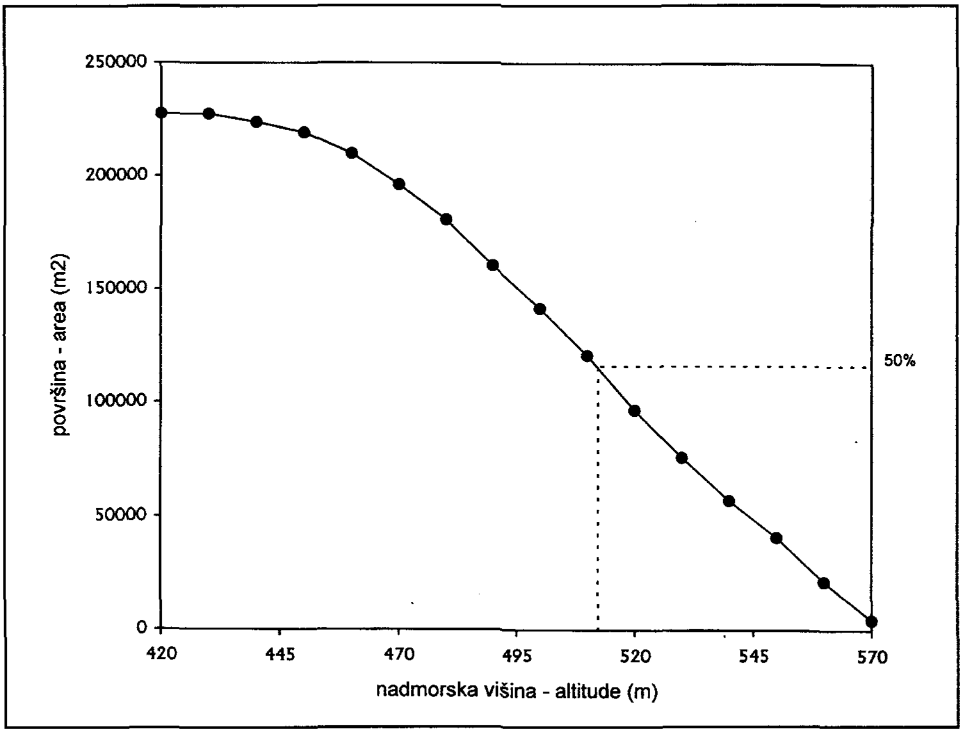


Sl. 1: Pregledna karta obravnavanega območja
Fig. 1: Location map of the studied area

Pri opredelitvi hidrogeoloških razmer imajo pomembno vlogo topografske značilnosti ozemlja. Predvsem z vidika padavin, evapotranspiracije in deleža površinskega odtoka so pomembni parametri površina in nadmorska višina površine bazena, nagib in orientacija pobočij ter sestava tal in vegetacijskega pokrova.

Določanje površine vodonosnika je običajno zahtevna naloga predvsem zaradi težav pri natančni postavitvi njegovih mej. Pri Tičnici tega problema ni, saj so meje geološko jasno določene in predstavlja površina 227.500 m^2 dokaj zanesljiv podatek.

Porazdelitev površine bazena glede na nadmorsko višino je opisana s kumulativno krivuljo na sliki 2. Linearnost krivulje v območju med 460 m in 570 m kaže na enakomerno razporeditev po višini. Pod 460 m se teren spusti samo v ozkem pasu na Čerinovšu. Srednja nadmorska višina obravnavanega območja je 512 m, vrh Tičnice je na 580 m, najnižja točka površine vodonosnika pa na 420 m. Tudi iz položaja izohips je razvidno, da se pobočje Tičnice enakomerno dviga od roba vodonosnika proti vrhu.



Sl. 2: Kumulativna krivulja nadmorske višine površine bazena
Fig. 2: Cumulative curve of the basin surface altitude

Stalnih površinskih tokov ni in številne manjše grape se napolnijo z vodo samo po močnejšem deževju. Na delež površinskega odtoka zelo vpliva strmina terena. Parameter, s katerim jo običajno opisujemo, je srednji nagib pobočij, ki je definiran kot kvocient med produktom ekvidistanc izohips z njihovo skupno dolžino ter med površino bazena (Veselič 1984). Skupna dolžina izohips z ekvidistanco 10 m je na območju vodonosnika Tičnice 12400 m, površina pa 227500 m^2. Razmerje med temi parametri da vrednost 0.55 oz. izraženo v stopinjah 29 . Pobočja so večinoma orientirana proti vzhodu, manjši del pa proti zahodu in severu.

Pomemben vpliv na pretakanje vode in določanje tipa odtoka ima sestava tal, ki je odvisna od klime, organskih snovi, kamninske podlage, reliefa in časa. Na Tičnici je osnovna kamnina prekrita s tudi do 4 m debelo dolomitno in tufsko preperino. Posledica sestave tal na pretakanje vode se kaže z zmanjšano efektivno infiltracijo.

Obravnavano območje je z izjemo manjše travnate površine v neposrednem zaledju izvirov pri Kosmaču v celoti poraslo z mešanim gozdom, ki ga lahko glede na njegovo sestavo uvrstimo v tip dinarskih jelovo bukovih gozdov (Kordiš 1993). Ta tip, v katerem prevladujeta bukev in jelka, je značilen za višje predele južne in jugozahodne Slovenije in se razprostira v praktično nepretrgani verigi od planot nad dolino Soče na zahodu do Bele krajine na vzhodu. Zajema večje število razgibanih gorskih planot z vmesnimi dolinami, pa tudi hribovito ozemlje s hitro spremenljivim reliefom in strmimi pobočji.

METEOROLOŠKI PODATKI

Klimatske razmere

Zaradi geografskega položaja in geomorfoloških značilnosti se klima znotraj Slovenije zelo hitro spreminja. Mešajo se mediteranski, celinski in alpski vplivi, razmere pa se še dodatno zapletajo zaradi pestre razgibanosti reliefa. V z gozdom poraščenem območju v okolici Idrije je pomemben klimatski vpliv dinarskega visokega krasa (Kordiš 1993). Značilne so razmeroma velike količine padavin, ki so razporejene tekom celega leta in imajo zelo izrazit jesenski maksimum in slabše izražen spomladanski višek. Obilne padavine so posledica visokih pregrad (Nanos, Trnovski gozd), ob katerih se zrak dviguje in ohlaja. Zaradi pospešene kondenzacije doseže v najvišjih predelih letna količina padavin tudi 3500 mm, nato pa se s spuščanjem terena proti notranjosti zniža do 1400 mm (v Idriji 2214 mm). Pomembna faktorja, ki vplivata na količino padavin, sta nadmorska višina in oddaljenost od pregradnih grebenov.

Tudi povprečna letna temperatura se spreminja v odvisnosti od nadmorske višine in sicer se na širšem območju giblje v mejah med 5° C in 8.5° C. Tičnico s temperaturami med 7.9° C in 8.2° C lahko uvrstimo v ta okvir. Za mikroklimo je pomembna še razvitost vegetacije, saj so v zavetju gozda temperaturna nihanja ublažena in je razpon med ekstremnimi vrednostmi manjši.

Temperatura zraka

Za območje Idrije obstajajo podatki o temperaturi zraka samo za obdobji 1926-1965 in 1980-1985. Te vrednosti sem sicer uporabila za oceno dolgoletnih povprečij, manjkali pa so mi podatki za postavitev odnosov vodne bilance v času opazovanja od 1.4.1993 do 31.3.1994. Srednje mesečne temperature zraka v tem obdobju sem zato ocenila statistično z metodo multiple regresije. Osnovno primerjavo sem izvedla med povprečnimi temperaturami v letih 1980-1985 za Idrijo (I) in temperaturne postaje v bližini: Vojsko (V), Bilje (B), Novo Gorico (G) in Postojno (P).

Regresijsko enačbo sem postavila v naslednji obliki:

$$I = b_0 + b_1 \cdot V + b_2 \cdot B + b_3 \cdot G + b_4 \cdot P \qquad (1)$$

Po metodi najmanjših kvadratov sem z uporabo matrik določila koeficiente b, pri katerih je bila korelacija med parametri najvišja (koeficient korelacije 0.9998) in enačbo zapisala kot:

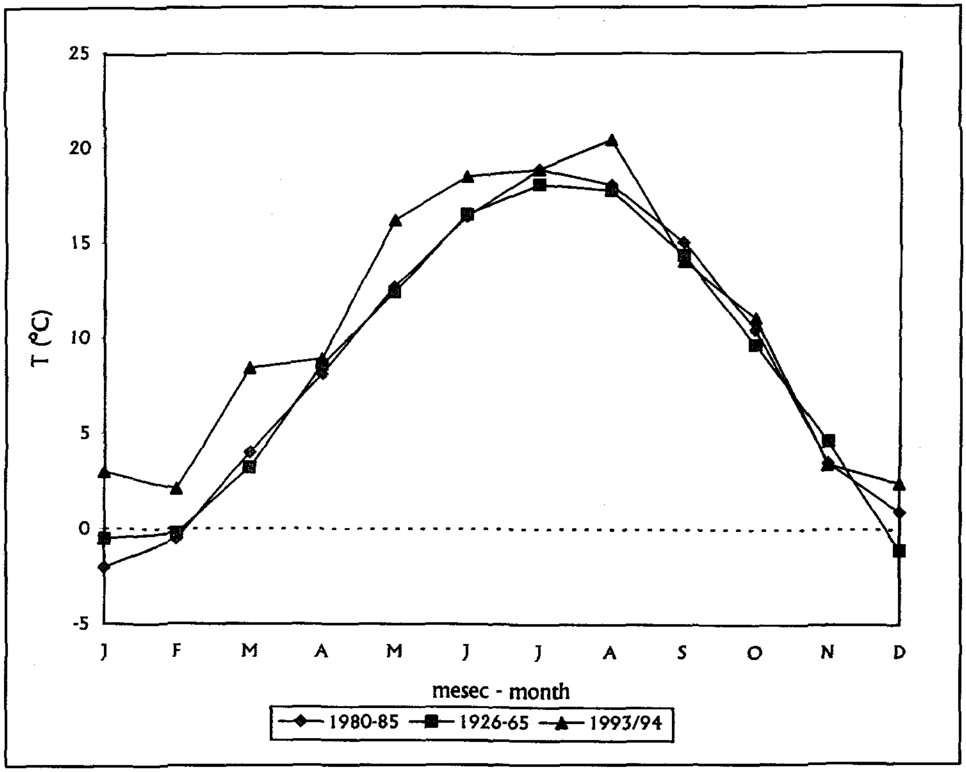
$$I = -3.72 - 0.48 \cdot V + 0.06 \cdot B + 0.76 \cdot G + 0.73 \cdot P \qquad (2)$$

Po tej enačbi sem z upoštevanjem izmerjenih temperatur v izbranih postajah za obdobje 1.4.1993 - 31.3.1994 določila vrednosti temperatur zraka za območje Idrije. Natančnost uporabljene metode opisuje 3% relativna napaka, ki je še vedno v okviru sprejemljivega. Rezultati so prikazani v tabeli 1 skupaj s temperaturami za Tičnico, pri katerih je upoštevan faktor korekcije zaradi nadmorske višine. Temperatura namreč z višino pada z gradientom 0.42° C/100 m (Šebenik 1986).

Srednje mesečne temperature zraka za obravnavano obdobje in dolgoletno povprečje so prikazane na sliki 3. Primerjava pokaže, da je bilo leto 1993/94 nadpovprečno segreto, saj so z izjemo jesenskih mesecev temperature višje od srednjih vrednosti. To se odraža tudi na srednji letni temperaturi 10.6° C za Idrijo in 10.0° C za Tičnico.

Tabela 1: Ocenjene srednje mesečne temperature (°C) v obdobju 1993/94 za Idrijo in Tičnico

	A	M	J	J	A	S	O	N	D	J	F	M
Idrija	8.9	16.2	18.5	18.9	20.5	14.1	11.1	3.4	2.4	3.0	2.1	8.4
Tičnica	8.3	15.6	17.9	18.3	19.9	13.5	10.5	2.8	1.8	2.4	1.5	7.8

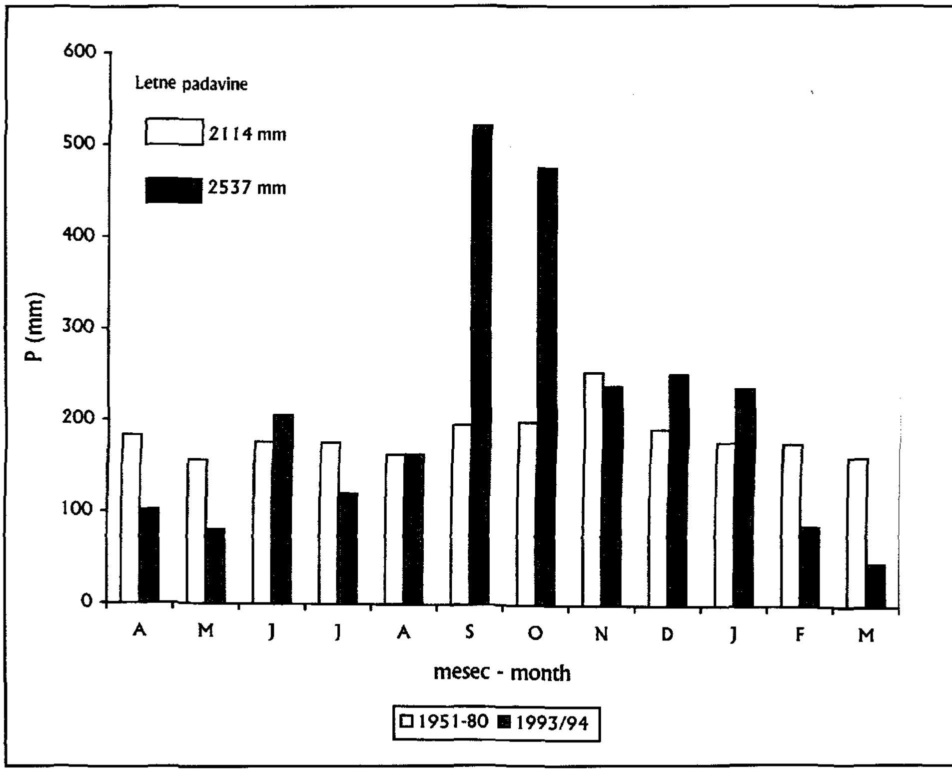


Sl. 3: Srednje mesečne temperature zraka v Idriji
Fig. 3: Average monthly air temperatures in Idrija

Padavine

Opis značilnega padavinskega režima temelji na dolgoletnem povprečju za obdobje 1951-1980 (slika 4). Srednje letne padavine na območju Idrije dosežejo 2214 mm, vrednosti za posamezna leta pa se gibljejo med 1602 mm in 3039 mm. Največ padavin je jeseni z viškom v novembru, od spomladanskih mesecev pa je najbolj namočen junij. Najhujša suša je v maju, le nekaj več dežja pa pade v avgustu in februarju.

Primerjava razporeditve padavin za opazovano obdobje 1993/94 kaže na velika odstopanja od povprečja in sicer so te razlike izrazite tako v razporeditvi ekstremov kot tudi v količinah mesečnih in letnih padavin. Za obdobje 1993/94 je s skupno 2537 mm padavin značilna nadpovprečna namočenost, še posebej izrazita pa sta maksimuma v septembru in oktobru (slika 4).

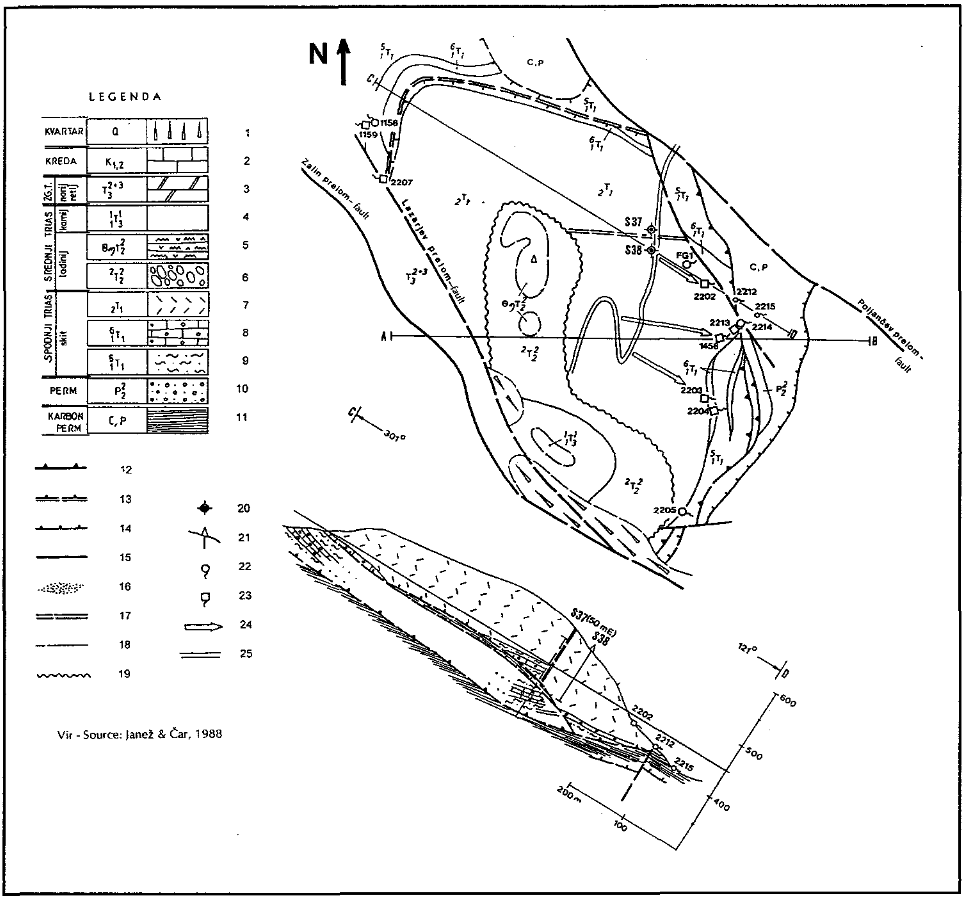


Sl. 4: Primerjava mesečnih padavin v obdobju april 1993 - marec 1994 s povprečnimi mesečnimi padavinami v obdobju 1951-1980

Fig 4: Comparison between monthly precipitation from April 1993 to March 1994 and average monthly precipitation in years 1951-1980

GEOLOŠKA ZGRADBA

Značilnosti geološke zgradbe Tičnice sem opisala na osnovi starejših raziskav območja Idrije (Mlakar 1969; Placer 1973; Janež & Čar 1988; Čar 1995). Po projektu določitve varstvenih pasov zajetij na Čerinovšu (Janež & Čar 1988) sem povzela geološko karto in prerez (slika 5) in ju dopolnila na podlagi novih ugotovitev.


LEGENDA
KVARTAR
Q
1
KREDA
$K_{1,2}$
2
T_3^{2+3}
3
4
5
6
7
8
9
PERM
P_2^2
10
KARBON PERM
C, P
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Vir - Source: Janež & Čar, 1988
N
C, P
S37
S38
FG1
2202
2212
2215
2213
2214
1456
2203
2204
2205
2207
1158
1159
A
B
Zalin prelom - fault
Lazarjev prelom - fault
Poljančev prelom - fault
307^o
127^o
S37(50 mE)
600
500
400
100
200m

Sl. 5: Geološka zgradba in prerez Tičnice. 1 - pobočni grušč, 2 - temno sivi bituminozni apnenec, 3 - svetlo sivi in beli zrnati dolomit, 4 - beli zrnati dolomit, 5 - sivozeleni tufi in tufiti z roženci, 6 - apnenčevo-dolomitni konglomerat, 7 - sivi zrnati dolomit, 8 - leče sivega oolitnega apnenca, 9 - rdečkasti meljevci in glinavci, 10 - rdečkasti do rjavosivi grödenski peščenjak, 11 - temnosivi do črni skrilavi glinavci in meljevci, 12 - meja notranje narivne grude, 13 - dvojna narivnica, 14 - narivnica znotraj pokrova, 15 - prelom, 16 - milonitna cona, 17 - triasni prelom, 18 - normalna meja, 19 - diskordanca, 20 - vrtina (tloris), 21 - vrtina (prerez), 22 - nezajeti izvir s katastrsko številko, 23 - zajeti izvir s katastrsko številko, 24 - dokazana smer pretakanja podzemne vode, 25 - gozdna cesta (Risal: A. Albreht)

Fig. 5: Geological map and cross-section of Tičnica. 1 - slope rubble, 2 - dark grey bituminous limestone, 3 - light grey and white granular dolomite, 4 - white granular dolomite, 5 - grey-greenish tuff and tuffit with chert, 6 - limestone-dolomitic conglomerate, 7 - grey granular dolomite, 8 - lenses of grey oolitic limestone, 9 - reddish siltstones and claystones, 10 - reddish to brown-grey Gröden sandstone, 11 - dark grey to black shale claystones and siltstones, 12 - border of inner thrust sheet, 13 - double thrust plane, 14 - thrust plane within the nappe, 15 - fault, 16 - milonitic zone, 17 - Triassic fault, 18 - normal border, 19 - discordance, 20 - borehole (ground plan), 21 - borehole (cross-section), 22 - uncaptured spring with cadastre number, 23 - captured spring with cadastre number, 24 - proved direction of underground water flow, 25 - forest road (Drawn by: A. Albreht)

Območje Idrije predstavlja majhen izsek iz krovne zgradbe jugozahodne Slovenije. Tičnica pripada Tičenski notranji narivni grudi, ki je narinjena na Idrijsko notranjo narivno grudo in predstavlja del Trnovskega pokrova. Glede na ugotovljene tektonske razmere jo razdelimo na 3 etaže (Čar 1995). Spodnja je Čerinova tektonska luska s spodnjeskitskimi meljevci in glinavci z vložki oolitnih apnencev, ki je od karbonskih in permskih klastitov Idrijske notranje narivne grude ločena s Tičensko narivnico. Navzgor preko narivnega stika znotraj pokrova sledi ozka cona karbonskih in permskih skrilavih glinavcev in meljevcev Kalanove tektonske luske. Vrhnji in hkrati osrednji del Tičnice pa gradijo spodnjeskitski meljevci in glinavci z vložki oolitnih apnencev, zgornjeskitski zrnati dolomit, ladinijski apnenčevo-dolomitni konglomerat ter tufi in tufiti z roženci. Od druge etaže so ločeni z narivnico znotraj pokrova in pripadajo Čukovi tektonski enoti. Tičnica je torej sestavljena iz dveh vodonosnih enot, ki ju loči vmesna cona paleozojskih klastitov.

Narivna zgradba je v neotektonski fazi doživela dodatne spremembe zaradi številnih zmikov. Na območju Idrije je najpomembnejši Idrijski prelom, ki predstavlja tektonsko strukturo regionalnih razsežnosti, v zvezi z vodonosnikom

Tičnice pa so zanimivi nekateri spremljajoči prelomi. Jugozahodno mejo Tičenske notranje narivne grude predstavlja Lazarjev prelom, Poljančev prelom na severovzhodni strani pa omejuje blok Tičnice znotraj širšega območja Tičenske notranje narivne grude.

HIDROGEOLOŠKE RAZMERE

HIDROGEOLOŠKE ZNAČILNOSTI

Kamnine na območju vodonosnika Tičnice lahko glede na hidrogeološke karakteristike uvrstimo v dva razreda. V prvem razredu prepustnih kamnin z razpoklinsko poroznostjo so spodnjeskitski oolitni apnenec, zgornjeskitski dolomit in ladinijski konglomerat. Drugo skupino predstavljajo neprepustne plasti: paleozojski skrilavi glinavci in peščenjaki, spodnjeskitski klastiti in ladinijske piroklastične kamnine. Vodonosnik se je razvil predvsem zaradi ugodnega strukturnega položaja vodonosnih kamnin na stiku z neprepustno podlago. Na osnovi ugotovljene geološke zgradbe ga lahko razdelimo v dva dela. Njegov osrednji del gradi zgornjeskitski dolomit, ki je v območju prelomnih in narivnih struktur pretrt do stopnje zdrobljene cone (milonitna moka), drugod pa le do stopnje razpoklinskih con. V dolomitu se pojavljajo do 1 cm široke vertikalne razpoke, ki so lahko tudi korozijsko razširjene. Zakraselost se kaže v žepih na površini, ki so zapolnjeni s preperino. Edini vir napajanja so padavine, podzemna voda pa odteka proti izvirom na Čerinovšu. Spodnji del vodonosnika predstavljajo oolitni apnenci v spodnjeskitskih meljevcih in glinavcih, ki so z ozkim pasom Kalanove tektonske luske ločeni od zgornje cone in se drenirajo proti izvirom pri Kosmaču.

Geometrija vodonosnika je definirana z njegovo geološko zgradbo. Spodnjo mejo predstavlja Tičenska narivnica, ki ga loči od neprepustnih skrilavih kamnin karbonske in permske starosti. Narivnica je vbočena in gradi ugodno strukturo za akumuliranje podzemne vode. Tudi bočne meje poligona na severni, vzhodni in južni strani so neprepustne karbonske, permske in skitske plasti, na zahodu pa ga omejuje milonitiziran zgornjetriasni dolomit ob Lazarjevem prelomu. Čeprav je vodonosnik zgrajen iz dveh delov z različnim hidrodinamičnim režimom, ga pri izračunu efektivne infiltracije obravnavam kot celoto. Edini vir napajanja so padavine, podzemni odtok pa sem spremljala z merjenjem pretoka izvirov na Čerinovšu in pri Kosmaču.

PODATKI O IZVIRIH

Izvire na območju Tičnice razdelimo glede na njihovo lego v dve skupini (slika 5). Na južnem in vzhodnem robu so izviri na Čerinovšu, ki drenirajo zgornji dolomitni del vodonosnika in jih označujemo z naslednjimi katastrskimi številkami: 2205, 2204, 2203, 1456, 2213, 2214, 2215, 2212, 2202 in FG1 (v smeri od juga proti severu). Izviri pri Kosmaču na severozahodnem robu z oznakami 1158, 1159, 2207 in 2208 pa so povezani s spodnjim delom vodonosnika z oolitnimi apnenci. Pri računanju efektivne infiltracije sem vse izvire obravnavala skupaj, saj me je zanimal celotni iztok iz vodonosnika.

IZMERJENE VREDNOSTI

PADAVINE

Po večletni prekinitvi je začela leta 1993 padavinska postaja v Idriji spet delovati. V času opazovanja od 1.4.1993 do 31.3.1994 je Hidrometeorološki zavod Republike Slovenije izvajal dnevne meritve količine padavin z ombrometrom. V aprilu in maju predstavljata praktično edine zaznavne padavine 5-dnevni deževni obdobji v sredini meseca. Več padavin je bilo junija, vendar dnevne količine ne presežejo 43 mm. V juliju in avgustu so bile z izjemo močnejšega dežja 27. julija (60 mm) in v obdobju od 26. do 29. avgusta (skupaj 156 mm, dnevni maksimum 90 mm) padavine le občasne. Tudi njihova intenziteta je bila zelo majhna, saj ne presežejo 20 mm. Največ padavin je bilo septembra, ko je deževalo kar 18 dni (maksimalno 90 mm), le malo manj pa oktobra z maksimalno količino 273 mm v 5-dnevnem intervalu od 21. do 25. oktobra. Novembra so bile padavine sicer pogoste in enakomerno razporejene, vendar dnevne količine ne presežejo 40 mm. Konec novembra in v začetku decembra je bilo obdobje brez padavin, v drugi polovici decembra pa je padla celotna mesečna količina 253 mm. 15. decembra je bil s 95 mm dosežen tudi dnevni maksimum opazovanega obdobja. V prvi polovci januarja so bile padavine še pogoste (do 81 mm dnevno), nato pa v februarju in marcu 1994 le občasne z dnevnimi vrednostmi do 24 mm.

PRETOK IZVIROV

Tudi pretoke izvirov sem v obdobju od 1.4.1993 do 31.3.1994 beležila enkrat dnevno. Izjema so bila daljša obdobja brez padavin, ko sem interval merjenja podaljšala na 2 do 3 dni. V teh primerih so bile spremembe pretokov tako majhne, da sem lahko te vrednosti ocenila iz krivulj praznjenja. Sodim, da tako pridobljena napaka ne izstopa iz siceršnjih okvirov natančnosti. Manjša je baza podatkov za izvira 1456 in 2202, ki dajeta del vode v skupni rezervoar, natančno pa lahko merimo samo preliv iz zbiralnika. Pri obdelavi sem zato upoštevala le podatke za obdobje 1.7.1993 - 25.12.1993, ko sta bila izvira zaradi neustrezne kvalitete izključena iz vodovodnega omrežja. Dotok v rezervoar je bil zaprt in na izvirnem mestu je bilo možno meriti celoten pretok za 1456 in 2202.

OCENA DELEŽA INFILTRACIJE

PREDSTAVITEV METODE

Infiltracija je eden bistvenih procesov za dinamiko podzemne vode. Predstavlja količino vode, ki se pretoči skozi površinski sloj tal. Odvisna je od časa trajanja padavin, stopnje predhodne zasičenosti tal z vlago, stanja vegetacije, tal in geološke podlage ter nagiba terena. Efektivna infiltracija pa je podana z deležem padavinske vode, ki neposredno napaja podzemni odtok. Nastopi šele takrat, ko se porabi voda za evapotranspiracijo in napolnitev deficita vlažnosti.

Faktorje, ki vplivajo na infiltracijo, je kvantitativno zelo težko opredeliti. Težave nastopijo zaradi nepoznavanja točnih mej vodonosnikov, pa tudi merjenje ostalih parametrov vodne bilance je zamudno in drago. Splošne empirične enačbe upoštevajo samo nekatere izmed teh faktorjev in zato ne dajejo realnih rezultatov. Ena izmed možnih metod, s katero bi lahko rešili ta problem, je usmeritev raziskav na manjše vodonosnike s točno določenimi mejami, znano geološko zgradbo in možnostjo postavitve opazovalnih točk na vseh pomembnih lokacijah, pri katerih lahko ovrednotimo dobljene rezultate in postavimo splošne odnose. S primerjavo med količino vode, ki v določenem obdobju opazovanja pade na površino bazena v obliki padavin in količine vode, ki v tem času odteče skozi vse izvire, lahko ocenimo karakteristično vrednost efektivne infiltracije za območja s podobnimi značilnostmi.

Karbonatni vodonosnik Tičnice ima take lastnosti eksperimentalnega bazena. Majhne dimenzije in znana geometrija sta omogočila postavitev študijskega poligona. Njegove meje in geološka zgradba so s površinskim kartiranjem in raziskovalnimi vrtinami zelo zanesljivo določene. Na severni, vzhodni in južni strani je omejen z neprepustnimi plastmi, na zahodni pa z milonitiziranim dolomitom ob Lazarjevem prelomu. V globino so vodonosne plasti omejene s Tičensko narivnico in neprepustnimi karbonskimi in permskimi klastiti. Edini vir napajanja predstavljajo padavine, za katere lahko kot reprezentativne privzamemo podatke s padavinske postaje Idrija. Iztok iz vodonosnika pa spremljamo z merjenjem pretoka izvirov na Čerinovšu in pri Kosmaču.

IZRAČUN EFEKTIVNE INFILTRACIJE ZA VODONOSNIK TIČNICE

V študijskem poligonu vodonosnika Tičnice sem torej zbrala podatke o dnevnih padavinah in pretokih izvirov za enoletno obdobje opazovanja od 1. aprila 1993 do 31. marca 1994 (Petrič 1995). Efektivno infiltracijo oziroma delež padavin, ki neposredno napajajo podzemni odtok, sem izračunala po naslednji enačbi:

$$I_{ef} = \frac{Q_m \cdot t}{P_0 \cdot F} \qquad (3)$$

kjer je:

I_{ef} infiltracija v določenem časovnem obdobju izražena v % padavin
Q_m skupna izdatnost izvirov v istem času
t trajanje osnovne enote merjenja (1dan = 86400 s)

F površina vodonosnika

P_0 skupne padavine v obravnavanem obdobju izražene v mm vodnega stolpca

Ker so bili pretoki nekaterih izvirov merjeni samo pol leta, sem efektivno infiltracijo najprej izračunala za obdobje od julija do decembra 1993. Za tri majhne, občasne izvire izdatnosti ni bilo možno določiti, obstaja pa tudi možnost, da se nekaj vode izceja skozi skrite izvire. Količino iztekle vode, ki ni bila merjena, sem na osnovi primerjave z opazovanimi izviri ocenila na 0.1 l/s. Upoštevanje skritega pretoka pri skupni izdatnosti izvirov spremeni vrednost infiltracije za 1 %. Napaka, ki sem jo na ta način naredila, je približno 5 % in je še vedno v okvirih sprejemljivega. Efektivno infiltracijo za vodonosnik Tičnice sem tako po enačbi (3) določila za posamezne mesece in letne čase v obdobju od julija do decembra 1993 (tabela 2).

Analiza dobljenih vrednosti pa je pokazala, da izračunane mesečne efektivne infiltracije ne kažejo realne slike. Uporabljena poenostavljena metoda ne upošteva razlik v stanju vodnih zalog, ki so za posamezne mesece očitne. Te razlike lahko zanemarimo samo pri računanju efektivne infiltracije za celotno obdobje opazovanja od aprila 1993 do marca 1994. Nivo podzemne vode v dveh vrtinah na območju Tičnice je namreč na začetku in koncu opazovanja praktično na enaki višini, kar kaže na zanemarljivo majhno spremembo stanja vodnih zalog. Ker pretoki nekaterih izvirov niso bili stalno merjeni, sem oceno povprečne infiltracije za enoletno obdobje omejila samo na jugozahodni del Tičnice. Na ta način sem ločila severovzhodni del, ki se drenira v izvire 2202, FG1, 1456, 2213 in 2214 s podatki o pretokih le za 6 mesecev. Mejo sem potegnila od severnega roba vodonosnika po grebenu do vrha Tičnice, od tu pa po stranskem grebenu proti jugovzhodu do kmetije Čerinovše. Po enačbi (3) sem za jugozahodni del s površino 162400 m^2 nato ocenila efektivno infiltracijo za celotno obdobje opazovanja od 1.4.1993 do 31.3.1994 (tabela 2). Primerjava rezultatov obeh izračunov je pokazala, da se vrednosti v poletnih in jesenskih mesecih dobro ujemajo. Zato sem tudi povprečno letno efektivno infiltracijo, izračunano v jugozahodnem delu, privzela za celotno območje Tičnice. Dobljena vrednost 17 % pove, da je delež padavin, ki napajajo podzemni odtok, majhen. Večji del vode, ki pade na površino vodonosnika v obliki padavin, torej odteče kot površinski tok ali pa se z evapotranspiracijo vrača v atmosfero. Strm relief in debela plast preperine sta vzroka za velik delež površinskega odtoka, zaradi goste poraslosti z mešanim gozdom pa je velika tudi evapotranspiracija.

	Tičnica		J-Z del Tičnice	
	I_{ef} (%) mesec	I_{ef} (%) letni čas	I_{ef} (%) mesec	I_{ef} (%) letni čas
A			18	
M			8	12
J			10	
J	5		4	
A	11	14	10	14
S	17		17	
O	20		18	
N	28	19	29	18
D	16		16	
J			23	
F			30	28
M			42	
L			17	

Tabela 2: Ocena efektivne infiltracije

OCENA VODNE BILANCE

Vhodno komponento vodonosnega sistema predstavljajo padavine. Z vodno bilanco pa skušamo določiti posamezne elemente v sistemu, na katere lahko razdelimo to začetno količino. V primeru Tičnice sem uporabila poenostavljeno bilanco s štirimi parametri: padavinami, evapotranspiracijo, površinskim in podzemnim odtokom. Predpostavila sem namreč, da so vodne rezerve v vodonosniku na začetku in koncu opazovalnega obdobja enake (majhne razlike v piezometričnih nivojih) in jih zato lahko izključimo iz bilančne enačbe. Evapotranspiracija obsega delež vode, ki se z izhlapevanjem oz. transpiracijo rastlin vrača v atmosfero. Površinski odtok je definiran kot ves odtok padavinske vode, pri katerem voda ne ponikne pod površino terena, podzemni odtok pa predstavlja del padavin, ki se je infiltriral in ga lahko beležimo kot pretok izvirov. Bilančno enačbo sem izrazila z odstotnimi deleži padavin, ki napajajo posamezne elemente (evapotranspiracija, podzemni odtok, površinski odtok).pa sem privzela efektivno infiltracijo 17 %. Izmerjenih podatkov o evapotranspiraciji in površinskem odtoku nimam, zato sem skušala vrednosti vsaj približno oceniti. Za izračun evpotranspiracije sem uporabila različne metode.

Metoda po Thornthwaitu

Thornthwaite je postavil enostavno empirično enačbo, pri kateri potencialno mesečno evapotranspiracijo izračunamo na osnovi mesečnih temperatur zraka (Veselič 1975):

$$ETP = \sum_{i=1}^{12} 16 \cdot (10 \cdot \frac{T_i}{I})^a$$

$$I = \sum_{i=1}^{12} (\frac{t_i}{5})^{1.514} \qquad (4)$$

$$a = \frac{1.6}{100} \cdot I + 0.5$$

kjer je:

ETP potencialna letna evapotranspiracija (mm)
T_i srednje mesečne temperature v obravnavanem obdobju (mm)
t_i povprečje mesečnih temperatur v daljšem časovnem obdobju (mm)
I letni termični indeks
a empirični koeficient

Thornthwaite in Mather sta enačbo dopolnila še s korekcijskim faktorjem f, ki ga izračunamo na osnovi dolžine astronomskega dneva N in števila dni v mesecu d (Schrödter 1985):

$$f = \frac{N \cdot d}{12 \cdot 30} \quad \text{in} \quad ETP_f = f \cdot ETP \qquad (5)$$

Ker na območju Idrije trenutno ni temperaturne postaje, sem srednje mesečne temperature za čas opazovanja od aprila 1993 do marca 1994 določila na osnovi statistične primerjave s temperaturnimi postajami v bližini (Vojsko, Bilje, Nova Gorica in Postojna). Postopek statistične analize je predstavljen v poglavju o temperaturi zraka, ocenjene temperature pa v tabeli 1. Dolžino astronomskega dneva sem za pas 46° severne širine privzela iz astronomskih tabel. Vsi potrebni podatki in izračunane vrednosti so zbrani v tabeli 3:

Tabela 3: Podatki za izračun potencialne evapotranspiracije (mm) po Thornthwaitu

	A	M	J	J	A	S	O	N	D	J	F	M	L
t - Idrija	8.1	12.7	16.4	18.9	18.1	15.1	10.5	3.5	0.9	-2.0	-0.5	4.0	8.8
t - Tičnica	7.5	12.1	15.8	18.3	17.5	14.5	9.9	2.9	0.3	-2.6	-1.1	3.4	8.2
I	1.85	3.81	5.71	7.13	6.66	5.01	2.81	0.44	0.01			0.56	34.08
T - Idrija	8.9	16.2	18.5	18.9	20.5	14.1	11.1	3.4	2.4	3.0	2.1	8.4	10.6
T - Tičnica	8.3	15.6	17.9	18.3	19.9	13.5	10.5	2.8	1.8	2.4	1.5	7.8	10.0
N	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7	9.1	10.4	11.9	
d	30	31	30	31	31	30	31	30	31	31	28	31	365
f	1.13	1.28	1.31	1.33	1.22	1.05	0.94	0.79	0.75	0.78	0.81	1.02	
ETP_f	45.8	100.4	118.6	123.2	123.4	70.8	48.7	10.3	6.2			38.8	**686.2**

Uporabljena metoda je dala vrednost letne potencialne evapotranspiracije okrog 686 mm. Po Thornthwaitu (Veselič 1984) sem realno evapotranspiracijo ocenila na osnovi primerjave z mesečnimi padavinami v obravnavanem obdobju, ki je prikazana v tabeli 4:

Tabela 4: Primerjava med potencialno evapotranspiracijo in padavinami (v mm)

	A	M	J	J	A	S	O	N	D	J	F	M	L
ETP_f	45.8	100.4	118.6	123.2	123.4	70.8	48.7	10.3	6.2			38.8	686.2
P	101.7	81.0	206.1	120.7	163.5	522.7	477.6	239.8	253.0	237.3	87.0	46.9	2537.0

Osnovna ideja metode je v tem, da je pri mesecih, kjer je količina padavin večja od potencialne evapotranspiracije, realna evapotranspiracija enaka potencialni. Kadar je padavin manj, primanjkljaj lahko nadoknadijo vskladiščene zaloge vode. Če so tudi te porabljene, je realna evapotranspiracija manjša od potencialne. Primerjava za poligon Tičnice v tabeli 4 kaže na višek padavin. Izjema sta meseca maj in julij, ko je $ETP_f > P$. Tudi za ta dva meseca pa zaradi obilnih predhodnih padavin sklepam, da so zaloge v vodonosniku zadostne za nadomestitev deficita vode. Zato sem za obravnavani vodonosnik privzela, da je realna evapotranspiracija enaka potencialni in sicer je njena letna količina 686 mm oz. 27 % od celotne količine padavin.

Metoda po Turcu

Pri tej metodi predpostavimo, da je evapotranspiracija enaka odtočnemu deficitu D, oz. razliki med padavinami in odtokom (Veselič 1984):

$$D = P - Q = \frac{P}{\sqrt{0.9 + \frac{P^2}{L^2}}} \qquad (6)$$

$$L = 300 + 25 \cdot T + 0.05 \cdot T^3$$

kjer so:

P letne padavine (mm)
T srednja letna temperatura (°C)

Formula je postavljena za vrednosti P in T, ki se nanašajo na dolgoletna povprečja. Zato sem za območje Tičnice upoštevala srednje letne padavine 2214 mm za obdobje 1951-1980, srednjo temperaturo 8.0 °C pa sem dobila s primerjavo med obdobji 1926-1965 in 1980-1985. Na osnovi teh parametrov sem po zgornjih enačbah (6) določila odtočni deficit D=513 mm. Ta vrednost predstavlja približno oceno evapotranspiracije. Po primerjavi s padavinami lahko povzamem, da se v povprečnem letu 23 % padavin vrača v atmosfero z evapotranspiracijo.

Za primerjavo sem v enačbe (6) vstavila še parametre za obdobje 1993/94. Pri skupni količini padavin 2537 mm in povprečni temperaturi 10.0 °C znaša odtočni deficit 585 mm. Delež evapotranspiracije je torej prav tako 23 %.

Metoda po Vacherju

Vacher (1971) je namesto Turcove enačbe za majhne alpske razpoklinske vodonosnike predlagal naslednji način izračuna odtočnega deficita D:

$$D = P \cdot (38 \cdot 10^{-4} \cdot T^2 + 12 \cdot 10^{-3} \cdot T + 0.085 \pm 0.035) \qquad (7)$$

kjer so oznake enake kot pri enačbi (6). Če sem upoštevala tudi enake vrednosti parametrov T in P kot zgoraj, sem dobila velikost odtočnega deficita med 862 mm in 1017 mm oz. med 39 % in 46 % za povprečno leto ter med 1395 mm in 1573 mm oz. med 55 % in 62 % za obdobje 1993/94.

Primerjava uporabljenih metod

Če torej v bilančno enačbo vključim podzemni odtok 17 % in evapotranspiracijo 27 % (po Thornthwaitu), odpade na površinski odtok 56 % vseh padavin. Podobne rezultate sem z evaporacijo 23 % in površinskim odtokom 60 % dobila pri uporabi metode Turca. Večji vpliv evapotranspiracije pa predvideva metoda Vacherja, kjer je pri evapotranspiraciji 39 % oz. 46 % delež površinskega odtoka 44 % oz. 37 % za povprečno leto ter pri evapotranspiraciji med 55 % in 62 % delež površinskega odtoka med 28 % in 21 % za podatke v obdobju 1993/94. Pri teh ocenah še enkrat povdarjam, da je evapotranspiracija določena na osnovi enostavnih empiričnih enačb, ki dajejo le približne rezultate.

V praksi so vrednosti potencialne evapotranspiracije največkrat izračunane na osnovi modificirane Penmanove enačbe, ki upošteva dnevne podatke o temperaturi, vlagi, vetru in osončenju. Vendar za Tičnico njena uporaba ni bila možna, saj območje Idrije nima metereološke postaje s kvalitetnimi potrebnimi podatki. Zanimiva pa je primerjava z vrednostmi, ki so bile po tej metodi določene za nekatere druge lokacije v zahodni Sloveniji. V zaledju izvira Hublja na Trnovski planoti je bila za leto 1993 skupna količina padavin na padavinski postaji Otlica 2249 mm, po modificirani Penmanovi enčbi izračunana potencialna evapotranspiracija pa 637 mm ali 28 %. Nekoliko manj padavin je bilo s 1822 mm v letu 1994, delež evapotranspiracije s 628 mm 34 % (Avbelj, 1995). Za isto območje je bilo za obdobje 1959-1979 evapotranspiracija ocenjena na 687 mm oz. 29 % pri povprečni letni količini padavin 2380 mm (Stahl, 1994). Dolgoletna povprečja so bila upoštevana tudi pri njeni oceni za Bilje in Ljubljano (Pristov, 1994). V intervalu 1961-1990 je v Biljah padlo povprečno 1455 mm padavin in evapotranspiracija je bila ocenjena na 770 mm ali 53 %, v Ljubljani pa na 735 mm oz. 53 % pri 1390 mm letnih padavin. Na podoben način je Matičič (1994) primerjal najbolj mokro (1965) in najbolj suho leto (1971) v tem obdobju. Iz njegovih diagramov lahko pri skupnih letnih padavinah med 1209 in 2300 mm delež evatranspiracije ocenimo na 737 in 690 mm (61 % in 30 %) za Ajdovščino ter pri padavinah med 1107 in 1854 mm na 642 in 575 mm (58 % in 31 %) za Ljubljano. Pri primerjavi teh rezultatov vidimo, da se evapotranspiracija giblje med 575 in 770 mm ter da je odstotni delež v veliki meri odvisen od skupne letne količine padavin (pri najmanjših padavinah je deležnajvečji). Če se vrnemo na območje Tičnice, je bila tam po metodi Thonthwaiteja evapotranspiracija ocenjena na 686 mm, po Turcovi enačbimed 513 in 585 mm, po metodi Vacherja pa med 682 in 1573 mm. Zadnji dve vrednosti sta verjetno previsoki, rezultati enačb po Thornthwaiteju in Turcu pa so primerljivi z ocenjenami evapotranspiracije za bližnje lokacije, ki so jih z uporabo modificirane Penmanove metode dobili različni avtorji.

SKLEP

S predstavljeno metodo sem torej določila efektivno infiltracijo in izdelala grobo oceno vodne bilance za mali karbonatni vodonosnik Tičnice. Hkrati sem ovrednotila tudi primernost različnih empiričnih enačb za izračun evapotranspiracije v obravnavanem tipu bazena. Odprto pa ostaja vprašanje, kakšna je splošna uporabnost dobljenih rezultatov. Od vsega začetka je raziskava temeljila na ideji, da so vrednosti, ki jih dajo izračuni v študijskem poligonu, karakteristične tudi za večje in bolj kompleksno zgrajene vodonosnike s podobnimi osnovnimi značilnostmi. In glede na končne rezultate lahko zaključim, da je vrednost efektivne infiltracije okrog 20 % z nekaterimi korekcijami res možno brez večje napake uporabiti pri približnih ocenah v praksi. V praksi namreč natančne, zamudne in drage metode običajno ne pridejo v poštev in se dostikrat poslužujemo le približnih ocen, pri katerih je bolj kot natančna vrednost posameznih parametrov pomemben njihov red velikosti. V študijskem poligonu izračunana efektivna infiltracija je torej karakteristična za tip vodonosnikov, ki ga določajo podobne reliefne, klimatske, vegetacijske in geološke razmere. V primeru Tičnice je to območje hribovitega sveta zahodne Slovenije z dolomitno podlago, relativno debelim slojem preperine, dinarskim jelovo-bukovim gozdom, srednje strmimi pobočji in klimatskim vplivom dinarskega visokega krasa. Razmere se sicer lokalno precej spreminjajo, a osnovne značilnosti ostajajo enake.

Ocena vodne bilance vključuje padavine, evapotranspiracijo ter podzemni in površinski odtok. Padavine so bile merjene, podzemni odtok sem izračunala kot povprečno letno efektivno infiltracijo, težave pa nastopijo pri določitvi ostalih dveh parametrov. Različne vrednosti, ki sem jih dobila pri oceni evapotranspiracije na osnovi enostavnih empiričnih enačb, kažejo na omejeno uporabnost teh metod. Vsaka izmed enačb je bila definirana na osnovi raziskav v določenem vodonosnem sistemu, zato daje dobre rezultate pri preučevanju območij s podobnimi značilnostmi. Privzamemo jih lahko pri približnih ocenah v praksi, za izdelavo natančne vodne bilance pa njihova uporaba ni najbolj primerna.

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ESTIMATION OF THE EFFECTIVE INFILTRATION IN THE TIČNICA EXPERIMENTAL BASIN

Summary

In studying the hydrogeological basins one often comes upon the question how to relate precipitation and spring discharge. One of the basic questions relates to the effective infiltration, or rather the percentage of precipitation supplying the underground discharge. Though the question seems apparently

simple, it can be only rarely answered accurately. In the article one of the possible solutions presented is the use of smaller experimental basins where a direct comparison of precipitation and discharge is possible. The carbonate aquifer Tičnica near Idrija in the north- east of Slovenia contains all the characteristics of such an experimental basin, for its dimensions, the ground structure, the geological structure, the relief and the state of vegetation are known. What is more, the daily precipitation and discharge data of all the springs in the area also have been gathered. Comparing the amount of water, which in the time of observation fell on the basin surface in form of rainfall, and the water amount which meanwhile flowed out at all the springs, the characteristic value of the effective infiltration for the areas of similar characteristics was estimated.

The experimental basin contains the carbonate aquifer on the upper side of the Tičnica hill, rising above the southern part of the town of Idrija (Fig. 1). The lowest point of the treated area, with a total surface of 227.500 m^2, is situated at 420 m, the top at 580 m above the sea. The average inclination of the slopes, which rise steadily from the edge to the top, is 29°. The whole area is now covered with mixed forest. There are no permanent surface streams, and numerous smaller ravines get filled with water only after heavy rainfall.

The climate affect of the Dinaric high karst is very important for the Idrija region. For the period 1951-1980 the average annual precipitation came to 2214 mm; the evaluation for individual years differs between 1602 mm and 3039 mm. The heaviest precipitation is in autumn, the maximum in November. Among the spring months the wettest is June. The greatest dryness is in May, a little more rain falls in August and February. The air temperatures were measured only in the periods 1926-1965 and 1980-1985. The average annual temperatures in the area of Tičnica range from 7,9° to 8,2°C at this time of the year.

Tičnica belongs to Tičnica inner thrust sheet, thrust onto Idrija inner thrust sheet, and represents a part of Trnovo nappe. According to the determined tectonic conditions it is divided into 3 tectonic units (Fig. 5). The lower is the Čerin tectonic slice with the Lower Scythian siltstones and claystones with lenses of oolitic limestone, which is separated from the Carboniferous and Permian clastic sediments of the Idrija inner thrust sheet by the Tičnica thrust plane. Upwards over the thrust plane within the nappe there follows a narrow zone of Carboniferous and Permian shale claystones and siltstones of the Kalan tectonic slice. The upper and at the same time the central part of Tičnica is made up of Lower Scythian siltstones and claystones with lenses of oolitic limestone, Upper Scythian granular dolomite, Ladinian conglomerate, tuff and tuffit with chert. They are separated from the second unit by the thrust plane within the nappe, and belong to the Čuk tectonic unit. The basic rock is covered also with up to 4 m of weathered rock. In the neotectonic phase the structure of thrusts went through additional changes owing to numerous faults. The south-west border of the Tičnica inner thrust sheet is represented by the Lazar fault. Poljanec fault on the north-west side is limited by the block of Tičnica inside the wider area of the Tičnica inner thrust sheet.

On the basis of the geological structure found the aquifer can be divided into two hydrogeologically separated parts. The central part is made up of the karstified Upper Scythian dolomite. It is recharged only by precipitation, and the groundwater flows towards the Čerinivše springs on the south-west. The lower part of the aquifer is made up of oolitic limestones in Lower Scythian siltstones and claystones, which are separated from the upper zone with a narrow zone of the Kalan tectonic slice. They are drained towards the north-west to the Kosmač springs. The borders of the aquifer are quite reliably determined. It is separated from the impermeable shale rocks of Carboniferous and Permian age by the lower thrust border. Also the lateral borders on the northern, eastern and southern side are impermeable Carboniferous, Permian, and Scythian layers. But on the west, at the Lazar fault, it is limited by the milonitic Upper Triassic dolomite. Though it is made up of two parts with a different hydrodynamic regime, it is treated as a whole at the evaluation of the effective infiltration. The only source of recharge is precipitation. The groundwater outflow, on the other hand, was determined while measuring the discharge of all the springs.

To estimate the effective infiltration during the year long observation, from 1st April, 1993 to 31st March 1994, data were gathered on the daily precipitation and discharge of all the springs of the Tičnica aquifer. The effective infiltration was expressed as the part of precipitation that feeds the underground discharge, by the following equation:

$$I_{ef} = \frac{Q_m \cdot t}{P_0 \cdot F}$$

where:

I_{ef} infiltration in a definite time period expressed as % of precipitation
Q_m total discharge of all springs in the same time
t duration of the basic time unit (1 day = 86400s)
F aquifer area
P_o total precipitation in the observation period

As the discharge of some springs was measured for only half a year, I first calculated the effective infiltration for individual months and seasons in the period between July and December 1993 (table 2). However, evaluations found in such a way do not show the real picture. The simplified method used does not consider any changes in storage, which are obvious for individual months.

These differences are neglectably small only for the whole observation period, for the underground water table in two boreholes in Tičnica area at the beginning of April 1993 and at the end of March 1994 are practically at the same level. Therefore for the south-west part of Tičnica, where the discharge of all the springs was measured regularly all the year, I made the estimation of the average infiltration for one year period (table 2). The results gathered in such a way for the summer and autumn months match very well the values of the effective infiltration determined for the whole Tičnica aquifer for the period between July and December 1993 (table 2). I therefore also accepted the average annual effective infiltration, evaluated in the south-east part, for the whole area of Tičnica. The value of 17 % found indicates that the portion of precipitation watering the groundwater discharge is small. A greater amount of water which falls on the aquifer surface in form of precipitation therefore flows out as a surface run off, or, evaporating, it returns into the atmosphere. The steep relief and the thick layer of weathered rock are the causes for a greater amount of the surface runoff. Owing to the dense mixed forest evapotranspiration is also great.

Elaborating the simplified water budget on the assumption that the change in water storage was insignificant, four parameters were taken into consideration: precipitation, evapotranspiration, and the surface and groundwater discharge. I expressed it by percentage portions of precipitation that feed the remaining three elements.

As a portion of underground discharge I accepted the evaluated average annual effective infiltration of 17 %. As there are no measured data of evapotranspiration and surface discharge, I tried to estimate the two parameters at least approximately. To evaluate the evapotranspiration I used various empirical equations, namely the Thornthwaite, Turc, and Vacher's ones. The calculated values are 686 mm (Thornthwaite), 513 or 585 mm (Turc) and 862 to 1573 mm (Vacher). I compared the gained results with the data from written sources, where the corrected Penman equation was used. For different locations in western Slovenia the values between 575 and 770 mm were calculated. On the basis of the comparison I concluded, that Thornthwaite and Turc's methods are more convenient for Tičnica area. Considering the amount of the groundwater discharge of 17 % and the evaluated evapotranspiration of 23 % or 27 %, the amount of the surface discharge comes to 60 % or 56 %. At these estimations I underline once more that the evapotranspiration was defined on the basis of simple empirical equations, which give only approximate results. So they are not most suitable for the elaboration of an accurate water budget. They are, though, often used in practice, for evapotranspiration measuring is very long, and, what is more, the measured data have only local value.

The question of what the general utility of the results is, remains open. From the very beginning the research was based on the idea that the values got in the experimental basin evaluation are characteristic also for larger and more complex aquifers, but with similar basic characteristics. To this point the value of the effective infiltration of about 20 %, with some correction, can be possibly used with approximate estimation in practice without any major fault. In practice, accurate, long and expensive methods usually do not come into consideration. Very often only approximate estimations of parameters are used, because their order of size is more important than the accurate value. The effective infiltration evaluated in the experimental basin is therefore characteristic for the type of aquifer which is determined by the similar relief, climate, vegetation, and geological conditions. In the case of Tičnica it is an area of hilly region in the West Slovenia with a carbonate aquifer, with a relatively thick layer of weathered rock, mixed forest, medium steep slopes and the climatic influence of the Dinaric high karst. The conditions can change very much locally, but the basic characteristics remain the same.

JAMSKI SKALNI RELIEF, KI GA DOLBE VODNI TOK

CAVE ROCKY RELIEF HOLLOWED OUT BY A TURBULENT WATER FLOW

TADEJ SLABE

Izvleček UDK 551.435.1(497.4)

Tadej Slabe: Jamski skalni relief, ki ga dolbe vodni tok

Najbolj izraziti dejavniki oblikovanja kraških votlin so vodni tokovi, ki zapuščajo speleomorfogenetsko pomembne sledi tudi v skalnem reliefu. Predstavljen je nastanek in razvoj najbolj značilnih tovrstnih skalnih oblik. Študij je dopolnjen z laboratorijskimi poskusi z mavcem. Posamezne skalne oblike so povezane v skalni relief, značilen za rove, ki se oblikujejo v različnih hidroloških conah krasa.

Ključne besede: jamska skalna oblika, jamski skalni relief, Slovenija, kras, speleomorfogeneza

Abstract UDC 551.435.1(497.4)

Tadej Slabe: Cave rocky relief hollowed out by a turbulent water flow

The most important factor that shapes the karst caverns is water flow that leaves important speleomorphogenetical evidences on a cave rocky relief. The origin and development of most typical rocky features of a kind are presented. The study is completed by laboratory tests in plaster of Paris. Single rocky features compose a rocky relief which is typical of the passages shaped in different hydrological zones of karst.

Key words: cave rocky feature, cave rocky relief, Slovenia, karst, speleomorphogenesis

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UVOD

Velik in koristno berljiv delež jamskega skalnega reliefa oblikujejo podzemeljski vodni tokovi, kar dokazuje tudi proučevanje raznovrstnih jam našega krasa. Zaradi izrazitosti in prevlade nad drugimi skalnimi oblikami so fasete, stropne kotlice, draslje in druge skalne oblike ohranjene tudi v starih, danes suhih rovih. Razlaga načina oblikovanja posameznih skalnih oblik nam nudi možnost tolmačenja skalnega reliefa kot speleogenetske sledi. Fasete, sem že predstavil v Krasoslovnem zborniku (Slabe 1993), tokrat pa dodajam še opis in razlago nastanka ostalih najbolj značilnih skalnih oblik, ki jih dolbe vodni tok. Opisane so tudi značilnosti skalnega reliefa rovov, ki se oblikujejo v različnih hidroloških pogojih. Po literaturi sem zato povzel splošne osnove hidravličnih značilnosti pretakanja vodnih tokov, ter lastnosti vrtinčenja ob gladkih in hrapavih površinah jamskih sten.

Oblikovanje skalnega reliefa sem proučeval v številnih naših jamah. Nastanek in razvoj posameznih skalnih oblik pa sem ponazoril tudi z laboratorijskimi poskusi z mavcem. Zaradi razdrobljene vsebine, ki je posledica večjega števila obravnavanih skalnih oblik, sem pregled literature razdelil po poglavjih. Proučevanje skalnega reliefa je potekalo v okviru projekta Nastanek in oblikovanje kraških votlin, ki ga je denarno podprlo Ministrstvo za znanost in tehnologijo Republike Slovenije. Večina gradiva je bila predstavljena v knjigi Cave rocky relief (Slabe 1995). Tokrat pa sem izpostavil predvsem učinkovanje vodega toka na skalni obod jamnskih rovov in kar je bolj pomembno, zbrani so predlogi za slovensko poimenovanje različnih skalnih oblik in procesov, ki jih ustvarjajo.

Raziskave so bile izvedene z denarno pomočjo Ministrstva za znanost in tehnologijo Republike Slovenije v okviru projekta Kras v Sloveniji 2.

HIDRAVLIČNE OSNOVE

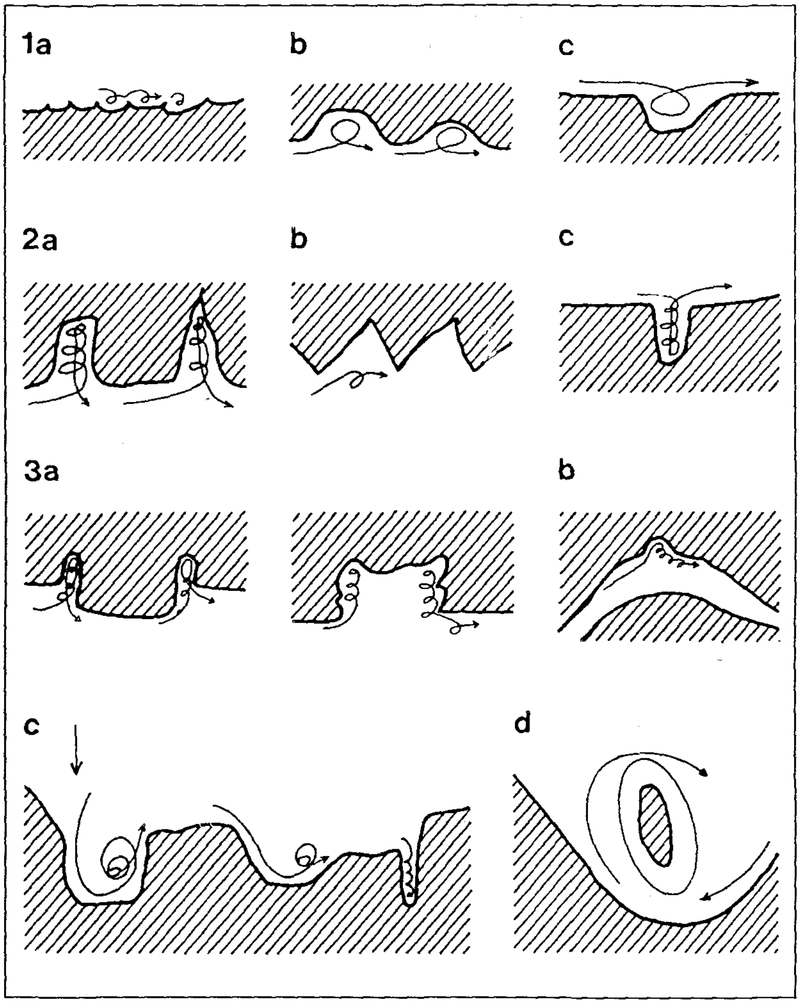
Hitrost in način pretakanja vode skozi rov določenega prereza ali povezane rove z različnimi premeri v zaliti coni sta posledici tlaka, pri vodnem toku s prosto gladino pa nagiba rova. Med rovi s prosto vodno gladino so lahko zaliti odseki, sifoni (Habič 1973). Za ožine v zalitih rovih je značilna večja hitrost pretakanja vode in manjši pritisk na stene kot v bližnjih večjih rovih. Večji je pritisk na stene, bolj teži voda k širjenju rovov in iskanju novih poti. V odprtem vodnem toku je pritisk na stene odvisen prav tako od hitrosti vode in od lege točke v strugi, torej od gladine toka, na katero deluje še atmosferski pritisk.

Na hitrost in način pretakanja vodnih tokov vplivajo tudi trenje, ki ga premaguje voda, ko obliva bolj ali manj nehomogeno in razpokano kamnino, izgube energije, ki jih povzročajo stiki rovov z različnimi premeri in nakloni, njihova posledica so hidravlični skoki, in premagovanje ovir v toku (čeri, skale). Voda pogosto prenaša tudi različno velike dele kamnine. V votlinah je moč opazovati samoizenačevanje različnih premerov rovov z erozijo in odlaganjem naplavin (Kranjc 1989, 20). Naplavina se odlaga pred ali za ožinami.

Posledica različnih premerov in oblike rovov, različne hitrosti viskozne vode, ki se pretaka skoznje in trenja ob hrapavih površinah ter ovir v toku sta laminarni in turbulentni tok. Prehod med tokovoma je funkcija hrapavosti in premera cevi (Round & Garg 1986, 22). Po mnenju Serbana (1987, 26) je kritični premer cevi za nastanek turbulentnega toka 2 cm, po Dreybrodtu (1988, 80) 1 cm, White (1988, 275) pa meni, da se turbulentni tok razvije v ceveh širokih 0,5-5 cm, pri 1 cm premera pa nastane okrogli prečni prerez cevi. Načina vodnega pretakanja ločimo z Reynoldsovim številom (Re), ki je ločnica med laminarnim in turbulentnim tokom v cevi z gladkim obodom. Če je število, ki ga povečujeta hitrost vode in premer cevi - manjša ga kinematična viskoznost tekočine - manjše od 2100 (White 1988, 164; Round & Garg 1986, 22), je tok laminaren, če pa je večje, je tok vrtinčast. Hitrost vrtinčastega toka se spreminja s kvadratom hidravličnega gradienta (White 1988, 163). Vrtinčasti tok v jamah zaradi hrapavosti in oblike rovov nastane pri manjšem Re kot v gladkih ceveh, kjer je odločilna predvsem hitrost toka. White (1988, 164) navaja kot ločnico med tokovoma Re= 10, Reynolds (1974, 207) pa Re= 10-200. V odprtih tokovih se voda vrtinči pri Reynoldsovem številu 500 (White 1988, 165). Tokovnice v laminarnem toku so vzporedne s stenami cevi, vrtinčasti tok pa lahko razdelimo na tanko laminarno mejno plast ob steni in vrtinčasto jedro. Hitrost ob stenah je zaradi adhezije delcev viskozne vode nanje enaka ničli (Boreli 1984, 357), od sten proti središču pa narašča in z njo tudi hitrost gibanja delcev vode zaradi vrtinčenja. Laminarna mejna plast, v kateri sta viskoznost in trenje odločilna pri določanju značaja toka (Boreli 1984, 359), se tanjša z večanjem Reynoldsovega števila (White 1988, 163), s katerim korenom je obratnosorazmerna. Vrtinčasto jedro se približuje steni. Ločimo dva vzroka vrtinčenja. Če je hrapavost stene tanjša od laminarne mejne plasti, je vrtinčenje posledica viskoznosti vode v mejni plasti (Duckworth 1977, 163). Inercialne sile postanejo prevelike, da bi viskozne sile oblažile trenje (Boreli 1984, 392). Če pa je višina hrapavosti večja od debeline laminarne mejne plasti, ovire povzročajo dodatne vrtince (Duckworth 1977, 163). Posamezne večje ovire lahko torej prekinejo mejno plast tudi pri nizkih Reynoldsovih številih. Pri izrazitem vrtinčastem toku se vpliv viskoznosti, izražene v Re, lahko zanemari (Boreli 1984, 359). Skratka pri visokih Re številih je koeficient trenja odvisen od hrapavosti kamnine in skorajda neodvisen od viskoznosti, pri majhnih Re pa je odvisen predvsem od viskoznosti in le malo od hrapavosti (Reynolds 1974, 5). V rovih zaradi omejene homogenosti kamnine in oblikovanosti sten vpliva na nastanek drobnih oblik (manjše fasete), ki jih vrezuje hitrejši vodni tok, predvsem prvi tip vrtinčenja. Pri nastanku večjih oblik (velike fasete), ki so posledica delovanja počasnejšega toka, je odločujoč drugi tip vrtinčenja. V toku nastanejo torej vrtinci različnih premerov in nestabilnih linij vodnih delcev.

Vrtinec je vrteča vodna masa, v kateri so tokovnice koncentrični krogi, hitrost v vsaki točki pa je obratnosorazmerna s premerom tokovnic (Duckworth 1977, 91). Proti središču vrtinca narašča hitrost, tlak pa se niža. V samem središču vrtinca je hitrost neskončna in viskoznost povzroči, da se jedro vrti kot trdno telo. Hitrost njegove osi je nič (Duckworth 1977, 92, 93). Manj je tekočina viskozna, manjši je premer vrtinca (Serban 1987, 16). Hitrosti vrtinčaste mase so tesno povezane z velikostjo in obliko prostora ter velikostjo toka. Različni vrtinci vplivajo drug na drugega, se deloma prekrivajo in kinetična energija se postopoma prenaša na manjše (Serban 1987, 17). Število majhnih vrtincev narašča z večanjem Reynoldsovega števila (Serbon 1987, 20). Poleg trenja ob obodu povzroča vrtince tudi oblika prostora, torej sprememba premera in nagiba rova, ter ovire v toku. Pred ožino se tok širi, v ožini pa se spušča, zožuje (Duckworth 1977, 182) in na prehodih nastane vrtinčata cona. Tudi na zavojih cevi se pojavljajo izgube, saj radialni gradient pritiska narašča navzven. Na zgornjem in spodnjem delu stene zunanje strani ovinka nastane radialni notranji tok (Duckworth 1977, 182). Posamezne zajede v steni povzročijo nastanek vrtincev že pri Re 10-200. Vrtinec je odvisen od oblike zajede in se zapleteno spreminja z Re (Reynolds 1974, 207). Večje vrtinčaste cone (sl. 1/3a) se odražajo predvsem v oblikovanju stropnih kotlic. Ko superkritični odprti tokovi, ki nastanejo z naraščanjem hitrosti na strmih pobočjih, naletijo na položna tla struge ali pa na podorne skale v njej, se sprosti veliko energije. Nastane hidravlični skok in erozija je zato izrazita (White 1988, 166). Na takšnih mestih ponavadi nastanejo draslje. Skratka hidravlične razmere so odvisne od številnih mejnih pogojev, na skali pa se odražajo v skalnih oblikah, ki jih bom skušal predstaviti v nadaljevanju.

Ločimo več tipov vodnih tokov. V stalnem enotnem toku se potencialna energija manjša zaradi manjšanja nagiba po toku navzdol ali tlaka v zaledju. Razporeda hitrosti ter pritiska sta v preseku enaka vzdolž celega toka (Vuković & Soro 1985, 58). Tok je stalni neenotni, ko se njegova debelina, hitrost in tlak spreminjajo skokovito. Zanj so značilni hidravlični skoki (Round & Garg 1986, 283). Posebej sta izdvojena tudi kritični tok, katerega hitrost je enaka hitrosti neskončno majhnih delcev in superkritični tok, ko majhne ovire vplivajo po toku navzdol (Round & Garg 1986, 284). Vodni tok se spreminja tudi v času, poleg osnovnega toka obstajajo še pulzirajoči tokovi (Boreli 1984, 359). Eden pomembnejših dejavnikov oblikovanja kraškega podzemlja je sezonsko, pogosto hitro in izdatno spreminjanje lastnosti vodnega toka. Tudi to nam izpričuje skalni relief.



Sl. 1: Značilno vrtinčenje vodnega toka

1. *vrtinčenje ob homogeni, nerazpokani kamnini*
   a. *fasete*
   b. *stropne kotlice*
   c. *draslja*
2. *vrtinčenje ob razpokah*
   a. *stropne kotlice*
   b. *noži*
   c. *draslja*
3. *vrtinčenje, ki ga povzroča oblika rovov*
   a. *stropne kotlice*

b. stenska kotlica na zavoju
c. draslje: pod slapom, spuščajoči tok, pred oviro
d. draslja ob zavoju rova

Fig. 1: Typical turbulence of water flow
1. turbulence at homogeneous, solid rock
a. scallops
b. ceiling pockets
c. potholes
2. turbulence along the fissures
a. ceiling pockets
b. knives
c. potholes
3. turbulence due to shape of a passage
a. ceiling pockets
b. wall pocket at meander
c. potholes; below a waterfall, falling flow, in front of obstacle
d. pothole; at passage meander

PROCESI NA KAMNINI

Procesa oblikovanja kamnine, ki jih povzročajo vodni tokovi, sta predvsem raztapljanje kamnine in njeno mehansko dolblenje. Pospešujeta tudi razpadanje skalnega oboda.

Stopnja **raztapljanja** (korozija) kamnine je odvisna od hitrosti površinske reakcije, stopnje transporta reaktantov in proizvodov raztapljanja ter produkcije H^+ in H_2CO_2 s konverzijo CO_2 (Dreybrodt 1988, 103). Vzporedno s hidrodinamično laminarno mejno plastjo v vrtinčastem toku lahko določimo tudi mejno plast, v kateri se transport reaktantov in proizvodov raztapljanja vrši z molekularno difuzijo. Plast se tanjša, ko kamnino obliva hitrejši vrtinčasti vodni tok. Ob njej je še prehodna mejna plast, v kateri se učinkovitost difuzije postopno povečuje proti jedru toka. Vrtinčasta difuzija je namreč znatno hitrejša od molekularne. V izrazitem vrtinčastem toku, ko je učinkovitost vrtinčaste difuzije 10^4 večja od molekularne, je mejna difuzijska plast zanemarljiva (Dreybrodt 1988, 154). Hitrost vodnega toka povečuje korozijsko stopnjo, če je reakcijska stopnja hitrejša kot transportna, če pa ni, površinska reakcija omejuje učinkovitost korozije (Trudgill 1985, 19). V vodnem toku je torej hitrost raztapljanja posledica hitrosti toka in kemične sestave vode, ki s skalnim površjem iz različno topljivih delcev, določajo stopnjo površinske reakcije. V vadoznih votlinah, skozi katere se pretaka hiter vodni tok, se lahko raztopi 1 mm kamnine na leto (Palmer 1982, 190).

Mehansko delovanje vodnega toka lahko razdelimo na delovanje same vodne mase in dolblenje z materialom, ki ga prenaša voda. Hiter, vrtinčasti vodni tok, ki ima tanko mejno laminarno plast, trga s skalne površine manjše delce, ki jih osami korozija.

Problem korozije mešanice različno nasičenih voda, ali voda z različno temperaturo, ki postanejo spet korozijsko učinkovite (Bögli 1971), sem skušal vrednotiti pri razlagi nastanka stropnih kotlic.

Kavitacija (Scheidegger 1961, 57; Splošni tehniški slovar 1978; Cigna 1983, 481) v kraškem podzemlju še ni dokazana. Je razjedanje materiala zaradi implozije parnih mehurčkov v vodnem toku, nastalih pri znižanem tlaku v področju povečanih hitrosti toka. Cikle kavitacije je Cigna (1983, 481) razdelil na nastanek cone nizkega tlaka v predelih nepravilnosti v toku, na nastanek žepov izparine, ko je lokalni tlak nižji od napetosti izparine in končno kolaps mehurjev izparine. Tako nastanejo na stiku s kamnino siloviti valovi. Številni mehurčki, ki se sesujejo v 10^{-3} do 10^{-4} sekunde in zopet nastanejo takoj po mikroimploziji, povzročijo tlake, ki lokalno dosežejo desetine megapaskalov. Hitro in veliko menjavanje tlaka vsrka zrak iz por kamnine in povzroči njen razkroj. Cigna (1983, 480) je predpostavil tudi možnost korozije, zaradi oksidacije v vodi, ki je obogatena z mehurčki kisika. Mehurčki se tvorijo v trenutku znižanja tlaka. V majhnih rovih je hitro dosežena največja možna hitrost vode. V večjih kanalih, kjer so večje razlike v tlakih, je kavitacija bolj verjetna. Proučiti bi bilo potrebno sifone, saj vodni tok v njih dosega največje hitrosti, tudi 10 m/s (Kranjc 1986, 209). V zalitem rovu naj bi bile s kavitacijo pogojene tudi oblike, ki nastanejo tik za ovirami, v vadoznem toku pa so takšne oblike pod slapovi. Zaradi kavitacije je skalna površina luknjičasta (Cigna 1983, 485). Serban (1987, 24) meni, da kavitacija naredi majhne vdolbinice, ki imajo 0,5 do 1,5 mm premera. Vdolbinice nastanejo na ravnih stropih v spodnjih delih sinusoidno vijugavega rova. Kavitacija naj bi bila mogoča le pri hitrostih, ki so večje od 20 m/s in s tlakom 9 m vodnega stolpca. Cigna (1983, 485) predlaga mikroskopsko opazovanje izpostavljene skalne površine zaradi morebitno premaknjenih kristalov.

Na oblikovanje oboda rovov vpliva tudi kamnina, ki je sestavljena iz delcev različnih velikosti in različne topnosti. Že sama velikost delcev vpliva na možnost nastanka skalnih oblik. Večje ovire onemogočajo nastanek faset, zlasti manjših, ki jih vrezuje hitri vodni tok. Značilno se oblikujeta apnenec in dolomit. Večji kristali sparita, ki so praviloma počasneje topni kot manjši delci mikritnega veziva, pogosto štrlijo iz sten. Šibkosti v kamnini so namreč manjši sestavni delci, ki nudijo raztapljanju večjo površino. Kamnina se najhitreje raztaplja ob stiku zrn, ki jo sestavljajo, redko pa nastanejo vdolbinice na kristalih (Herman & White 1985). Štrleči delci kamnine so bolj izpostavljeni vodnemu toku, polzeči vodi, ali pa zaradi teže sami odpadajo. Pod vrstičnim mikroskopom lahko opazujemo, da so večji kristali na površju kamnine, ki je korozijsko razjedena, obdržali svoje pravilne oblike. Tudi Ek in Roques (1972,

71) ugotavljata, da je počasnejše raztapljanje velikih kristalov posledica večje odpornosti njihovih ploskev in omrežne energije. Dolomit pogosto hitreje razpada, če pa ga povezuje kalcitno vezivo, je v vodnem toku odpornejši od apnenca (Križna jama). Bolj je kamnina porozna, učinkovitejša je korozija. Skalne oblike so pravilnejše, čimbolj so enotni sestavni deli kamnine.

SKALNE OBLIKE, KI JIH DOLBE VODNI TOK

V tabeli 1 so združene skalne oblike, ki so značilne za relief rovov v različnih hidroloških conah. Pretok vode skozi te rove je različno hiter. Skalne oblike nastanejo zaradi vrtinčenja vode ob hrapavi skalni površini, vrtinčenja ob razpokah ali vrtincev, ki jih povzroči oblika rovov (sl. 1/3a, b). Procesa njihovega oblikovanja sta raztapljanje in njeno mehansko dolblenje.

Fasete, ki so ena najbolj značilnih tovrstnih oblik, sem predstavil v 22. številki Krasoslovnega zbornika (Slabe 1993).

STROPNE KOTLICE

Stropna kotlica (sl. 2), ki doseže meter in več premera, je vdolbina na stropu ali na zgornjih delih sten rova, (fr.: coupole la voute (Renault 1968, 29; Quinif 1973; Maire 1980, 35), marmite inverse, marmite de pression (Gèze 1973, 9); an.: ceiling pocket, solution pocket (Bretz 1942; Bögli 1971; Ford 1988, 43); it.: cupole (Pasquini 1975; Binni & Cappa 1978); nem.: Korrosionskolke (Bögli 1978, 163)).

Kotlice so pogoste sledi vrtinčenja vodnih tokov v epifreatični in freatični coni. Skozi epifreatične vodne rove (Ponikve v Jezerini, Ponor v Odolini, Križna jama, Ponorna jama Lokve v Predjami, Osapska jama, Dimnice, stari suhi tovrstni rovi pa so v Trhlovci, Brlogu na Rimskem, Stari jama v Postojnski jami in v zgornjih rovih v Predjami) se pretaka srednje hiter vodni tok, po fasetah sklepam na njegovo hitrost od 25 do 50 cm/s. Tla prekrivata prod ali ilovica. V ponorni Griški jami pod Ribniško Malo goro, kjer se skozi začetni del jame počasneje pretaka voda po ilovici, so nastale kotlice tako na stropu kot na zgornjih delih sten. Vodni tok v njej je prepočasen, da bi vrezoval fasete. Najmanjše kotlice pa so na stropih manjših, ponavadi nekoliko dvigujočih rovov, pred katerimi so globlji sifoni. To so rovi v izvirnih jamah na vznožju visokega krasa. Hitrost toka v teh jamah preseže tudi 2 m/s (Babja jama). Spodnji deli oboda teh jam so ponavadi mehansko zglajeni: Matijeva jama, Babja jama, ali pa so na njih fasete kot v Kompoljski jami.

Iz skalnih oblik, ki so danes v suhih jamah, sklepam, da so kotlice nastale tudi v globlje zalitih, freatičnih rovih zaradi vrtinčenja počasnega vodnega toka, o čemer pričajo tudi velike fasete na stenah Divaške jame, Dvorane palm v Pivki jami, Vodne jame v Lozi in večje niše za vhodom v Križno jamo (Slabe 1989 b, 209), Brezna na Škrklovici, Mežnarjeve jame in Pečine v Radotah.

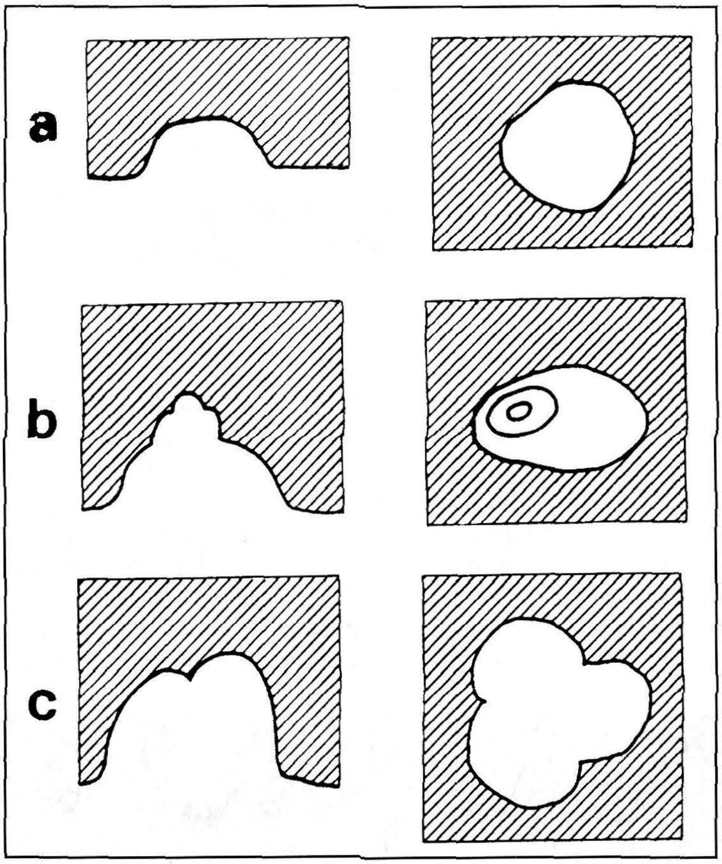
Sl. 2: Stropna kotlica v Ponorni jami Lokve
Fig. 2: Ceiling pocket in Ponorna jama of the Lokva

Po mnenju Renaulta (1968, 582) in Quinifa (1973, 569), ki povzema tudi mnenja drugih avtorjev, so kotlice značilnost rovov, skozi katere se pretaka počasen vodni tok, in ki imajo dno prekrito z ilovico. Trudgill (1985, 76) jih imenuje kupole, ki nastanejo zaradi vrtinčenja vode pod piezometričnim nivojem.

Quinif (1973) je na podlagi značilnih oblik stropnih kotlic ugotavljal načine njihovega nastanka. Posebej je poudaril in s poskusom dokazoval pomen korozije mešanice. Sam pomen tega procesa oblikovanja kotlic še nisem uspel dokazati. Ugotavljam pa, da so nastanek, velikost, oblika in položaj kotlic posledica razmerja hitrosti in tlaka vodnega toka ter sestave in zlasti razpokanosti kamnine v značilno oblikovanih rovih.

Oblika, velikost in položaj stropnih kotlic

Stropne kotlice so samostojne in sestavljene. Samostojna kotlica (sl. 3a) se sama zajeda v skalo. Enostavna je, ko je enotnega, večinoma polkrožnega prereza, ki se oža navznoter. V drugo skupino sodijo samostojne nadstropne kotlice (sl. 3b). Nadstropnost pomeni skokovito spremembo premera kotlice. V tretjo skupino sem uvrstil sestavljene nadstropne kotlice (sl. 3c) na razpokani ali nerazpokani skali. V sestavljenih kotlicah je znotraj večje kotlice več manjših, ali pa so enake in različne kotlice bočno povezane. Sestavljene kotlice

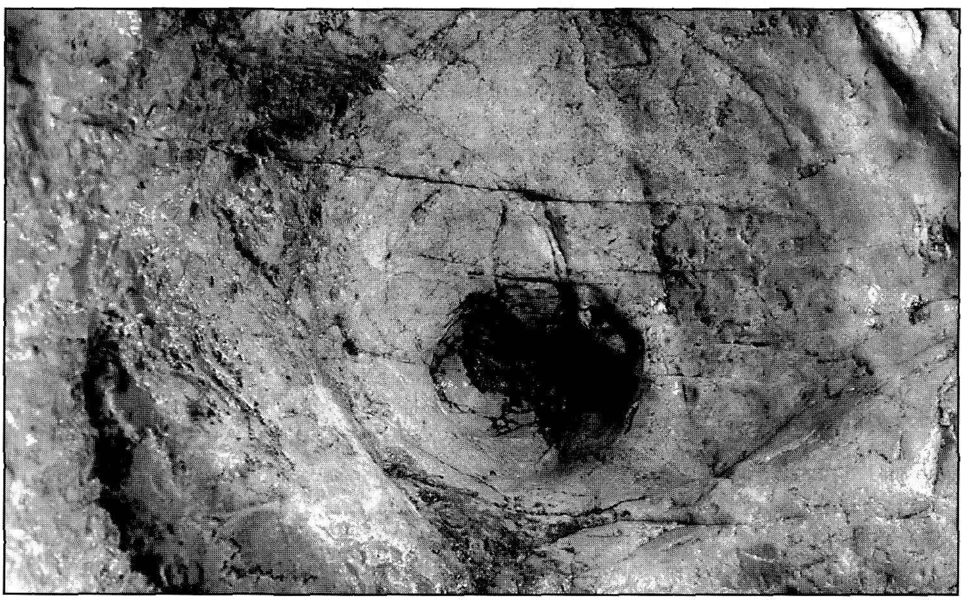


Sl. 3: Tipi stropnih kotlic: vzdolžni in prečni prerez
a. samostojna, enostavna kotlica
b. samostojna, nadstropna kotlica
c. sestavljena, nadstropna kotlica

Fig. 3: Types of ceiling pockets: longitudinal and cross section
a. independent, simple pocket
b. independent pocket in levels
c. composed pocket in levels

so tudi nadstropne. Na manj razpokani skali so kotlice večinoma polkrogelne, ob izrazitih razpokah pa ožje in globlje. Slednje so v prerezu krožne ali pa razpotegnjene v elipse. Kotlice različnih oblik so lahko na istem stropu kot v Zelških jamah, v Stari jami v Predjami in v Baru v Dimnicah (Slabe 1989 a, 29).

Kotlice v prvi skupini lahko razdelimo na manjše in večje. Manjše kotlice, katerih premer meri od 8 do 15 cm, prav toliko so globoke, so dokaj pravilnih polkrogelnih oblik ali pa so ob razpokah nekoliko podaljšane v elipse. Takšne kotlice so značilne za strope manjših rovov v izvirnih jamah na vznožju visokega krasa (sl. 4). V Matijevi jami (Slabe 1989 a, 188; sl. 5) so kotlice tesno druga ob drugi, torej povezane v mreži. Večje samostojne kotlice, ki imajo premer velik 30-150 cm, globoke pa so od 15 do 75 cm, so razmeroma plitke. Dna kotlic so polkrogelno zaobljena, njihove osi so praviloma bolj ali manj navpične. Tudi ob razpokah je globina takšnih kotlic manjša od premera vdolbine. Nekoliko globlje so kotlice na konkavnih stenah zavojev v ozkih rovih (sl. 6). Samostojne nadstropne kotlice so široke 20-150 cm, globoke pa 30-120 cm. So torej globlje od enostavnih. Takšne kotlice so praviloma razčlenjene v 3-4 nadstropja in premer najožjega zgornjega dela je ponavadi 3-4 krat ožji kot premer odprtine. Kotlice, ki so glede na premer plitke, so polkrogelnih prerezov. Druge so ob nadstropju razširjene. Ob izrazitih razpokah so kotlice ozke in globoke ter imajo oblike valjev, njihova dna pa so krožna in ravna (sl. 7). Poseben primer so spiralasto poglobljene kotlice.

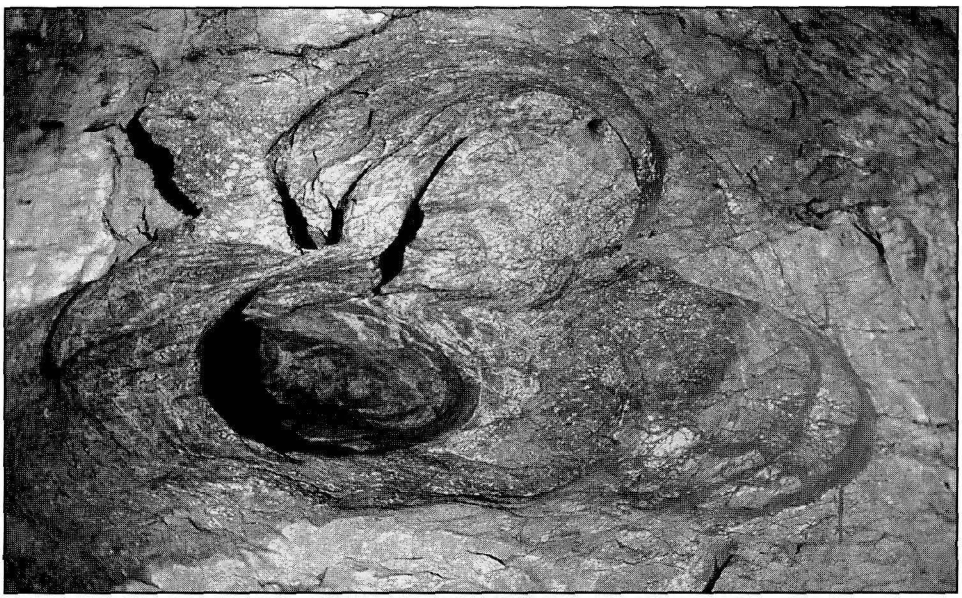


Sl. 4: Stropna kotlica v Peklu v Babji jami
Fig. 4: Ceiling pocket in Pekel, Babja jama

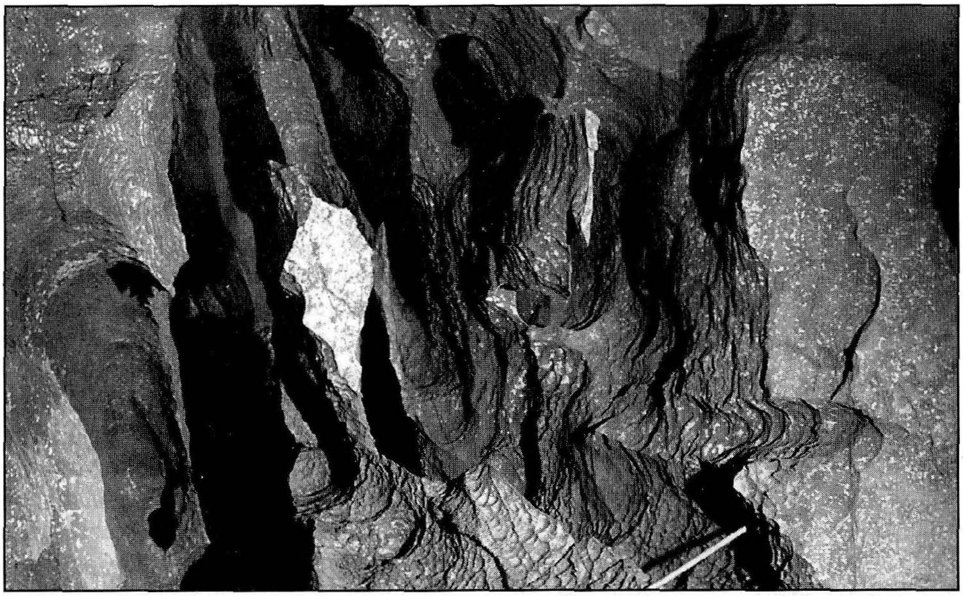
Sl. 5: Stropne kotlice v Matijevi jami
Fig. 5: Ceiling pockets in Matijeva jama

Sl. 6: Kotlica na zgornjem delu stene Ozkega rova v Ciganski jami
Fig. 6: A pocket at the upper part of the wall in Ozki rov, Ciganska jama

Sl. 7: Stropne kotlice v Nebesih v Zadlaški jami (merilo = 15 cm)
Fig. 7: Ceiling pockets in Nebesa, Zadlaška jama (scale = 15 cm)



Sl. 8: Stropna kotlica v Stari jami Predjame
Fig. 8: Ceiling pocket in Stara jama, Predjama



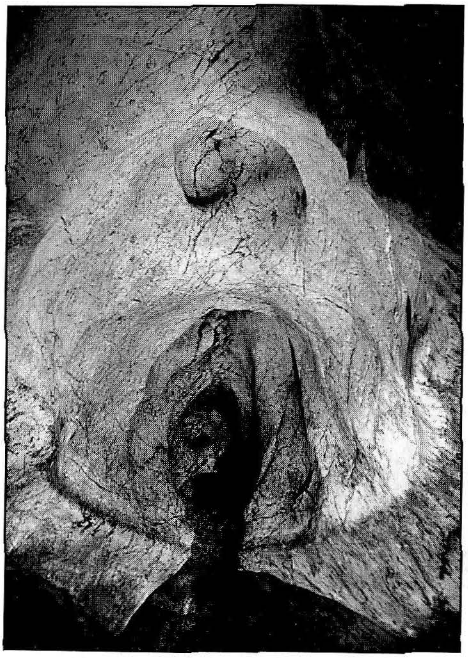
Sl. 9: Strop sifona v Krožnem rovu Črne jame (merilo = 15 cm)
Fig. 9: The ceiling of a siphon in Krožni rov, Črna jama (scale = 15 cm)

V dno sestavljene kotlice se zajedajo manjše (Slabe 1989 a, 31) ali pa so bočno povezane. Povezujejo se dve ali tri kotlice (sl. 8). Praviloma je ena globlja. Ob razpokah so često povezane v nize. Najbolj gosto pa so kotlice povezane na razpokani skali, kjer so združene v večjo stropno zajedo. Kotlice v zajedi so različnih velikosti. Ob izrazitih razpokah se kotlice nadaljujejo v ozke špranje, tako da njihovega dna ni moč videti, ali pa so njihova dna ravne krožne ploskve. V gosto razpokani skali so lahko anastomozno povezane, saj so robovi med njimi prežrti. Takšne kotlice so dokaj nepravilnih oblik (sl. 9).

Izdvojim naj kotlice, ki so široke 1-3 m in globoke do 1 m. Imajo dokaj ravna dna, njihove osi pa so navpične. Kotlice v Vzhodnem rovu v Predjami imajo na robu manjši žleb. Takšne kotlice so na nekoliko nižjih delih stropa. Prerezi kotlic so polkrožni ali pa so razpotegnjeni ob razpokah. V vodnem rovu Zelških jam dna polkroglastih kotlic, ki so nastale ob razpokah, sestavljajo krožne površine, zalitost z vodo pa izpričujejo vermakuliti. V Rakovem rokavu Planinske jame imajo velike in plitke kotlice hrapavo površino, voda jih v občasno poplavljenem delu rova ne doseže več, jih pa popolnoma zapre.

Značilnih oblik so tudi kotlice na strmo ali položno nagnjenih stropih, ki se spuščajo pred ali dvigajo za zožitvijo v rovih. Pred zožitvijo so 1 m dolge kotlice prečno podolgovate, široke so 20-30 cm in 25 cm globoke. Na odtočni strani ožin so kotlice nekoliko razpotegnjene v smeri vodnega toka, dolge so

1-1,5 m in globoke do 0,75 m. Pogosto so (Babja jama) so nanizane druga za drugo (sl. 10). V ponorni jami Lokve v Predjami je pritočni rob kotlice za ožino prerezan. Pri poskusu na mavcu je najbolj izrazita zajeda s kotlicami nastala pred ožino v cevi.



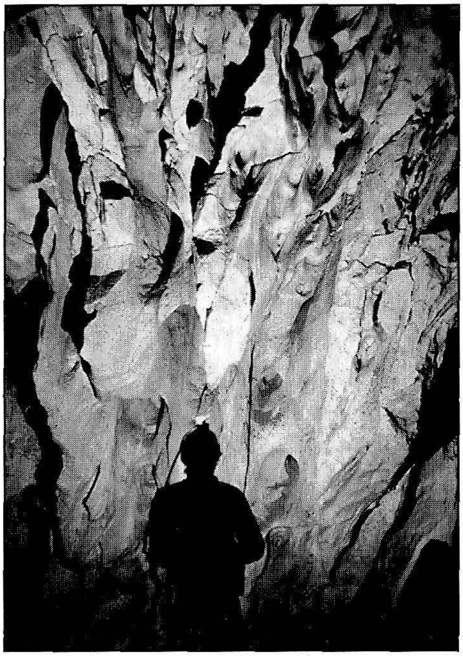
Sl. 10: Stropna kotlica v Ponorni jami Lokve v Predjami
Fig. 10: Ceiling pocket in Ponorna jama of the Lokva, Predjama

Nastanek in razvoj stropnih kotlic

Kotlice nastanejo zaradi vrtinčenja vodnega toka ob razpoki, večji nehomogenosti v kamnini ali pa so vrtinci pogojeni z obliko rova. Začetni vrtinci pri nastajanju kotlic so odvisni predvsem od hitrosti in tlaka vodnega toka ter položaja v rovu, nato pa vrtince določa tudi oblika kotlic sama. Že manjši vrtinci nimajo več iztočnih repov, ki so značilni za fasete (Slabe 1993). Začetni vrtinci, ki oblikujejo polkrogelne kotlice, imajo tokovnice pravokotne na steno. Takšno vrtinčenje je značilno tudi za večje kotlice s polkrogelnim dnom, če se kotlica enakomerno širi in poglablja. V kotlicah, ki nastanejo ob izrazitih razpokah in so globlje od premera odprtine, ali v kotlicah, ki so razpotegnjene ob razpokah, so tokovnice vrtincev vzporedne s steno ali pa svedraste. To nam potrdi tudi ravno krožno dno kotlic (sl. 7). Kotlice so zato podobne valjem ali prisekanim stožcem. Njihovo dno je pogosto sestavljeno iz več krožnih ravnih delov. V večjih stropnih zajedah, kjer je združenih več kotlic, je vrtinčenje raznovrstno. V sestavljenih kotlicah prevlada eden izmed vrtincev. V Matijevi jami so kotlice združene v kamin, ki ima stene polkrožno razčlenjene.

Nadstropne kotlice so praviloma sestavljene, le redko so samostojne. Pri sestavljenih kotlicah prevladuje eden izmed vrtincev in je nadstropnost zato razumljiva. Skokovita sprememba premera vrtincev je lahko posledica skladovitosti kamnine (Slabe 1989 b, 207) in značilnosti razpoke, če so kotlice nastale ob njej. Se v nadstropnosti kotlice odraža tudi širjenje rovov, upad gladine vode, torej manjši pritisk na stene, in se premer kotlic zato navzgor manjša? Nadstropnost je lahko tudi posledica spremembe smeri strujnic vodnih vrtincev v globljih kotlicah.

Kot smo ugotovili iz oblik kotlic, je za lokalni položaj, nastanek in obliko pomembna predvsem razpokanost ali skladovitost kamnine. Večina kotlic je vezana na razpoke in lezike. Če so razpoke izrazite in gosto prepredajo kamnino, kotlice pravilnih oblik ne morejo nastati, ali pa se pravilno razviti. Takšen primer je tudi v Zelških jamah (sl. 11). Na nastanek kotlic manj vpliva sestava kamnine. Kotlice nastanejo tudi na kamnini, katere sestava je preveč nehomogena ali pregosto razpokana, se prehitro drobno kruši, da na njej ne morejo nastati fasete. Tako so kotlice nastale na drobnozrnatem dolomitu v Turkovi jami, na prekristaliziranem apnencu v Finkovi jami, v Predjami pa so se kotlice oblikovale tudi preko manjših leč roženca (Slabe 1994). Stene teh so hrapave.



Sl. 11: Strop Blatnega rova v Zelških jamah
Fig. 11: The ceiling of Blatni rov in Zelške jame

Kotlice nastanejo lahko tudi ob razpokah na stenah, kjer so fasete (sl. 12; Slabe 1989 a, 84). V površino takšnih kotlic se zajedajo fasete. V zatišjih kotlic so fasete nekoliko večje kot na izpostavljenih delih oboda.

Od nastanka kotlice z vrtincem ali njenega oblikovanja z zračnimi mehurji in od sestave kamnine je odvisna tudi zglajenost njene površine. Kotlice, ki jih obliva hitrejši vodni tok, imajo gladke obode ali pa iz njihove površine štrlijo počasneje topni deli kamnine (Matijeva jama), roženci. Kotlice, v katerih je občasno ujet zrak, imajo hrapavo površino, oziroma so hrapavi le njihovi vrhovi, ki so nad vodno gladino (Rakov rokav v Planinski jami; Slabe 1989 b, 207).

Poudarim lahko tudi značilne položaje kotlic v rovu. Kotlice so največkrat na stropu širših in višjih delov rovov, zlasti izrazite so pred in za ožinami, na začetku ravnega stropa za dvigajočim ali spuščajočim rovom, ali pa v večjih stropnih zajedah. To so deli rovov z večjimi izgubami energije in v njih nastajajo značilne cone vrtinčenja (sl. 3). Vrtinčenje vode torej ni povzročeno le z drobnimi ovirami na kamnini, temveč predvsem z značilno oblikovanostjo rovov. To nam je potrdil tudi poskus z mavčno cevjo različnih premerov. V krajšem, prostornejšem delu cevi, torej med ožjima deloma, so nastale le kotlice, v ožjem pritočnem in odtočnem delu cevi pa fasete. Na stikih cevi z različnimi premeri so nastale večje zajede s kotlicami.

Sl. 12: Stenska kotlica s fasetami v Markovem spodmolu (merilo = 15 cm)
Fig. 12: Wall pocket with scallops in Markov spodmol (scale = 15 cm)

Zakaj so kotlice le na stropu in na zgornjih delih sten, saj se vrtinčenje širi na vse strani? Plinom (Cser & Szenthe 1986, 279), ki so ujeti pod stropom ter pospešujejo korozijo, pripisujem manjši pomen. Odločilen je predvsem razvoj in oblika rovov ter vrtinčenje vodnega toka v njih. Različna sestava kamnine, skladovitost in pretrtost oboda rovov povzročajo različne premere in naklone rovov. S stropa odpadajo večji skalni bloki in nastajajo zajede. Prav v večjih zajedah na razpokani kamnini so kotlice najbolj pogoste. Voda prenaša material, in ko ga odlaga v večjih prostorih, uravnava pretok. Tla se izravnavajo, stropovi pa razčlenjujejo. Zato lahko v večini razčlenjenih rovov opazujemo, da so na spodnjih delih sten fasete, na stropu pa kotlice. V enakih hidravličnih pogojih bi na obodu cevastega rova z enotnim premerom nastale večje fasete (Kozinski rov v Lipiški jami), ali pa bi bil rov meandrast. Pri poskusu z mavčno cevjo so kotlice nastale po vsem obodu širšega dela cevi. Podarjena cona vrtinčenja, ki je posledica sprememb premera cevi, se je razširila čez celo dolžino širšega dela cevi. Če bi bil srednji in širši del cevi daljši, bi kotlice nastale le ob razširitvi oziroma zoženju cevi, med njimi pa bi se oblikovale fasete.

Jedro vrtinca v kotlici se približa steni in poveča korozijski izkoristek vode. V manjših kotlicah, ki so nastale v rovih s hitrejšim pretokom, deluje vodna masa tudi mehansko. S skalnega površja odnaša še neraztopljene delce. Njihova površina je gladka.

Pogosto se pri razlagi nastanka kotlic omenja pomen plinov s CO_2, ki se v vrtinčastem toku dvigujejo navzgor in pospešujejo raztapljanje. Tudi raztapljanje CO_2 iz zraka, ki je pod visokim tlakom ujet pod stropom, naj bi povečalo lokalno korozijsko stopnjo (Bögli 1978, 158; Ford & Williams 1989, 298; Cser 1988, 132). Nastanek kotlic z ravnim dnom Cser in Szenthe (1986, 279) razlagata s premikanjem zračnih mehurjev pod stropom. Stare kotlice z ravnim dnom, ki nimajo izrazitih znakov vrtinčenja, so tudi v Vodni jami v Lozi in v Divaški jami, na steni pod njimi pa so velike fasete, ki so značilne za globlje freatične rove. V času obiska so bila dna kotlic prekrita z gosto mrežo svetlečih kapljic. Te bi lahko zaradi korozije pod njimi vplivale na preoblikovanje starih kotlic. Mucke, Völker in Wadevitz (1983) poudarjajo pomen kondenzne korozije v stropnih zajedah, v katerih je ujet zrak. Kondenzacija je mogoča, če je voda toplejša od kamnine. V Rakovem rokavu v Planinski jami visoke vode stisnejo in osamijo zračne mehurje v stropne zajede. Površina plitkih, a dokaj širokih kotlic nima izrazitih znakov vrtinčenja vode in je hrapava. To bi bila lahko posledica kondenzne korozije, ki pa je kotlice verjetno le preoblikovala. Podobno hrapava so tudi dna kotlic v Križni jami. Pri nastanku kotlic s počasnejšim tokom bi lahko imela večji pomen tudi konvekcija nenasičene vode, ki se dviguje na sredini kotlice, ob stenah pa odteka nasičena. Forti (1989, 72) opozarja na pomen oksidacije sulfidov, ki se vključujejo v konvekcijo. Serban (1987) razpravlja tudi o majhnih vdolbinicah na stropu rovov. Te naj bi bile posledica majhnih vrtincev, ki se razvijajo iz večjih. Bögli pa meni, da so te oblike, zajedene tudi v večje fasete in stropne kotlice, posledica kondenzacije vlage, ki jo stisnejo poplavne vode pod strop. Pri proučevanju majhnih oblik (0,5-3 mm) je treba posebno pozornost poznavanju kamnine, saj so lahko posledica njene sestave.

Nastanek ozkih in globokih stropnih kotlic, ki se na vrhu nadaljujejo v špranje, se pogosto razlaga s korozijo mešanice različno nasičenih voda, ali voda z različnimi temperaturami. Zaradi mešanja voda postane zopet agresivna (Bögli 1969). Quinif (1973, 570) tudi nadstropnost kotlic razlaga s korozijo mešanice. Ozke in globoke kotlice je naredil s poskusom. V posodo z vodo je do polovice potopil prelomljeni kamen in skozi razpoko nalival HCl. Binni in Cappa (1978, 58) dodajata, da je za nastanek takšnih kotlic potreben počasni vodni tok, ki naj bi sesal vodo iz razpok. Sam korozije zaradi mešanja voda še nisem uspel razločiti. V večini proučenih kotlic pa korozija mešanice ni povzročila njihove nadstropnosti. Pri razlagi stropnih kotlic v Logaški jami kot možni proces njihovega oblikovanja Gams (1964, 13) navaja korozijo mešanice. Poleg kotlic, ki se navzgor zožujejo in njihovega dna ni videti, obstajajo tudi kotlice, ki imajo ravna krožna dna, kar je sled vrtinca. Korozija mešanice verjetno lahko razširi razpoke, da jih lažje izkoristi vrtinec. Tako ugotavljata tudi Ford in Williams (1989, 298). Razpoke pa lahko širi tudi voda, ki prenika v občasno suh rov, seveda če se pri prenikanju ne nasiti. V že suhi Logaški jami je prenikajoča voda med kotlicami oblikovala večje kamine.

Najvišje vode v večjih delih rovov, skozi katere se pretakajo počasneje, odlagajo ilovico na zgornjih delih oboda. Ilovica se obdrži tudi na položnejših stenah globljih kotlic, ko se iz nje izceja voda, vrezuje podnaplavinske žlebiče (Slabe 1994a).

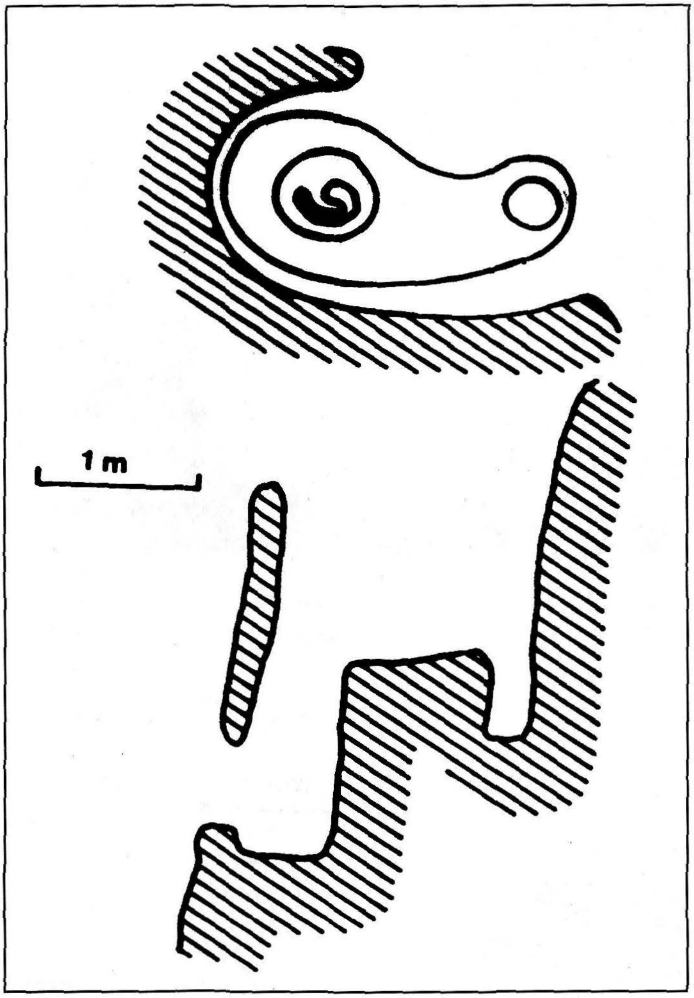
DRASLJE

Oblika, velikost in položaj draselj

Draslje (fr. marmite de géant (Renault 1958, 30, 31; Viehman 1959; Corbel 1962; Gèze 1973, 9; Maire 1980, 35; Lismonde 1987), an. pothole (Bretz 1942); nem.: Erosionskolke (Bögli 19789, 165)) so samostojne (sl. 13) ali sestavljene (sl. 14) kotlice na skalnih tleh rovov. V sestavljenih drasljah ena prevladuje. So enostavne ali pa nadstropne. Izdolbe jih vodni tok, ki vrtinči tudi prod in pesek.

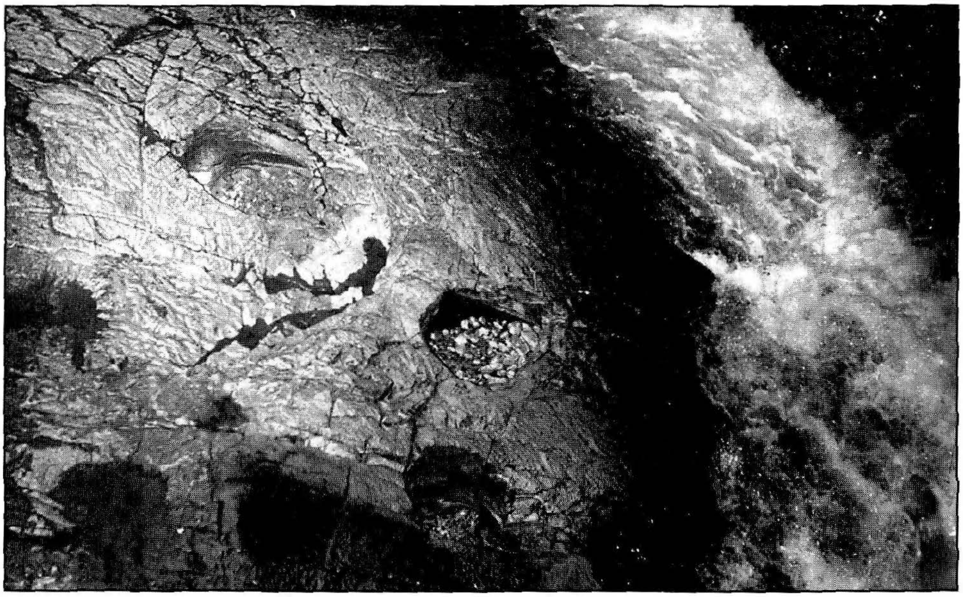
Draslje lahko razdelimo polkrogelne in na tiste, ki so globlje od premera odprtine (sl. 1c). Manjše draslje prve skupine imajo premer velik 5 do 10 cm in dokaj pravilno obliko polkrogle. Pogosto so podaljšane na odtočni strani. Le redko so majhne draslje globlje od premera odprtine, če pa so že, njihovo obliko pogojuje položaj pred oviro (sl. 1c). Velike polkroglaste draslje, katerih premer preseže tudi meter, so glede na velikost plitke. V njihovo dno se pogosto zajeda polkrožna vdolbina z ravnim dnom. V drugo skupino sodijo

Sl. 13: Draslja v Kopalnici v Mali Boki (merilo= 15 cm)
Fig. 13: Pothole in Kopalnica, Mala Boka (scale = 15 cm)

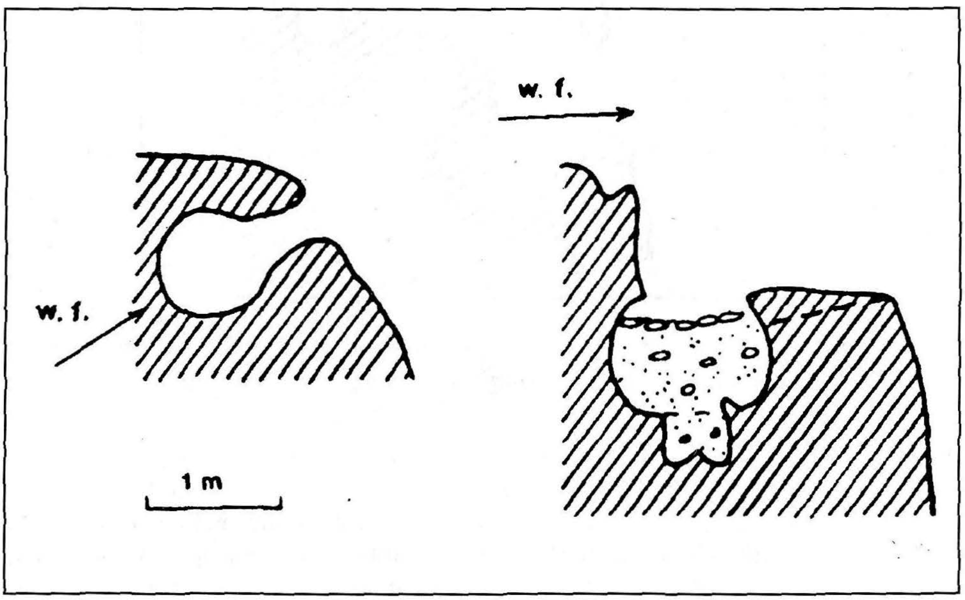


Sl. 14: Draslja na skalnem bloku v Hankejevem kanalu v Škocjanskih jamah
Fig. 14: Pothole in rocky block in Hankejev kanal, Škocjanske jame

draslje, ki so globlje od premera odprtine. Njihove stene so navpične, draslje se navznoter ožijo (sl. 13), polkrožno širijo (sl. 15) in so različnih premerov, od 20 cm do več metrov. Pritočni robovi, zlasti polkrogelnih draselj, so nekoliko bolj strmi kot odtočni. Dna plitkih draselj so polkrogelno zaobljena, dna globljih draselj pa so ravna, se zožujejo, imajo na dnu spiralo (sl. 16) ali pa na sredini široko konico. Pogosto je v draslji ostalo kamnito jedro, ki je nagnjeno v smeri vodnega toka. Manjše polkrogelne draslje, ki so nastale ob razpokah, so razpotegnjene v elipse, skorajda vse večje pa imajo bolj ali manj



Sl. 15: Draslje v Šumeči jami v Škocjanskih jamah
Fig. 15: Potholes in Šumeča jama, Škocjanske jame



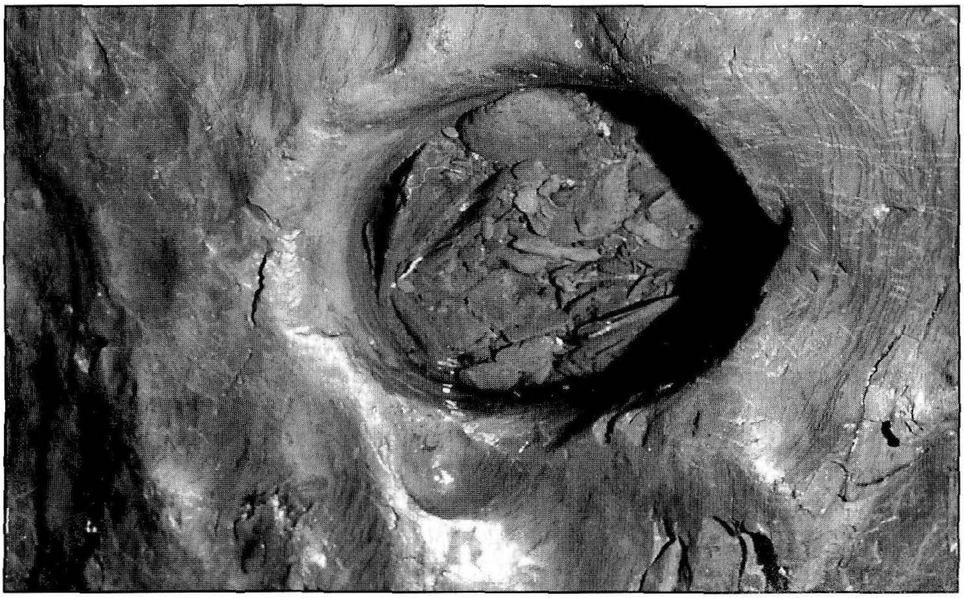
Sl. 16: Draslja na skalnem bloku v Hankejevem kanalu v Škocjanskih jamah
Fig. 16: Pothole in rocky block in Hankejev kanal, Škocjanske jame

pravilne krožne prečne prereze. Manjše draslje so ob razpokah razvrščene v zaporedne ali vzporedne nize. Draslje imajo praviloma navpične osi, tako da so na nagnjenih površinah (sl. 15) zgornje stene višje. Draslje na skalnih blokih so pogosto podaljšane v iztočne repe (sl. 16) ali pa se na odtočni strani nadaljujejo v žlebove.

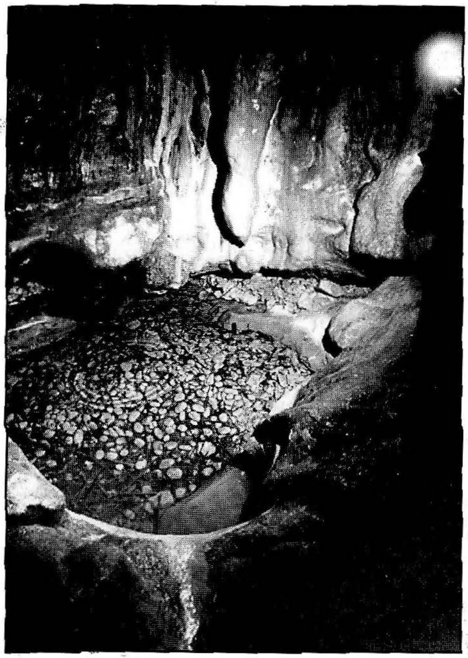
Draslje nastanejo v apnencu, breči in peščenjaku

Površina draselj je gladka ali pa so na njej razvidne tanke raze. Te so v globljih drasljah vodoravne. Tudi 10-20 cm pas okoli draselj je pogosto zglajen, za njim pa so na skali fasete. Fasete lahko segajo vse do roba draselj (Slabe 1989 a, 86, 87). Obod okoli draslje je mehansko zglajen v Babji jami, v Polhovem rovu v Mali Boki pa je brečasta skala grobo hrapava (Slabe 1994). Gladka je tudi površina draselj, ki so nastale na kremenovem peščenjaku v Smoganici (sl. 17). Mikroskopska opazovanja nam pričajo o trenju trdnih delcev ob skalno površino, kar povzroči njeno drobno hrapavost, ki jo s prostim očesom opredelimo kot gladko.

Velike draslje so v prostornejših rovih za ožinami. V Babji jami je takšna draslja široka 4 m, do prodnega zasutja pa je globoka 2 m. Manjše, zlasti ožje, so draslje v manjših cevastih rovih, ki imajo do 1,5 m velik premer. Te v celoti preplavi hiter vodni tok. Značilne draslje so na skalnem dnu skokov v strmih



Sl. 17: Draslja v peščenjaku v Smoganici
Fig. 17: Pothole in sandstone, Smoganica



Sl. 18: Draslja pod breznom v Beško Ocizeljski jami
Fig. 18: Pothole below the shaft in Beško Ocizeljska jama

strugah, kakršna je v Ponoru v Odolini, kjer draslje dosežejo 1 m premera. V Beško Ocizeljski jami so pod brezni nastale draslje (sl. 18), ki imajo 5 m in več premera, njihovo dno pa zaradi prodne naplavine ni vidno. Draslje so 1-2 m oddaljene od stene kamina, so torej na mestu, kamor pade največja količina vode. V Mohorčičevi jami v Škocjanskih jamah so draslje na dnu kanjonske struge, njihov premer je enak širini struge, ločijo pa jih tanke stene. Višje, na robu širšega dela struge, so polkrožne stenske zajede, ki so ostanki draselj. Poseben položaj in obliko imajo draslje na večjih skalah, ki prekrivajo strugo. Opazoval sem nekaj primerov v Hankejevem kanalu v Škocjanskih jamah. Na pritočni zgornji ploskvi skale nastane polkrožna zajeda, ki je prečna na smer vodnega toka in široka 0,5 m. Na pritočni strani je zajeda plitkejša, na odtočni strani, kjer so v nizu razvrščene manjše kotlice, pa je njena stena strma. Na odtočni strani skal so kotlice pogosto nanizane v nižjih zajedah in imajo odtočne žlebove. Draslje nastanejo tudi med skalami, ki tesno druga ob drugi prekrivajo strugo. V Markovem spodmolu je kotlica na skalni čeri.

Nastanek in razvoj draselj

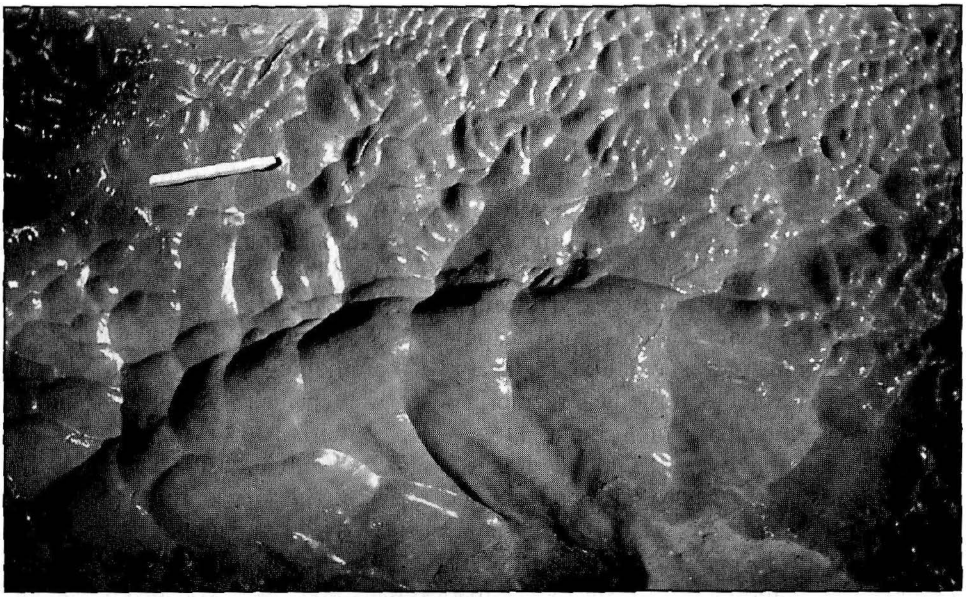
Pri nastanku in oblikovanju draselj ima odločilen pomen material, ki se vrtinči v vodnem toku. Draslje zato praviloma nastanejo na spodnjih delih oboda rovov, preko katerih voda prenaša večino grobozrnatega vlečenega tovora (Kranjc 1986, 24). V ožjih rovih lahko mehansko delovanje hitrega vodnega toka oblikuje ves obod (Babja jama), vendar je njegov vpliv zaradi teže materiala največji na skalnih tleh.

Draslja nastane na mestu izrazitega vrtinca. To je v enakomerno oblikovanih rovih določeno predvsem z nehomogenostjo ali razpoko v kamnini, torej s točko šibkosti, v razčlenjenih rovih pa z opisanimi položaji, v katerih se razvije izrazito vrtinčenje. Oblika draslje nam odraža značilnost vrtinca v njej. Draslje, ki so glede na premer plitke in imajo polkrogelna dna, večkrat tudi iztočne repe, oblikujejo vrtinci, katerih tokovnice krožijo pravokotno na steno. Draslje, ki so globlje od premera odprtine, njihova dna pa so ravna ali spiralasta, pa dolbejo svedrasti vrtinci, katerih tokovnice so skorajda vzporedne z dnom. Večji prodniki, ki so v večjih kotlicah, izpričujejo večjo moč dolbenja vode. Velikost draslje torej ni neposredna posledica hitrosti toka. Premeri vrtincev v hitrejšem vodnem toku so manjši, hiter in močan tok pa prenaša več večjega materiala. Pri oblikovanju draselj je torej pomembna tudi količina vode, ki z večjim pritiskom deluje na stene, ali pa pada preko strmih skokov v strugah. Največje draslje so zato nastale v podzemnih rečnih strugah (Škocjanske jame), pod breznastimi strugami (Ponor v Odolini), slapovi (Beško Ocizeljska jama) ali na mestih najbolj izrazitega vrtinčenja kot je to primer za ozkim rovom v Babji jami. Pri nastanku oblik pod slapovi bi lahko sodelovala tudi kavitacija. Tudi nadstropnost draslje lahko razlagamo s spremembo moči vrtinca.

Globina draslje je posledica razmerja hitrosti in pritiska vode na kamnino ter količine in velikosti materiala, ki ga voda prenaša. Je seveda tudi odsev časa njenega oblikovanja. Globlje draslje so nad dnom pogosto zožene ali pa se cela draslja stožčasto zožuje (Habič & Krivic 1972, 105). To je posledica manjše moči vode v globini. Če je draslja pregloboka in zapolnjena z naplavino, ali pa če se zmanjša moč vode, se njeno oblikovanje prekine. Globoke in zapolnjene draslje v Hankejevem kanalu v Škocjanskih jamah pričajo o le občasno ali nekdanji večji moči vodnega toka. Zaradi prevladujočega pomena mehanskega dolblenja pri nastanku draselj, se lastnost kamnine in njena razpokanost na obliko draselj, razen najmanjših, ne odraža. Draslje imajo večinoma pravilne krožne prereze. Osi draselj so zaradi teže materiala, ki jih sooblikuje, navpične. Na obliko vpliva tudi značaj vrtinca, ki je posledica značilnega položaja na obodu. Na odtočni strani skalnih blokov nastanejo zaradi prostega odtoka vode, in zato značilnega vrtinčenja, draslje, ki so na odtočni strani bolj plitke ali iz njih vodi odtočni žleb. Na robu struge Hankejevega kanala so široke draslje, ki imajo ozko kamnito jedro nagnjeno v smeri vodnega toka. Je takšna oblika kotlic povezana s položajem v strugi?

Izrazito vrtinčenje pogojuje tudi boljši korozijski izkoristek vode. Nekatere talne kotlice nimajo sledov brušenja sten. Njihova dna sestavljajo zavita rebra, ki so razporejena v rozeto (sl. 19). So to draslje, ki so bile preoblikovane s korozijo ali pa so kotlice že nastale tako? Polovična kotlica v Markovem spodmolu in stenska kotlica v Velikem Hublju nakazujeta drugo predpostavko. Sklepam, da na tleh lahko nastanejo kotlice tudi brez sodelovanja materiala, ki bi ga prenašala voda. Takšne so tudi polkrogelne manjše talne kotlice, katerih površina je pod mikroskopsko povečavo le delno drobno hrapava. Podobna je površini manjših faset, ki tudi nastanejo v zatišnih legah. V Le trou qui souffle (Lismonde 1987) je velika talna kotlica s fasetami na stenah. Torej brez izrazitih sledi mehanskega delovanja vode, ki so značilne za draslje.

Draslje nastanejo v rovih, skozi katere se pretaka hiter, ponavadi odprt vodni tok, lahko pa jih hiter tok občasno povsem zalije. Nastajajo torej v vadozni in epifreatični coni. Rovi z najbolj hitrim vodnim tokom in večjo



Sl. 19: Stenska kotlica v Markovem spodmolu (merilo = 15 cm)
Fig. 19: Wall pockets in Markov posmol (scale = 15 cm)

količino tovora so pogosti v ponorih jamah (Škocjanske jame, Beško Ocizeljska jama, Novokrajska jama, Ponikve v Jezerini) ali pa v izvirnih jamah, ki imajo občasno v zaledju visok vodni tlak (Babja jama, Matijeva jama). Prod v slednjih je avtohton. Preoblikovana so tudi dna strug v večjih pretočnih jamah (Križna jama, Vzhodni rov v Predjami). Draslje v teh jamah so praviloma manjše. Oblikuje jih počasnejši vodni tok.

Hiter vodni tok, ki lahko prenaša grobozrnat material, teži k odnašanju naplavin iz jam (Kranjc 1986, 278) in odkriva ter poglablja skalno dno struge. Draslje so torej značilna skalna oblika v rovih, skozi katere se pretaka voda s hitrostjo, ki je večja od 0,5 m/s, kar lahko razberemo iz velikosti faset na bližnjih stenah. Tako hiter tok s seboj nosi tovor, ki je sestavljen iz delcev, ki so večji od 3 mm. Seveda pa so za nastanek draselj pomembnejše lokalne hidravlične značilnosti v rovih. V Smoganici, kjer so draslje nastale na peščenjaku pri toku s hitrostjo 0,35 m/s, na bližnjem konglomeratu pa jih v enakih okoliščinah ni, pride do izraza tudi pomen odpornosti kamnine proti mehanskemu dolblenju z vodnim tokom. Peščenjak je manj odporen in lažji. Voda že pri manjši hitrosti v svoje vrtinčenje vključuje prodnike iz peščenjaka.

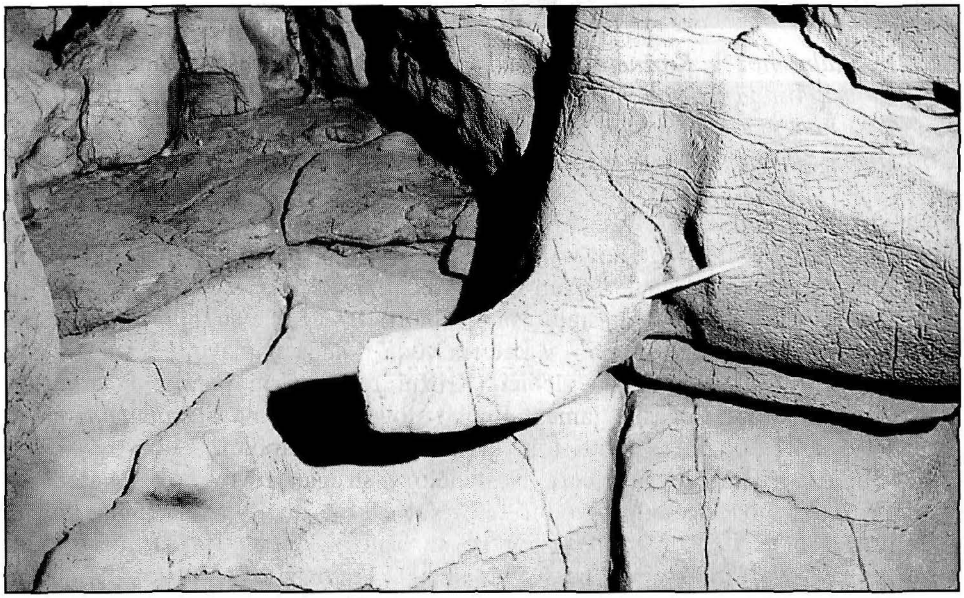
Voda lahko dolbe kamnino hkrati z drugimi procesi. Delno preoblikovane fasete smo že omenili (Slabe 1993, 1996). V Matijevi jami pa so na tleh ozke (nekaj cm) in razmeroma globoke vdolbinice z navpičnimi stenami. Vdolbinice so nastale kot splet korozije pod drobnoznato naplavino, ki jo odlaga nižja poplavna voda in mehanskega dolblenja s peskom, ki ga vrtinči občasni hiter vodni tok, ko bruha iz jame.

STEBRI, ROGLJI, NOŽI, ČERI IN MOSTIČI

Združeni so večji deli kamnine, ki štrlijo iz skalnega oboda. Opisane (Slabe 1994) so že manjše štrline na stenah, ki jih obliva vodni tok. Hrapavost je predvsem posledica sestave kamnine. Iz površine štrlijo deli kamnine, ki sestavljajo brečo v Mali Boki, večji kristali apnenca v Velikem Hublju, vezivo konglomerata v Smoganici.

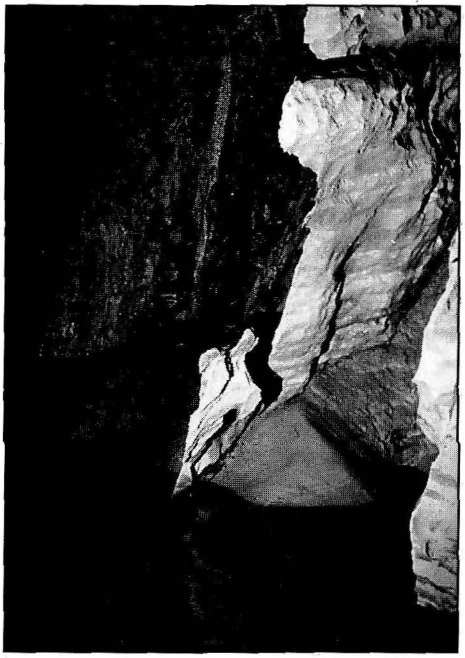
Stebri (an.: pillar (Lange 1959, 81)) so večji, navpični deli oboda rovov. Imajo oglate prečne prereze. Nastali so ob razpokah, ki pokončno prepredajo kamnino. Pri oblikovanju stebrov so razpoke razporejene redkeje, ob gosti mreži razpok namreč nastanejo noži.

Roglji so posamične štrline, ki imajo ovalne prečne prereze. Njihova pritrdišča so ponavadi enako široka kot končni deli. Lahko so tudi razčlenjeni. V veliki niši za vhodom v Križno jamo je rogelj (sl. 20) na steni ostal kot odpornejši del kamnine med velikimi fasetami. Nastal je torej v zalitem rovu zaradi počasnega vodnega toka.



Sl. 20: Skalni rogelj v niši za vhodno dvorano v Križni jami, njegova površina je razjedena s kondenzno korozijo

Fig. 20: Rocky cusp in a niche behind the entrance chamber, Križna jama; its surface is etched by condesation corrosion



Sl. 21: Skalni nož v Krožnem rovu v Črni jami (Postojnske jame)
Fig. 21: Rocky knife in Krožni rov, Črna jama (Postojnska jama)

Nože (skalni nož, Slovenska kraška terminologija, 1973, 26) imenujem podolgovate štrline, ki se navzven ožijo. V Divaški jami so na steni širši noži, ki so polkrožno razčlenjeni in valoviti. Nastali so kot robovi med velikimi fasetami. Večji in širši noži so med stropnimi kotlicami, ki so nastale ob razpokah v Zelških jamah (sl. 11) in v Podzemeljski Pivki (sl. 9). Oblikoval jih je počasnejši tok v zalitih rovih. Ožji in ostri noži prepredajo strop v Malih jamah v Postojnski jami in v Mali Karlovici. Na stenah rovov so srednje velike fasete. V Krožnem rovu v Črni jami (Postojnska jama) so na stenah tanki noži (sl. 21), ki so razčlenjeni, robove pa imajo nazobčane. Skozi rov se občasno pretaka vodni tok s hitrostjo 0,25 m/s. V pritočnem delu Vzhodnega rova Predjame, ki je oblikovan ob porušeni coni in prečno nanjo, so kratki noži, ki imajo razmeroma močna pritrdišča, a ostre robove. So na stenah, stropu in na tleh. Skozi rov se višje vode pretakajo s hitrostjo večjo od 0,5 m/s. Noži so torej lahko na celem obodu rova, so pravokotni na steno, kot so v Krožnem rovu, ali pa so v različnih kotih obrnjeni proti ali od smeri vod-nega toka, tako kot kamnino prepredajo razpoke, med katerimi so nastali. Na nožih so fasete, če je njihova površina večja od dolžine faset. V jamah, v katerih voda odlaga naplavino, so na nožih, ali med njimi, podnaplavinski žlebiči (Krožni rov v Črni jami v Postojnskih jamah, spodnji del Logaške jame). Enako dolge štrline na stropu (pendants; Bretz 1956, 22) oblikuje vodni tok, ki rov občasno zapolni.

Posamične štrline so tudi čeri. Nastanejo v strugah rovov, skozi katere se pretaka hiter, pogosto odprt vodni tok. Največkrat imajo razmeroma močna pritrdišča (Slabe 1989 a, 88) navzgor pa se ožijo v konico. Takšne čeri vodni tok preplavi. V Vzhodnem rovu v Predjami je 1,5 m visoka čer (sl. 22), ki je najožja na spodnji tretjini, navzgor pa se razširi. Na najožjem delu, na pritočni strani, je nekoliko globlje zajedena in gladka. Na ostalih stranicah pa čer prekrivajo fasete. Tok je strugo naprej hitro poglobil, nato pa so prevladale srednje visoke vode in čer je do njihove gladine zato ožja. V Markovem spodmolu je večja čer, ki ima na vrhu plitko drasljo, na pritočni strani pa

Sl. 22: Čer v Vzhodnem rovu Predjame
Fig. 22: "Čer" in Vzhodni rov, Predjama

Sl. 23: Čer z erozijsko kotlico v Markovem spodmolu (merilo = 15 cm)
Fig. 23: "Čer" and erosion pocket in Markov spodmol (scale = 15 cm)

polkrožno zajedo (sl. 23). Na ostalih stenah čeri so fasete. Za čeri je značilno, da so dokaj oglatih, trikotnih prerezov. Pritočna ploskev je ponavadi ravna ali polkrožno zajedena, na odtočni strani pa se zaključijo z ostrim ali širšim razom. To je posledica vrtinčenja vodnega toka ob oviri. Za oviro z obeh strani nastane vrtinčasta cona. Čeri v širšem delu vodnega rova v Križni jami so razčlenjene v več krakov. Njihovi robovi so nazobčani in na njih so podnaplavinske vdolbinice (Slabe 1992, 24). Čeri so le občasno poplavljene in zato podnaplavinska korozija prevladuje nad kratkotrajnim delovanjem višjega vodnega toka.

V Golobini je vodni tok prežrl stenski nož. Nastal je mostič (natural bridge (White 1988, 102), window (Jennings 1979, 21)).

Oblika štrlin, ki so največkrat posledica vrtinčenja vodnega toka ob razpokah in lezikah, je rezultat razmerja med lastnostmi razpok in njihovo razporeditvijo ter hitrostjo in vodnim tlakom. Hitrejši je vodni tok, bolj koničaste in kratke so štrline. Čeri nastanejo na tleh, kjer je vodni tok najmočnejši, saj pogosto prenaša tudi tovor. Ohrani se torej le najbolj odporen ali proti toku zavarovan del kamnine. V rovih, ki jih oblivajo najhitrejši tokovi, štrline ne nastajajo, saj voda s tovorom izravnava skalni obod.

STENSKE NIŠE

Niše (Slovenska kraška terminologija 1973, 22) so večje polkrožne ali podkvaste vdolbine z metrskimi premeri. Niše v zgornji etaži Dimnic (Slabe 1994) in v Križni jami (Slabe 1989 a, 29) so oblikovali večji vrtinci, na kar kažejo tudi kotlice na zgornjih delih sten in na stropu. Vrtinčenje je povzročilo hitrejše zajedanje vodnega toka v kamnino, ki je bila zaradi pretrtosti manj odporna kot stena okoli niše. To je oblival hiter vodni tok. Na vhodnih stenah so namreč manjše fasete. V Križni jami so fasete v lokalnem zatišju niše večje. V prostornejši niši v Dimnicah (Bar) pa so le kotlice.

V Blatnem rovu Križne jame, so manjše stenske niše, ki imajo 1 do 2 m premera. Nastale so zaradi vijuganja počasnega vodnega toka po drobnozrnati naplavini (an.: meander niche (Bretz 1956, 18)). Vodni tok odlaga naplavino zlasti na notranji strani vijug, na zunanji, če teče ob steni, se zato vrezuje vanjo. Podobno je razčlenjen tudi obod manjšega vhodnega rova v Griški jami. Niše se polkrožno širijo tako, kot se veča premer vijuge.

Podkvaste niše so posledica vijuganja vodnega toka ob pravokotni mreži razpok ali razpok in lezik. Njihova oblika je določena s prepustnostjo kamnine. Pogosto so odsev spremenjenih hidroloških razmer. V Križni jami se je rov iz zalitega, ki ga je oblikoval počasen vodni tok, spremenil v vadozni prevodnik in hitri vodni tok si je skrajšal pot (Slabe 1989 b, 217). Tudi zaradi zapolnjevanja rovov z naplavinami in sigo, si voda poišče novo pot ali preseka vijuge. Če se rov nato veča, ostanejo takšne niše oblike v steni, mnogokrat pa so to stranski rovi.

STENSKE IN STROPNE ZAJEDE

So polkrožne žlebaste zajede, ki potekajo vzdolžno po stenah ali stropu rovov. So večje skalne oblike in lahko zavzamejo večino skalnega oboda. Na njih so pogosto fasete in rebra.

Zajede so lahko sledi združevanja rovov. V Fiženci v Predjami sta se združila manjši zgornji in večji spodnji rov. V Ponoru v Odolini pa kažejo na vzporedno združevanje manjših rovov (sl. 24).

Plitke zajede so pogosto na vseh stenah večjih rovov (Križna jama, Markov spodmol, Dimnice). Prekrivajo jih fasete. Odražajo dolgotrajnejši nivo vodnega toka (water level horizon, Lange 1963, 41). Rov se je poglabljal (vodni rov v Škocjanskih jamah), ali pa se je voda pretakala nad prodno naplavino (Slabe 1989 a, 24, 27). V Trhlovci je zgornji del meandrastega rova razčlenjen v zajede s premerom 1 do 2 m. Na obodu zajed so fasete, ki so dolge do 15 cm. Stenske zajede so nanizane ena nad drugo. Podobno je skalni obod oblikovan v Rovu koalicije v Postojnski jami in v Ključavnici v Vodni jami v Lozi. Zajede izpričujejo poglabljanje rova z različnimi pretoki vodnega toka.

Velikost in oblika zajed sta torej posledici velikosti vodnega toka, njegove hitrosti ter trajanja na določenem nivoju. Enakomerno hitro vrezovanje toka navzgor ali navzdol ustvari kanjonske rove brez stenskih zajed (Brlog na Rimskem). Povečan vodni pretok lahko preoblikuje manjše zajede. Pomembno je ločiti opisane zajede od zajed, ki so posledica hitrejšega zajedanja vode ob

Sl. 24: Stropni zajedi v Ponoru v Odolini
Fig. 24: Ceiling notches, Ponor v Odolini

lezikah ali razpokah in od zajed, ki so posledica različne odpornosti skladov kamnine (Smoganica). Tako lahko nastanejo tudi navadne ali inverzne stopnice.

Pogosto se zajede preoblikujejo zaradi naplavine, ki jo na njihovih položnih spodnjih delih odlaga voda. Naplavina jih ščiti pred korozijo. Voda se zato zajeda v bok in zgornji del zajede.

Stenske zajede so tudi na zgornjih delih oboda rovov (Slabe 1989 a, 23, 36), ki so bili zapolnjeni z ilovico, nad katero se je pretakala voda (Kamnešca, Ciganska jama). V večjih rovih so na stenah zajed večje fasete, ki pričajo o počasnem vodnem toku (Dimnice).

Zajede s premerom manjšim od metra, ki se pod vodno gladino strmo zaključijo, nastanejo tudi v vodnih kotanjah ali v jezerih. Ford (1988, 46) razlaga njihov nastanek s celično konvekcijo, ko se potapljajo težki ioni, konvekcija pa prinese na površje sveže H^+ ione. Če pa je rov zalit, ta proces, ne glede na geološko osnovo, povzroči nastanek ravnih stropov (Ford & Williams 1989, 307). Stenske zajede so nastale tudi ob gladini vode pri poskusu oblikovanja nadnaplavinskih žlebov na mavcu (Slabe 1992).

TALNI ŽLEBOVI

Ločim žlebove, ki jih vrezuje vrtinčasti vodni tok in tiste, ki so posledica pretakanja manjših količin vode po skalnih tleh.

Sl. 25: Vzdolžni talni žlebovi na skoku struge v Markovem spodmolu
Fig. 25: Longitudinal bottom channels in the riverbed jump, Markov spodmol

V Markovem spodmolu so na strmem skoku struge (750) vzdolžni talni žlebovi (sl. 25). Široki so 30 cm in globoki 15 cm. Razčlenjeni so v prečne, plitve polkrožne zajede. So posledica prelivanja hitrega in plitkega vodnega toka, ki se razdeli v vzdolžne tokovnice. Podobni žlebovi so nastali tudi pri poskusu, ko se je plitev tok pretakal po mavcu. Žlebove razčleni vrtinčenje, podobno tistemu, ki vrezuje rebra.

V Ponoru v Odolini je na najnižjem delu strme struge polkrožen vzdolžni žleb (Slabe 1994). Njegova površina je fasetirana. Večja količina vode, ki žleb občasno zapolni, vrezuje majhne fasete.

Na pritočnih in odtočnih delih večjih skal v vodnih strugah nastanejo prečne žlebaste vdolbine. V žlebovih, ki so na začetku skale in so na pritočni strani plitvejši, na odtočni pa bolj strmi, na koncu skale pa je nižja odtočna stena žleba, so namreč pogosto manjše draslje. Takšne žlebove lahko vidimo v Hankejevem kanalu Škocjanskih jam. Za manjšimi skalami na tleh skalnih strug (Novokrajska jama), za prečnimi grbinami in ob večjih prečnih razpokah nastajajo manjši prečni žlebovi. Tudi ti so pogosto poglobljeni z manjšimi kotlicami. Vse te oblike nastajajo v strugah, ki jih oblikuje hiter, odprt vodni tok. So posledica vrtinčenja vode ob ovirah. Tudi na mavcu, ki sem ga prekril s povoščenim papirjem, je na robu nastal zaradi vrtinčenja plitvega vodnega toka 1 cm širok in 0,5 cm globok prečni žleb. Voda v žlebovih se razdeli v posamezne vzporedne vrtince in žleb je zato lahko razčlenjen v rebra.

Na odtočni, navzdol nagnjeni površini velike skale v Hankejevem kanalu, so nastali ozki vzdolžni žlebiči, ki so različno dolgi. Med njimi so zaobljeni razi. Žlebiči so posledica goste vzdolžne razpokanosti kamnine. Če jih oblikuje tudi voda, ki se plitvo preliva čez skalni blok, in kakšen je pomen nihanja vodne gladine, še nisem uspel ugotoviti.

V drugo skupino sodijo žlebovi, ki so sled pretakanja manjših količin vode po skalnih tleh.

V Markovem spodmolu je manjša količina vode, ki se ob nizkih vodah pretaka iz jezerca ujetega nad gladino sifona, vrezala 1 m globok, vijugast žleb (sl. 26). Žleb je zgoraj širok 1 m, spodaj, kjer se pretaka voda, pa le nekaj cm. Majhen naklon tal je povzročil vijuganje manjše količine vode. Na posameznih mestih si je voda že skrajšala pot in zavoje zapustila. Ozko dno žleba je gladko, stene, ki so polkrožno razširjene zaradi pretakanja občasnega vodnega toka skozenj, pa so prekrite z manjšimi fasetami.

Na bolj strmi strugi v Ponoru v Odolini je raven žleb (Slabe 1994 a), ki je na dnu širok 5 cm in ima prečni prerez oblike črke V s prirezano konico. Spodnjih 10 cm stene žleba je gladkih, na zgornjem delu pa so fasete. Žleb vrezujejo nizke vode, ki v suhem delu leta pritekajo iz stranskih rovov.

Nekoliko večji, vijugasti žlebovi so v Osapski jami. Široki so do 0,5 m in globoki 0,2 m. Njihove stene so gladke. Na tleh Brežanskega rova so nastali dokaj ravni žlebovi, ki so plitvega polkrožnega prereza in so do 5 cm široki. So posledica pretakanja majhne količine vode iz višjih jezer. Rovi izvirne jame

Sl. 26: Talni žleb v Markovem spodmolu
Fig. 26: Bottom channel, Markov spodmol

se zlasti v pritočnem delu jame dvigujejo navzgor, proti izhodu, in ob nizkih vodah ujeta voda odteka proti smeri vodnega toka.

Vijugasti žleb, ki je širok do 50 cm in je 15-20 cm globok, na strmih odsekih pa je globlji in ožji, je tudi na tleh ozkega rova v Ciganski jami. Tla širšega dela žleba so sestavljena iz dveh vzporednih nizev plitkih kotlic. Po žlebu se pretaka manjša količina vode. Voda se ob večjih sparitnih kristalih, ki štrlijo iz dna žleba, vrtinči in nastajajo plitke kotlice.

V Beško Ocizeljski jami so majhni vijugasti žlebovi, ki so globoki do 15 cm. Vodijo od žlebičev, ki so na stenah brezen, do velikih draselj, ki so meter ali dva odmaknjene od sten. Po žlebovih se pretakajo vode, ki polzijo v suhih obdobjih leta po stenah brezen. Preko sten občasno pada večji slap.

Oblika, velikost in vijugavost žlebov je posledica količine vode, ki jih vrezuje, naklona kamnine po kateri se pretaka, in sestave oziroma razpokanosti kamnine. Žlebovi so ob nekoliko večji količini vode dokaj ravni, če je nagib kamnine večji od 100 (Osapska jama). Vijugasti žlebiči nastajajo tudi v gorskih jamah pod brezni ali pa na dnu meandrov, ki vežejo brezna (Velika ledenica v Paradani). Nastanek tovrstnih žlebov je mogoč le, če tla ne prekriva naplavina ali podorno skalovje. Gola tla pa so najbolj pogosta v rovih, skozi katere se vsaj občasno pretaka hiter in močan vodni tok. In res je v takih rovih, v katerih so na višjih delih kotanje z ujeto vodo, manjši talni žleb pogosta skalna oblika. Žlebove pogosto sooblikuje hiter vodni tok. Zgornji deli vijugastega žleba v Markovem spodmolu so polkrožno razširjeni in stene so prekrite z majhnimi fasetami, zapuščene, višje vijuge pa so preoblikovane v kotlice z večjimi fasetami na robu. Podoben je raven, bolj strm žleb v Ponoru v Odolini, ki ima prav tako gladke le spodnje dele sten. Po njem se pretaka več vode in njeno vrezovanje prevladuje nad delovanjem občasnega hitrega toka. Žlebovi torej nastajajo sočasno z oblikovanjem rovov, ali pa kot mlajše oblike v že oblikovanem rovu, kot je to primer v Ciganski jami.

STROPNI ŽLEBOVI

Na nagnjenem stropu (45°) pod ponornim breznom v Ponoru v Odolini so plitki in do 5 cm široki, vzdolžni žlebovi (Slabe 1994 a, 158). Dna širših delov žlebičev so ravna, ožji pa imajo polkrožne prečne prereze. Med žlebovi so zaobljeni robovi. Na odtočni strani se zaključujejo v polkotličaste zajede. Nastali so z oblivanjem previsne stene z večjo količino vode, ki hitro odteka s skale.

POVRŠINA SKALNIH OBLIK POD VELIKIMI POVEČAVAMI ELEKTRONSKEGA VRSTIČNEGA MIKROSKOPA

Površino jamskega skalnega reliefa sem natančneje že opisal (Slabe 1994 b). Tokrat naj povzamem izsledke o površini skalnih oblik, ki jih dolbe vodni tok.

Gladkost skalne površine, ki jo nazorno razčlenimo šele pod večjimi povečavami, je posledica različnih procesov, ki delujejo nanjo. Zglajena površina manjših faset in manjših kotlic je posledica prevladujočega, pretežno korozijskega delovanja vodnega toka, katerega vrtinčasto jedro se povsem približa steni in odnaša tudi počasneje topne delce kamnine, ki štrlijo iz nje. Za obe obliki je značilno, da sta v v zatišnih legah, odmaknjene od vlečenega vodnega tovora, torej na odtočni strani grbin, zgornjih ploskev večjih skal, ali pa višje na steni. Mehansko zglajene površine, ki imajo dokaj ravne osnovne ploskve, so pod velikimi povečavami drobno hrapave zaradi trenja prodnikov in peska ob skalo. Najbolj izpostavljeni deli skalnih blokov in izboklin na dnu struge so pogosto obtolčeni.

ZNAČILNOSTI SKALNEGA RELIEFA ROVOV, KI GA OBLIKUJE VODNI TOK

Oblikovanost votlin je predvsem posledica hidravličnih pogojev, v katerih nastajajo. Ti se značilno odražajo v različni kamnini in jamskem skalnem reliefu. Hidrološke cone so največkrat posledica položaja kamnitega bloka glede na okolne neprepustne kamnine, doline ali podolja (Habič 1982, 13, 14). Z nižanjem vodne gladine so pogosto ostale stare, vodoravne jame, ki so bile nekoč zalite, suhe, ali pa jih zlasti v gorskem krasu preoblikujejo razpršeni curki prenikajoče vode.

Način oblikovanja rovov pogosto razberemo iz njihovega prečnega prereza in skalnega reliefa. Po razporeditvi skalnih oblik in njihovi prepletenosti na obodu rovov lahko sklepamo na spremenljive speleogenetske pogoje. Enaki pogoji in procesi pa se samosvoje odražajo tudi v različno velikih in oblikovanih rovih. To lahko opazujemo zlasti ob njihovem vzdolžnem prerezu.

Prečni jamski profil je ena izmed osnov za študij speleogeneze, je ugotovil Gams (1961, 47), ko je po dognanjih iz naših jam in literature pregledno strnil različne prečne prereze rovov in njihovo odvisnost od lege skladov. Sam uporabljam izraz prečni prerez rova (prečni profil jamskega rova v Slovenski kraški terminologiji 1973, 23), saj jame lahko sestavlja več rovov z različnimi prečnimi prerezi. Gams (1961, 48) meni, da je prečni prerez rova posledica prvotne oblike rova, strukture in petrografske sestave kamnine, hidravlike, vpliva sosednjih prerezov, predhodnih razvojnih oblik in jamske akumulacije. Šušteršič (1985, 81), ki se opira na dognanja Langa, rezultate odnašanja kamnine imenuje speleogene. Izdvoji pasivne faktorje, ki so odsev lastnosti kamnine in aktivne faktorje, ki so neposredni dejavniki odnašanja kamnine. Poudarja (Šušteršič 1985, 85), da so različne oblike prečnih prerezov lahko le zaporedno stanje v njihovem razvoju. Maire (1980, 29) razvojne faze rovov z ustreznimi prečnimi prerezi deli na singenetske, paragenetske in na obdobja pretakanja odprtih vodnih tokov. Ford in Williams (1989, 294, 299, 272) rove in njihove prereze delita na freatične, vadozne in paragenetske.

Značilnosti rovov, zlasti raznovrstnih v večjih jamskih sistemih, so temelj za razlago speleogeneze kraškega podzemlja. Predstavil bom skalni relief rovov, ki jih v značilnih hidroloških pogojih oblikujejo vodni tokovi.

A. SKALNI RELIEF ROVOV V FREATIČNI CONI

V freatični coni (Slovenska kraška terminologija 1973, 7; Gams 1974, 34; prežeta cona, Šušteršič 1991; an.: phreatic conditions, Bretz 1956, 15; Trudgill 1985, 72; Ford 1988, 34; Ford & Williams 1989, 263, izdvajata še jame v globlje zaliti coni: bathiphreatic caves; fr.: zone noyé, Maire 1980; nem.: phreatisch Zone, Bögli 1978, 219) se trajno zalite votline oblikujejo s tlačnim in počasnejšim pretakanjem vode. Rove delim po skalnem reliefu, oblikovanim z različno hitrim vodnim tokom, ki se pretaka skoznje. V rovih, ki so bili globlje zaliti, skozi njih pa se je pretakal počasen vodni tok, so na obodu velike fasete, v razčlenjenih rovih tudi stropne kotlice. Hitrost toka je dosegala 5 cm/s. V izbranih jamah so to večinoma večji rovi, smer pretoka vode pa je iz skalnih oblik težko razbrati. Voda, ki se je pogosto pretakala nad drobnozrnato naplavino, je omenjene skalne oblike vrezala v položnih ali nagnjenih rovih, kjer se je pretakala navzgor (Vilenica) ali navzdol (Pečina v Radotah, Brezno na Škrklovici). V rovih zalitih z nekoliko hitrejšim tokom, kot v zgornjem primeru, so večje fasete 2. skupine. Dolge so 15 do 40 cm. Na stropu pa so pogosto kotlice. Vodni tok se je pretakal s hitrostjo 5 do 20 cm/s.

Opazoval sem lahko le stare (starostna, akumulacijska faza, Gams 1961, 51) takšne rove. Njihov obod je pogosto preoblikovan zaradi razpadanja, odprtih vodnih tokov in korozije na stiku z drobnozrnato naplavino (Volčja jama, Kozinski rov v Lipiški jami). Stare skalne oblike so prekrite z mlajšimi, ali pa so mlajše oblike le na spodnjih delih sten (Logaška jama, Fiženca v Predjami). Deloma jih preoblikuje tudi kondenzna korozija (Križna jama). Podobni odseki votlin so tako v nizkih pretočnih kot v visokih, danes odtočnih predelih našega krasa. V nerazpokani in debelo skladoviti kamnini so prerezi freatičnih rovov (Kozinski rov v Lipiški jami) lahko dokaj okrogli (eforacijski profil, Gams 1974, 103), podobni elipsam (niša v Križni jami) ali pa se prilagajajo pretrti in skladoviti kamnini (dolomitu v Turkovi jami).

Gosto prepletenih rovov (spongework; Jennings 1980, 6), ki bi jih oblikoval vodni tok s hitrostjo le nekaj m na dan in za katere so značilni kupolasti stropi, v izbranih jamah nisem zasledil. Je to posledica značilnega zakrasevanja kraških predelov s pretakanjem vode na nekraško obrobje v izrazitejših tokovih? Ali pa so takšne oblike predvsem značilnost počasnega oblikovanja bolj poroznih kamnin.

B. SKALNI RELIEF ROVOV V EPIFREATIČNI CONI

V epifreatični coni (iztočna cona, Gams 1974, 34; v angleščini tudi shallow phreatic zone, Palmer 1982, 178; Ford & Williams, 1989, 263; fr.: zone épinoyé) so deli votline, ki so na lokalnem piezometričnem nivoju vode, občasno zaliti. Skozi rove se praviloma pretaka hitrejši vodni tok kot v globlje zaliti coni Razdelimo jih na rove, skozi katere se pretaka srednje hiter in hiter vodni tok.

V rovih, skozi katere se pretaka srednje hiter vodni tok, so na obodu srednje velike fasete 2. skupine (Slabe 1993, 163), ki so dolge od 5 do 15 cm, na razčlenjenem stropu pa kotlice. V širših delih rovov, kjer so na stenah večje fasete, so pogosti tudi podnaplavinski žlebiči in vdolbinice (Slabe 1992, 21). Rove, ki imajo razpokan obod, pa razčlenjujejo noži (Vzhodni rov v Predjami). Tok v takšnih rovih doseže hitrost 20 do 50 cm/s. Hitrejši vodni tok preoblikuje morebitne sledi starejšega oblikovanja rova, le redki so primeri, ko so mlajše sledi na starejših (Novi rov v Beško Ocizeljski jami: manjše fasete na velikih).

Epifreatični, s hitrim tokom občasno zaliti rovi, imajo na obodu majhne fasete 2. skupine (Slabe 1993, 163), v ožinah pa pogosto 1. skupine. Fasete so dolge le nekaj cm, torej se skozi takšne rove pretaka vodni tok s hitrostjo, ki večinoma presega 50 cm/s. Hitre, zlasti ponorne vode, prenašajo pesek ali prod in na tleh lahko nastanejo draslje. Hiter vodni tok zabriše vse morebitne sledi starejšega oblikovanja rovov.

V vzdolžnem prerezu rova, ki je različno velik, lahko opazujemo sledi prvega in drugega tipa toka, saj se skozi ožine pretaka voda hitreje. Rovi so položni ali strmi in, kot lahko opazujemo v Mali Boki, tudi navpični.

Značilen odsek rova s sifonon, v katerem se menjavata počasen in srednje hiter vodni tok, je Krožni rov v Črni jami. Občasen, hitrejši vodni tok ob višjih vodah vrezuje srednje velike fasete in stropne kotlice. Iz počasnejšega toka ob nizkih vodah ali iz ujete vode, se odlaga drobnozrnata naplavina. Pod njo se preoblikujejo fasete, nastajajo pa tudi podnaplavinske konice. Podobno je oblikovan Blatni rov v Zelških jamah, katerega voda poplavi le še v spodnjih delih.

Izdvojimo lahko še majhne rove, skozi katere se občasno hitro pretaka voda z visokim tlakom v zaledju. Takšni rovi so v izvirnih jamah na robu visokega krasa (Babja jama, Matijeva jama in Suhadolica), v katerih se vrtinči avtohtoni prod. Na razčlenjenem stropu rovov so majhne kotlice, tla in stene pa so mehansko zglajene. Ob povzročenih vrtincih so draslje. Vodni tok v teh rovih pogosto presega hitrost 2 m/s, kar dokazuje tudi velikost proda, ki prekriva dno rovov. Prevladujoče mehansko delovanje vodnega toka onemogoča nastanek faset.

Rovi imajo podobne prečne prereze kot tisti v freatični coni, le redko so struge poglobljene zaradi občasno hitrega vodnega toka s prosto gladino (Tentera, vhodni del Ponorne jame Lokve in Jama v Peklu). Vzdolžno povezanost rovov z okroglim ali elipsastim prerezom s špranjastimi rovi lahko opazujemo v Mali Boki. Okrogli in elipasasti rovi so nastali v debeloskladovitem apnencu, špranjasti pa v gosto pretrti breči. Prve prekrivajo majhne fasete, drugi pa imajo obod razčlenjen v majhne štrline in vdolbine. V enakih hidroloških pogojih torej prevlada pomen kamnine. Špranjasti rovi so značilni tudi za dolomit (Jama v peklu). Manj primerna je pogosta delitev rovov na tiste nastale z mehanskim delovanjem vodnega toka in materiala, ki ga prenaša, na kamnino, in druge, ki nastajajo predvsem z raztapljanjem kamnine. Njihove značilnosti je povzel Gams (1961, 49). Prvi imajo bolj zaokrožen profil in obrušene stene, oblika drugih pa se prilagaja sestavi in pretrtosti kamnine. Ugotovimo pa lahko, da imajo tako špranjasti rovi (Slepič v Križni jami, del rova v Podpeški jami) kot veliko rovov z okroglim prečnim prerezom (Mala Boka, Beško Ocizeljska jama, Zelške jame, Ponikve v Jezerini, Ponor v Odolini) lahko po vsem obodu fasete. Prevladujoč proces oblikovanja faset pa je korozija. Pretežno mehansko oblikovani rovi imajo skalni obod zglajen (Babja jama).

Značilen tip skalnega reliefa lahko prisodimo estavelam. Proučeval sem Matijevo jamo (Slabe 1996) in Gabranco. Na stropu jame so manjše polkroglaste kotlice (sl. 5). Spodnji del jame je občasno poplavljen. Tla in položne stene spodnjih delov jame prekrivajo podnaplavinske vdolbinice. Visoke vode pa se s precejšnim pritiskom prelivajo po jami navzgor in vrtinčijo prod in pesek. Dno pokončnih, vhodnih rovov je mehansko zglajeno. Skalni relief torej odraža menjavanje pogostega manjšega nihanja vodne gladine v njenem spodnjem delu in občasnih izbruhov vode iz jame oziroma vodnega toka v jamo.

C. SKALNI RELIEF ROVOV V VADOZNI CONI

Hiter vodni tokovi s prosto gladino (free surface cave stream, Bretz 1956, 15) v vadozni coni (aeracijska cona, Slovenska kraška terminologija 1973, 6; Gams 1974, 33; neprežeta cona, Šušteršič 1991; an.: vadose zone, Bretz 1956, 17; Trudgill 1985, 72; Ford & Williams 1989, 267; fr.: zone vadose, Maire 1980, 28; nem.: vados Zone, Bögli 1978) so značilni predvsem za večje ponorne in izvirne jame, kjer se oblikujejo prave rečne struge (Škocjanske jame, Postojnske jame: del Podzemeljske Pivke, Pivka jama, odtočni del Planinske jame). Na obodu rovov prevladujejo majhne fasete 3. skupine (Slabe 1993, 148), rebra, draslje, čeri in talni žlebovi. Pritočna, izpostavljena skalna površina je pogosto obtolčena.

Odprti vodni tok obliva tudi brezna ali navpične rove (Ponor v Odolini, Beško Ocizeljska jama, del rova v Markovem spodmolu). Nastajajo stropni žlebovi, na položnejših odsekih talni žlebovi prekriti z majhnimi fasetami (sl. 26), pod brezni ali strmimi deli struge pa draslje (sl. 18).

Manjši odprti vodni tokovi se pretakajo tudi v dnu meandrov (Kamnešca, Velika ledenica v Paradani). V Kamenšci so na dnu meandra manjše fasete, pod strmimi odseki tal pa plitke kotlice.

Prečni prerezi vadoznih rovov velikokrat kažejo na poglabljanje freatičnih ali epifreatičnih rovov z odprtim vodnim tokom (Križna jama). Krožni ali elipsasti rovi so tako poglobljeni z meandri (pritočni rov v Brlogu na Rimskem, zgornji rov v Trhlovci) in kanjoni (spodnji del Beško Ocizeljske jame (Mihevc 1991, 46)). Lep primer prereza rova v obliki ključavnice, ki kaže na poglabljanje rova z različnimi količinami vodnega toka, je v Vodni jami v Lozi. V Smoganici pa je podoben prečni prerez rova predvsem posledica različne odpornosti raznovrstnih, položnih skladov kamnine.

SKLEP

Skalne oblike, ki jih dolbe vodni tok, so odsev hidravličnih razmer v rovih, ki so različno veliki in oblikovani. Vodni tok z različnimi hitrostmi in značilno velikimi vrtinci korozijsko razjeda ali mehansko gladi različno sestavljeno in pretrto kamnino oboda rovov.

Na homogenih, nerazpokanih skalnih površinah, ki so vzporedne z vodnim tokom in večje od premera vrtincev v toku določene hitrosti, nastanejo fasete, v vzdolžnih zajedah pa rebra. Površino oboda namreč prekrije enakomerno vrtinčenje (sl. 1, 1a). Z večjimi vrtinci ob razčljenjenem stropu in na prehodih med rovi, ki so različno veliki ali različnih naklonov, nastanejo stropne kotlice. Tla izravnavata erozija in naplavina. Ob večjih razpokah, ki prepredajo stene, so pogosto niše. Na skalnih tleh rovov, skozi katere se pretaka hiter, ponavadi odprt vodni tok, so draslje. Sooblikuje jih material, ki ga prenaša voda. Če je obod izrazito nehomogen, kar onemogoči nastanek manjših faset, ali pa je močno razpokan, kar vpliva na oblikovanje večjih faset in stropnih kotlic, med razpokami nastanejo štrline (sl. 1, 2b). Kaotičnost vrtinčenja onemogoča nastanek pravilnih vdolbljenih skalnih oblik. Ko je vodni tok hitrejši, pridejo do izraza že manjše razpoke. Na stropu in na steni so zato pogosti skalni noži. Na tleh, ki jih oblikuje najhitrejši vodni tok, ki prenaša tudi tovor, pa so čeri.

Združil sem nekaj značilnih vrtincev, ki nastanejo v vodnem toku in ponazarjajo zgornje trditve. Ločimo vrtince, katerih tokovnice so pravokotne na steno, ti oblikujejo razmeroma plitke vdolbine, ter svedraste vrtince, ki so značilni za globlje kotlice. Velikost in značaj vrtinca sta posledica hitrosti vodnega toka ter položaja v rovu. Cone vrtinčenja namreč nastajajo pred in za ožinami rovov, v stropnih zajedah, pod skoki v strugi, na skalnih blokih, zavojih sten, voda pa se hitreje zajeda tudi ob razpokah. Spreminjanje nivoja vodnega toka ali pa združevanje rovov odražajo stropne in stenske zajede.

Zaradi zakrasevanja pogosto lahko sledimo spremembi hidroloških pogojev razvoja votline. Skozi nekoč zalite rove se danes pretaka hitrejši vodni tok s prosto gladino, ali pa so sledi vodnih tokov že stare. Spremembe se odražajo tudi na skalnem reliefu, ki ga sestavlja en tip skalnih oblik ali pa več različnih. Hitrejši vodni tokovi hitro vrežejo manjše fasete preko morebitnih večjih starejših. Tako se lahko spremeni ves obod rova ali pa se preoblikuje le njegov spodnji del (Slabe 1993, 165). Tudi manj izraziti dejavniki kot so pretakanje vode nad drobnozrnato naplavino, biokorozija, ki delujejo le na posamezne dele oboda ali pa so manj učinkoviti, omogočajo ohranjanje starih, nekoč prevladujočih sledi. Skratka skalni relief, ki ga oblikujejo vodni tokovi, je raznovrstna in pomembna sled oblikovanja in razvoja kraških votlin.

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CAVE ROCKY RELIEF HOLLOWED OUT BY A TURBULENT WATER FLOW

Summary

A large and very instructive part of a cave rocky relief is shaped by underground water flows. Due to their prominent form and prevalence over other rocky features the scallops, ceiling pockets, potholes and other features of this kind may often be preserved in old, now dry passages. The understanding how a single rocky feature was shaped offers the opportunity to interprete rocky relief as a speleogenetical evidence. I already presented in Acta carsologica (Slabe 1993) the scallops which are the most prominent features; this time I add a description and explanation of origin of other typical rocky features hollowed out by a water flow. The properties of a cave rocky relief developed in different hydrological conditions are described. After literature I summarized general bases of hydraulic properties related to water flow, either those that fill entire tube or free surface flows and also the properties of turbulence at smooth or coarse surfaces.

I studied the development of rocky relief in numerous Slovene caves; the origin and development of single rocky forms is illustrated by laboratory experiments in plaster of Paris.

Rocky features hollowed out by water flow reflect the hydraulic conditions in the passages which are of various size and shape. The water flowing with different velocity and having typical turbulence dissolves and mechanically smoothes variously composed and crushed rocks on a perimeter of a passage.

Homogeneous, non-fissured rocky surfaces, parallel to water flow and larger than the diameter of turbulence in the flow of a defined velocity generate scallops; in longitudinal rocky notches these are flutes. The surface of a perimeter is covered by even turbulence (Fig. 1, 1a). Larger turbulences along a dissected roof and at the transition between passages, that have different size or different gradients, generate ceiling pockets. The bottom is levelled by erosion and sediments. Along larger fissures on the walls niches are frequent. On rocky bottom of the pasages where fast and usuallly free surface flow flows, potholes develop. The material transported by water help to shape them. When a perimeter is conspicously inhomogeneous it unables development of smaller scallops, or when it is strongly fissured it influences the formation of larger scallops and ceiling pockets, pendants occur between the fissures (Fig. 1, 2b). Chaotic turbulence unables the origin of regular incised rocky features. When water flow is faster even smaller fissures may play an important role. On the ceiling and on the wall rocky knives are therefore frequent. At the bottom that is shaped by the fastest water flow transporting load, "čer" develops.

I combined some typical turbulences of a water flow to illustrate the above statements. We differ the turbulences that have their flow lines rectangular to wall and they shape relatively shallow hollows and spiral turbulences that are typical of deeper cups. The size and the property of an eddy depends on velocity of water flow and on location in the passage. The turbulence zones appear in front and beyond the narrowness in the passage, in ceiling notches, below the jumps in a riverbed, on rocky blocks, in wall meanders and water is stengthened also along the fissures. The water level change or linking of passages are reflected by water level horizons.

Due to karstification one may frequently perceive the change of hydrological conditions during the cave's development. The passages that were in past filled up by water display today faster free surface flow or the traces of water flow are fossil already. These changes are reflected on a rocky relief also, which is either composed by one type of rocky features or by several different types. Fast water flow quickly incises smaller scallopes over eventual larger and older. Thus the entire perimeter of the passage might change or only its lower part is transformed (Slabe 1993, 165). Also less prominent factors than is water flowing above fine-grained sediments, for example biocorrosion that acts only on single parts of a perimeter or is less effective, enables the preservation of older, prevailing traces of past periods. In short, rocky relief shaped by water flow is diversified and important evidence of formation and development of karst caves.

REPORTS

POROČILA

CHINA CO-OPERATION REPORTS

POROČILA O SODELOVANJU S KITAJSKO

RESULTS OF TECTONIC MEASUREMENTS IN THE LUNAN STONE FOREST, CHINA

REZULTATI TEKTONSKIH MERITEV V "KAMNITEM GOZDU" PRI LUNANU, KITAJSKA

STANKA ŠEBELA

Izvleček UDK 551.241(513.21)
551.435(513.21)

Stanka Šebela: Rezultati tektonskih meritev v "Kamnitem gozdu" pri Lunanu, Kitajska

V Kamnitem gozdu pri Lunanu so glavne smeri tektonskih razpok 315-330° (SZ-JV), sledi smer 45-60° (SV-JZ) in smer 285-300° (SZ-JV). Plasti permijskih apnencev vpadajo proti SZ in Z pod kotom 5-20° ter so blago nagubane v več manjših antiklinal in sinklinal.

Ključne besede: Kamniti gozd, Lunan, merjenje razpok in plasti, rozeta, provinca Yunnan, Kitajska

Abstract UDC 551.241(513.21)
551.435(513.21)

Stanka Šebela: Results of Tectonic Measurements in the Stone Forest, Lunan, China

The main tectonic trending in the Lunan Stone Forest is from 315 to 330° (NW-SE), followed by a trending 45 to 60° (NE-SW) and by 285 to 300° (NW-SE). The layers of Permian limestones strike towards NW and W dipping by an angle of 5 to 20° and are slightly folded into several smaller anticlines and synclines.

Key words: measurements of fissures and layers, roseta, Lunan Stone Forest, Yunnan Province, China

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INTRODUCTION

Within an international cooperation between the Karst Research Institute ZRC SAZU and Yunnan Institute of Geography, Kunming, Yunnan Province, China, we explored karst terrains in wider regions of Lunan Stone Forest in July 1996. The project entitled A Study of Lunan Stone Forest Karstic Phenomena and Underground Water Reservoir Leakage Problem is financially supported by a Committee of Scientific and Technological Cooperation (at Ministry of Icience & Technology RS) between the Republic of Slovenia and People' s Republic of China. The main topic of Slovene-Chinese researches is to help the Lunan Stone Forest to be listed into UNESCO World Natural Heritage.

The Lunan Stone Forst lies 126 km SE from Kunming and about 10 km NE from the town of Lunan (Figs. 1 and 2) from 1750 to 1950 m a.s.l. It covers 26.000 ha and 80 ha are displayed for tourist visit. In 1995 more than 1,4 million of tourists visited this park.

GEOLOGICAL DATA

"Stone forests“ belong to karst plateaus in Eastern Yunnan (Sweeting 1995). Devonian and Permian limestones are covered by Eocene (and possibly Miocene) lake muds and clays and a deep lateritic soil cover.

The Lunan Stone Forest consists of Permian limestones and dolomites. According to geological map (1:50.000) the beds in park gently dip from 2° to 8°, in average for 5° and strike towards west. In the base the Devonian beds are overthrusted to the Permian beds.

In limestone open synclines and anticlines with dips from 3° - 17° may be seen. Where the limestones are thick-bedded and strongly jointed, rock columns up to 30 m high can be formed (Sweeting 1995).

The stone pillars are developed in the Lower Permian Maokou (354 m thick) and the Qixia (100 m thick) limestones. Both of these limestones are very uniform in composition and are thickly bedded.

The Maokou is a platform, sparitic and bioclastic limestone (Song 1986). It is slightly dolomitized in places. The Qixia is a massive reef limestone and also dolomitic.

The outlines of the pillars are related to the directions of the jointing, the

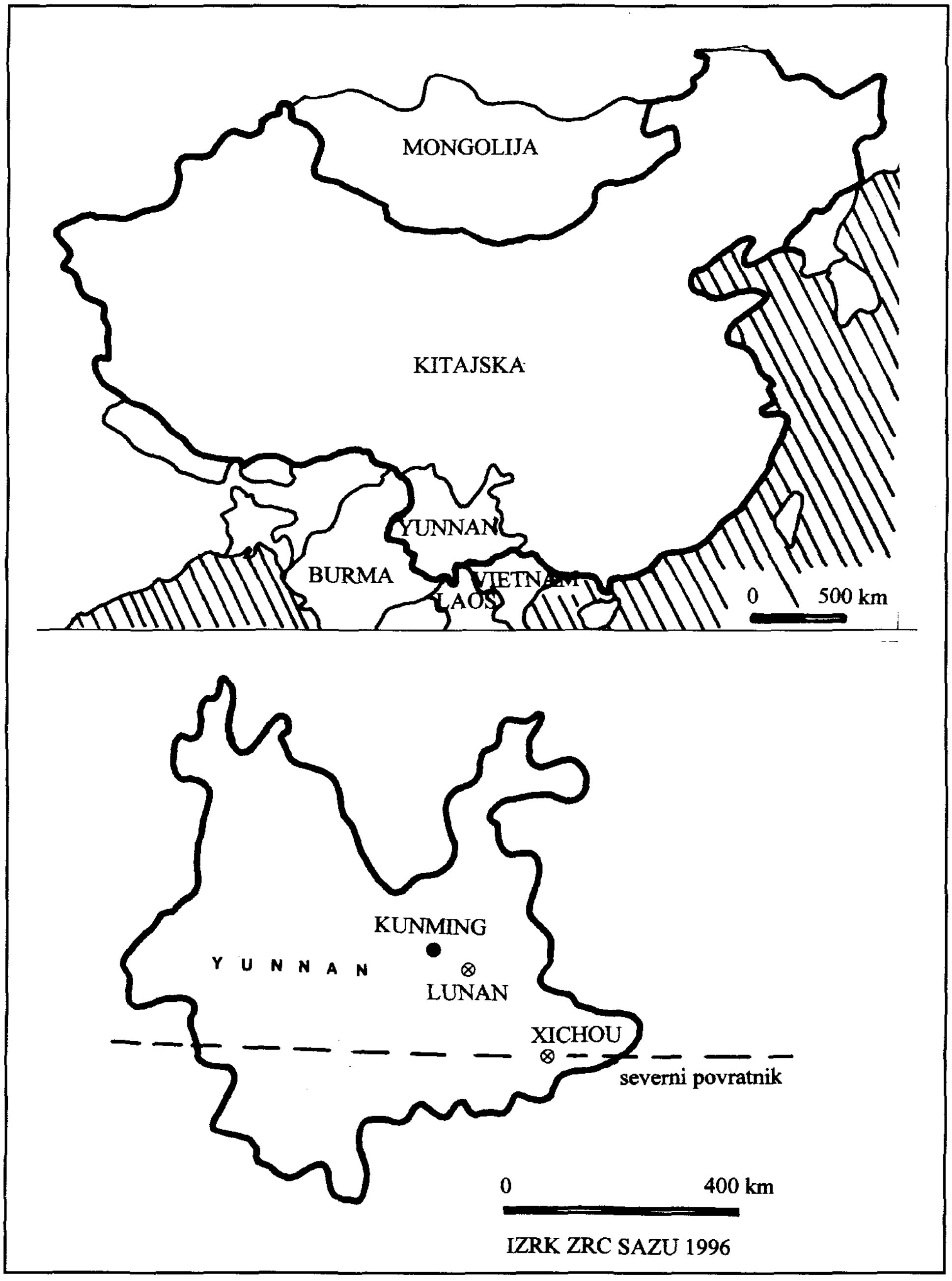

Fig. 1: The situation of the Yunnan province
Sl. 1: Položaj province Yunnan

main joints at the Lunan Stone Forest being N20°W, N50°W and N50°E. The N20°W joints are pre-Cenozoic and are filled with calcareous tufa, but the other joints are Cenozoic in age and are open vertical intersecting fissures which cut the subhorizontal Maokou limestones (Sweeting 1995).

Lunan Stone Forest lies east from Jiu-Xian-Shiyakou fault which makes part of Xiaojiang folded belt. Geological elements of the fault are 70-80/60.

Local water table in the Lunan area are Sword Peak Pond, Lotus Flower Pond and Stone Forest Lake. The superficial and underground waters drain into the river Bajiang, towards S and SW. The underground water flows in epiphreatic channels.

Water level in Sword Peak Pond and Lotus Flower Pond may increase for 10 m (Song 1986).

The situation of the Lunan Stone Forest is determined by movements along Jiu-Xian fault zone. These movements controlled the deposit of Eocene rocks and permitted gentle covering of Permian limestones. More than 500 m thick layer of red loam was deposited in the Lunan area.

Zhang (1980) distinguishes three stages in karst development:

1. early stage - pre-Triassic includes the oldest appearance of karst. After Indo-Sinian and Yanshan movements and also after early Himalayan movements these clastic rocks over the limestone had been removed and caused a new phase in a karst development.
2. Young stage lasted from the Mesozoic to the end of Miocene.
3. Modern stage includes the late Miocene to the Holocene, some 7 to 4 million years ago. This stage corresponds to intensive uplifting of the Tibet plateau and records the appearance of deep valleys (Miocene - Holocene). The uplifting of the Earth crust in the Tertiary and the Quaternary played an important role at karst development in southern and western China. It caused the changes in karst water level. Continental crust of China is intensively affected by neotectonic movements (the modern Himalaya's displacements) which is important for development and various types of karst in China.

MEASUREMENT OF FISSURES IN THE LUNAN STONE FOREST

I measured dip and strike of fissures in the area of the Lunan Stone Forest. Limestone pavement is formed along the most frequent trendings of fissures.

In a rosette (Fig. 3 and Table 1) is shown the frequency of the fissure directions. Out of total number of fissures (N=202) the direction 315-330° (NW-SE) is the most common (20.79%). The second place (15.34%) occupies the direction 45-60° (NE-SW) and the third one (14.35%) the direction 285-300° (NW-SE).

Table 1. Statistical evaluation of fissures trending in the Lunan Stone Forest (N=202)

direction (smer)	no. of measurements (št. meritev)	%	position (zaporedno mesto)
1-15^0	0	0	12
16-30^0	5	2.47	11
31-45^0	8	3.96	9
46-60^0	31	15.3	2
61-75^0	22	10.9	4
76-90^0	17	8.4	6
271-285^0	8	3.96	9
286-300^0	29	14.4	3
301-315^0	19	9.4	5
316-330^0	42	20.8	1
331-345^0	10	4.95	8
346-0^0	11	5.44	7

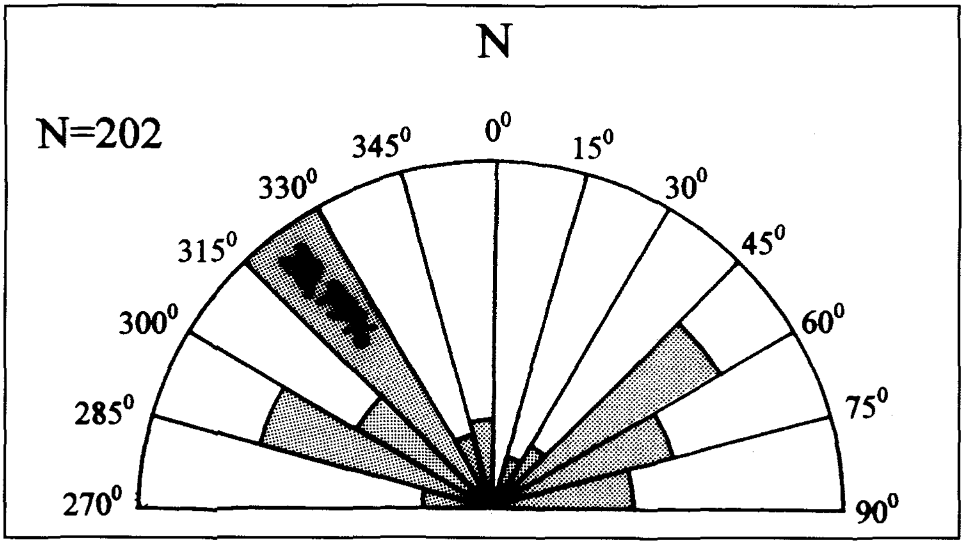

Fig. 3: Rosetta diagram of jointings in the Lunan Stone Forest (N=202)
Sl. 3: Rozeta smeri razpok

Poorly are represented the directions N-S although regionally important geological structure lines are of this direction. This fact implies the idea that the area of stone forest lies among stronger faults; a block is broken in two main jointings, NW-SE and NE-SW.

When the pathways in the park were made the fissures among the pinnacles were used and thus the main tourist ways are concordant to fissures in a limestone (Fig. 4).

It is typical of the fissures to dip very steeply, almost vertically (80-90°).

According to Sweeting (1995) the main joints are N20°W which differs for at least 10° from mine measured and analysed data.

In the book Karst of China (1991) Yuan summarizes the researches done by Shouyue (1983) who was the author of a linear structures map in the Lunan Stone Forest. According to this map the most frequent tectonic structures are N50°W.

In a central part of the Lunan Stone Forest (Fig. 5) the most expressed dip is 50° and transverse dip 140°, 160° and 180°. In E part of Stone Forest the dip 80° (N100W) prevails. West from touristically displayed pathways in the Lunan Stone Forest there is a thicker layer of red loam deposited in a valley, oriented to 110° (N10°E). South from the Stone Forest Lake and along the southern touristic pathway the direction of the jointing is 0-20° (E-W, N80°W, N70°W).

During field mapping I could not determine displacements along some joints. It is fact that on the mapped area (Fig. 5) there is not an uniform direction of joints intersecting all the others. Thus we perceive that directions NW-SE are intersected by directions NE-SW and vice versa. The relative age of the main joints in the Lunan Stone Forest thus cannot be determined for sure.

MEASUREMENT OF LAYERS IN THE LUNAN STONE FOREST

I measured 52 dips and strikes of strata. The results are shown in structural-geological sketch (Fig. 5), in Schmidt net (Fig. 6) and in rosetta (Fig. 7). The main direction of strike is NW and W (Fig. 6).

Due to small dipping of beds lithological column is accessible in a thickness of 200 m. In its lower part, accessible in the eastern part of the Stone Forest and also in its central part through deep fissures it contains limestone with inliers of cherts jutting out of a limestone. The layers in upper part of the lithological column are the least stable in case of earth-quakes. It is evidenced by numerous collapse blocks that had fallen into the fissures during the earth-quakes of the last decades.

At least 21.2 % of limestone layers have direction N16-30°E (Fig. 7 and Table 2) striking westwards for 5-20°, in average for 5°.

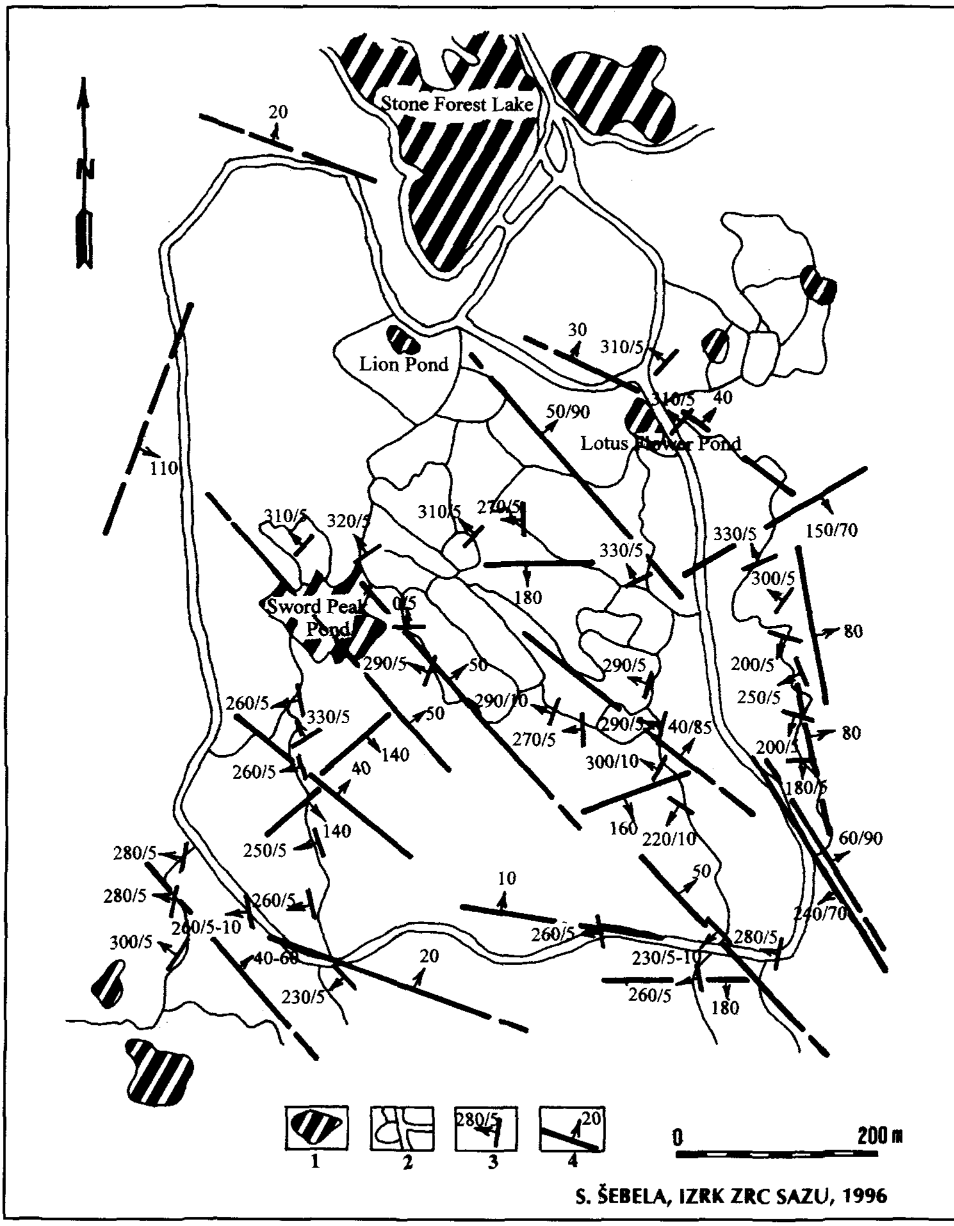

Fig. 5: Structural-geological sketch of the Lunan Stone Forest. 1-lake or pond, 2-touristic pathways, 3-strike and dip of strata, 4-strike and dip of structural zones

Sl. 5: Strukturno-geološka skica lunanskega Kamnitega gozda. 1-jezero ali ribnik, 2-turistične poti, 3-smer in vpad plasti, 4-smer in vpad tektonskih con

Table 2. Statistical evaluation of the direction of layers in Lunan Stone Forest. N=52

direction (smer)	no. of measurements (št. meritev)	%	position (zaporedno mesto)
1-15^0	5	9.6	4
16-30^0	11	21.2	1
31-45^0	4	7.69	6
46-60^0	8	15.4	3
61-75^0	2	3.8	8
76-90^0	2	3.8	8
271-285^0	0	0	12
286-300^0	2	3.8	8
301-315^0	1	1.9	11
316-330^0	3	5.76	7
331-345^0	5	9.6	4
346-0^0	9	17.3	2

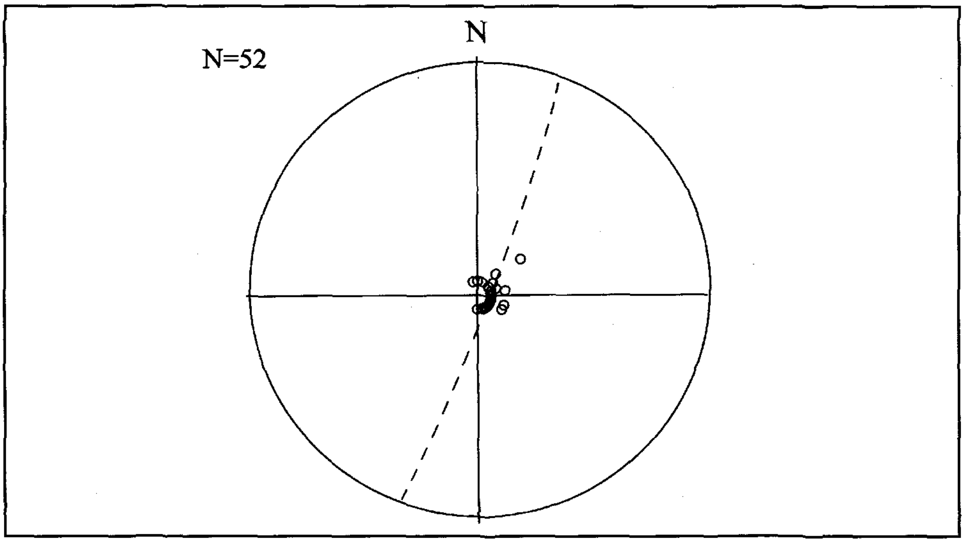

Fig. 6: Schmidt's net - the layers of limestone in the Lunan Stone Forest (N=52)
Sl. 6: Schmidtova mreža - plasti apnenca v lunanskem Kamnitem gozdu (N=52)

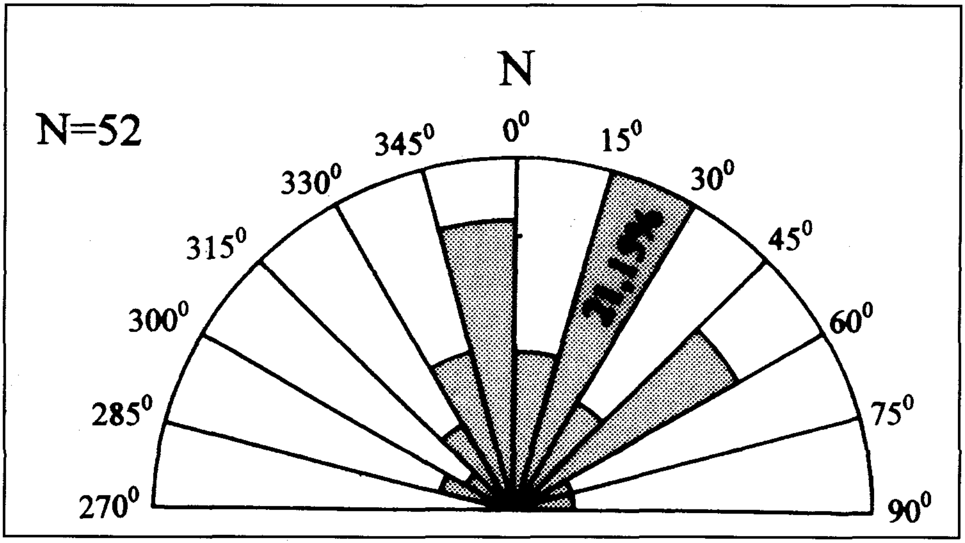

Fig. 7: Rosetta diagram of layers in the Lunan Stone Forest (N=52)
Sl. 7: Rozeta smeri plasti v lunanskem Kamnitem gozdu (N=52)

In the southern part of the stone forest (Fig. 5) the layers of limestone dip not only towards NW and W but also towards SW.

As already Sweeting (1995) pointed out the structures in the limestones of the Lunan Stone Forest are open synclines and anticlines. The anticline ridge is the most obvious in S and SE part of the Stone Forest (Fig. 5).

CONCLUSIONS

The stone pillars or pinnacles that form a Stone Forest developed below soil, the fissures widened and later some typical below sediment features developed.

By measuring geological elements of strike and dip of fissures in the Lunan Stone Forest and by basic statistical data processing it was established that in the Lunan Stone Forest three main directions of fissures prevail. These are 315-330° (NW-SE), 45-60° (NE-SW) and 285-300° (NW-SE). As the main regional tectonic structures are directed N-S the area of the Lunan Stone Forest presents morphologically slightly elevated terrain between two stronger fault systems inside which the limestones jointed in three main directions. The fissures that widened below the sediment cover are displayed as pinnacles of the stone forest since the sediment cover had been removed.

The layers of Permian limestones strike towards NW and W dipping for 5 to 20°, they are gently folded into several smaller anticlines and synclines.

To attain a more complex explanation of tectonic conditions it would be necessary to widen the researches over the borders of touristic part of the Lunan Stone Forest.

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Fig. 2: The Lunan Stone Forest (Photo by S. Šebela, July 1996)
Sl. 2: Lunanski Kamniti gozd (Foto: S. Šebela, julij 1996)

Fig. 8: Karst polje in Xichou (Yunnan) (Photo by S. Šebela, July 1996)
Sl. 8: Kraško polje v pokrajini Xichou (Yunnan) (Foto: S. Šebela, julij 1996)

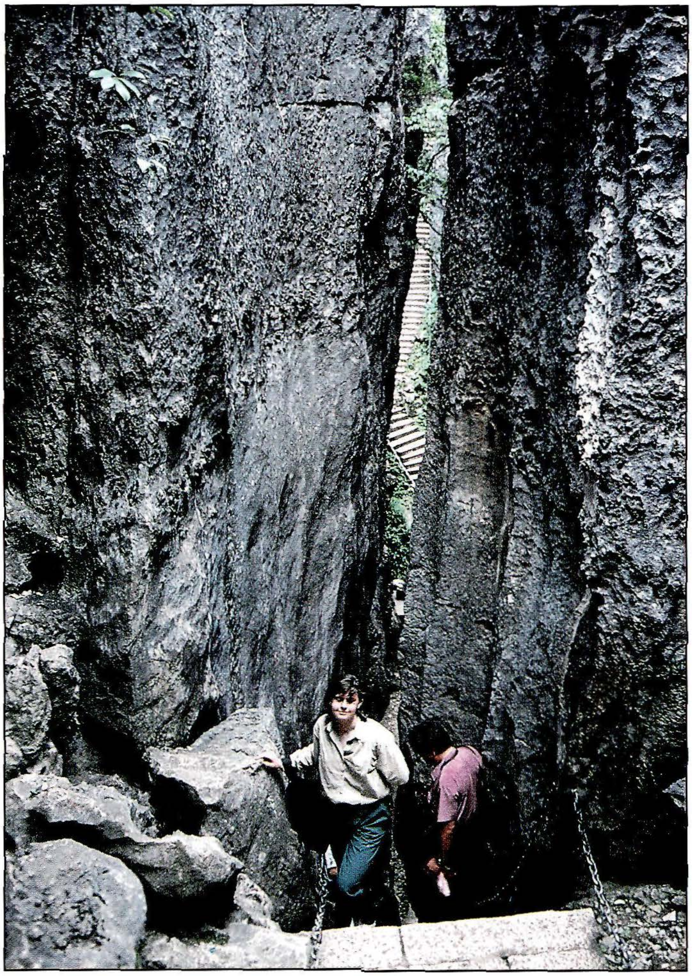

Fig. 4: The fault zone in the Lunan Stone Forest (Photo by S. Šebela, July 1996)
Sl. 4: Prelomna cona v lunanskem Kamnitem gozdu (Foto: S. Šebela, julij 1996)

Nadja Zupan Hajna

REPORT ABOUT THE KARST RESEARCH INSTITUTE ZRC SAZU CO-OPERATION WITH PR OF CHINA IN 1995

The co-operation of the Karst Research Institute ZRC SAZU with PR of China is organized by the Ministry of Science and Technology at two projects; one involves the Institute of Geology of the Chinese Academy of Science, Beijing and the other Institute of Geography, Kunming, Yunnan. The projects were accepted by the agreement of scientific technologic co-operation between the governments of Slovenia and China in February 1995 in Beijing. The cooperation will last three years with the possibility of prolongation of both projects. Project No. 01-3-03, SLO-3 with Institute of Geology of the Chinese Academy of Sciences, Beijing is entitled Karst Environment Protection and Exploitation of Cave Resources. The main topics are exploration and development of large cave systems and the protection of cave environment, safeguarding and restoration of deserted karst areas. The project No. 01-3-05, SLO-5 with Yunnan Institute of Geography, Kunmming is entitled A Co-operative Research on Karst Phenomena Preservation, Protection and Large Cave Systems Exploration in Yunnan Province. The topics within this project are protection of karst phenomena associated with karst tourism development and exploration and exploitation of large cave systems.

The co-operation at both projects started in 1995 by visit of Chinese researchers to Slovenia at the end of September and at the beginning of October 1995. Our visit to China took part in November 1995.

Within the project Karst Environment Protection and Exploitation of Cave Resources three researchers of the Institute of Geology of the Chinese Academy of Sciences visited our Institute at Postojna from September 22 to October 5, 1995. The member of the delegation were Prof. Zhang Shouyue, geologist, Mrs. Jin Yuzhang, chemist and Mr. Shi Mengxiong, hydrogeologist. During their visit they were mostly interested in karstology and speleogenesis in Slovenia, protection against soil erosion and karst reforestation. They were also interested in research and exploitation of large cave systems and protection of cave environment. They visited the classical Karst, cave Vilenica and got acquainted with problems resulting in motorway construction over karst. During their visit to Ljubljana they were received at the Ministry of Science and Technology, by the director of the ZRC SAZU and at Economic and Commercial Office of PR of China.

Within the project A Co-operative Research on Karst Phenomena Preservation, Protection and Large Cave Systems Exploration in Yunnan Province five researchers of Yunnan Institute of Gerography, Kunming visited our Institute at Postojna from October 4 to October 19, 1995. The members of the delegation were Dr. Guo Laixi, Director of the Institute, touristic geographer, Dr. Zhang Fan, biologist, assistant of speleology, Dr. Liu Hong, hydrogeologiost, assist. prof. of speleology and geomorphology, Dr. Chen Xiaoping, geographer, assist. prof. of speleology and eng. Huang Wenkun, a representative of Science Foundation of Yunnan Province. During their visit they showed the interest in protection of karst phenomena associated with karst tourism development and exploitation of large cave systems, and new research methods related to karst hydrology and speleogenesis. They visited Classical Karst, got acquainted with problems of motorway construction over karst, visited blind valley in Matarsko Podolje, karst poljes, alpine and high-mountainous karst of Trnovski Gozd and karst springs at the foot of Trnovski Gozd and Banjška Planota. They were received at the Ministry of Science and Technology, by the director of Znanstvenoraziskovalni center SAZU, by Economic and Commercial Office of PR of China and by Biological Centre of Biotechnical Faculty, Department of Biology.

Related to the programs between both institutes two our researchers visited Chinese karst from November 2 to December 5, 1995 in order to gather suitable locations for further joint researches.

Together with Yunnan's Institute of Geography, Kunming we visited three karst areas where a cooperative research may be undertaken. Yunnan province lies in the southwest of China and covers 390.000 square kilometres. It is situated near the border of Vietnam, Laos, Burma and Chinese provinces Tibet, Sichuan, Guizhou and Guangxi. The above sea level altitudes vary from 100 to 5000 m. The hydrogeological system drains the Yellow, Pearl and Red rivers. One third of the surface belongs to carbonate rocks, mostly of the Upper Paleozoic and Triassic age. In the western part of the province the carbonate rocks outcrop at the surface most of them are at the border with Guizhou province. In Yunnan the following types of karst are distinguished: the karst of tropical rainforest in the south (at the border with Burma); the karst of tectonic basins (basin around Kunming, Mengzi basin); stone forests on plateaus (in Lunan) and cone karst in the southeast (Xichou). During our visit of the Yunnan Institute of geography in Kunming we visited karst surface of Western Hill, west from Kunming, show cave Jiu Xiang, Stone Forest, Nai Gu Stone Forest and the area where the underground water reservoir is planned. Shilin or Stone Forest is one of the most famous karst areas in the world. It lies about 1750 to 1950 m a.s.l. It is divided into seven tourist parts with stone forests, caves, lakes and waterfalls. There is an impressive tufa waterfall Da Die Shui, 90 m high at 1540 m a.s.l. in the valley oriented east-west.

The area of Great and Small Stone Forest National park is covered by thick red soil, where the soil is missing variously tall karren are exposed, the highest among them are 20 to 30 m high. Lower features are termed stone teeth and higher stone forest. They developed below the soil cover. Stone forests in this area developed in Permian limestones and dolomites. There is no connection between lithology and rock structure and development of large karren. They developed in limestones and dolomites, with cherts or without them or with inliers of dolomite. They may develop in carbonate rocks with sequences of many different genetic types. The inclination of layers is small, 5^o or even less and this is important for their stability; karren are very stable against collapse and they may even reach the height of 30 m. The area makes an application for being inscribed into World Natural Heritage List at UNESCO. Near the Mengzi town we visited blind valley called Wulichong where a water reservoir is being built in a karst terrain. At the border between Vietnam and Yunnan, near Xichou, we visited a region of cone karst. Among 200 m high cones variously large karst depressions are lying, cockpits and karst poljes; the soil is preserved in the bottom of depressions only.

The second part of our visit to China was organized by the geologists from the Institute of Geology of Chinese Academy of Science, Beijing to the Guizhou province. Guizhou covers 170.000 square kilometers in the south of China and lies from 1000 to 3000 m a.s.l. Hydrogeologically it belongs to drainage systems of the Pearl and Yellow rivers. The main difference in regard to Yunnan lies in important quantities of coal deposited in the Lower and Upper Permian. Main coal layers were deposited in the Lower and Upper Permian while in the north of China main coal layers belong to the Upper Carboniferous. 75% of surface belong to carbonate rocks. The most important for karst development are Permian limestones, from 400 to 1000 m thick, locally interrupted by diabase dikes. The second the most common limestones where karst developed are middle Triassic. The limestones are massive and more than 300 m thick. The prevailing morphological feature is cone karst, single cones or hums diplaying various forms. The most impressive is their areal distribution. Among them are cockpits, ouvalas and karst poljes of different dimensions. Local relief differences are smaller than 400 m, but in some gorges they may even exceed 1000 m. Several types of karst are distinguished in Guizhou according to their topography, lithology and tectonics: the karst of the western, northern, central, southern, southwestern and eastern Guizhou. Near the town Pang Xian we visited several smaller karst poljes, sinking streams and caves and near Liu Pan Shui high karst plateau where the river Bai Pan Jiang cut its canyon and natural arch Tian Sheng Qiao. On our way back we visited the geological institute for karst in Guilin.

Martin Knez

30th INTERNATIONAL GEOLOGICAL CONGRESS (BEIJING, CHINA, 4-14 AUGUST 1996)

On behalf of the Karst Research Institute ZRC SAZU and as the only reperesentative of Slovenia I attended the 30th jubilee International Geological Congress in Beijing, China. In the capital of China where 12 millions of people live and which covers 16.800 square kilometers the geologists from all over the world gathered between August 4 and 14 trying to find out the actual state in geology and at the same time to issue guidelines for the third millenium. We spent ten interesting and instructive days in Beijing.

All the aspects of the International Geological Congress appear in superlatives. About 8000 men registered to the Congress and the same number of abstracts was published. Later it was shown that "only" about 6500 papers were held. The number of all the participants together with locals that attended the Congress for some days only, was unofficially more than 10.000!

The Organizing Committee numbered 77 men, Scientific Committee 86 men, Honorary Committee 26 men, other committees 131 men, altogether more than 300 men. The Honorary President accompanied by six Vice-Presidents was the president of P.R. China Li Peng; after scientifically and culturally rich opening ceremony he solemnly declared the 30th International Geological Congress open.

The Chinese geologists prepared 10 pre-Congress, 14 during-Congress short courses, 6 workshops during the Congress and 20 Congress workshops. There were 316 pre- during- and after-Congress field trips (some of them cancelled later) covering the area of entire China! Most of them were dedicated to geomorphology, mineral resources, petrology, structural geology, sedimentology, stratigraphy and tectonics.

Scientific Symposium's Programme was divided into 22 sections from stratigraphy, paleontology and sedimentology at first places to marine geology, structural geology, igneous petrology, mineralogy, Precambrian geology, geology of mineral deposits, geology of fossil fuels, mineral economics, geochemistry, geophysics, seismogeology, Quaternary geology, hydrogeology, engineering geology, environmental geology, mathematical geology and geoinformatics, comparative planetology, geological education and history of geoscience.

In addition to the above mentioned the programme included also several touristic, cultural and artistic performances giving animation to day and evening.

The so-called Special Symposia appeared within 11 sections: Origin and history of the Earth, Geosciences and human survival, Global changes and future environment, Structure of the lithosphere, Contemporary lithospheric motion, Global tectonic zones, Orogenic belts, Basin analysis, Energy and mineral resources for the 21st Century, New technology for geosciences and Progress of international geoscience projects.

From August 4 to 9 the Organizing Committee of the 30th International Geological Congress together with some participants prepared the exhibition Geoexpo '96 at which about 150 exhibitors from China and abroad have taken place.

The 30th International Geological Congress was organized in collaboration with the International Union of Geological Sciences (IUGS), the Geological Society of China, the Ministry of Geology and Mineral Resources of P.R. China and the relevant Chinese governmental agencies, scientific institutions and industrial organizations.

A lot of various papers were held, in particular outstanding were two papers of Prof. W. Fyfe, University of Western Ontario and the President of International Union of Geological Sciences.

Slovenia, Karst Research Institute ZRC SAZU appeared within a section Formation and Evolution of Karst and Data on Environmental Changes with a paper Karst Cave Development from a Bedding-plane Point of View (Škocjanske jame Caves, Slovenia) and by poster entitled Development of Phreatic Channels in Škocjanske jame Caves, Slovenia. In addition I took part at the meeting of IGCP UNESCO Project 379, Karst Processes and the Carbon Cycle where our Institute figures as a collaborator to a project.

As a congress of such dimensions deserves the organizers published, in addition to other items, a detailed programme with names of all the participants in a booklet of more than 300 pages, a booklet containing a list of guests and their distribution in hotels, a booklet containing the donors of financial means where are listed all that have given at least 100 yuans and also three volumes of abstracts and posters of more than 2000 pages, that were presented at ten days of Congress.

After four years geologists of all countries will gather again in Brazil.

OTHER REPORTS

OSTALA POROČILA

R. Schleyer

MARKIERUNGSVERSUCHE IN GEWÄSSERN UNGEFÄHRLICH?

Markierungsversuche im Grundwasser und in Oberflächengewässern sind für die Gewässerbewirtschaftung und den Umwelt- und Gesundheitsschutz notwending, um beispielsweise Schutzzonen für Wasserwerke festzulegen oder die Ausbreitung von Schadstoffen im Grund- und Oberflächenwasser zu simulieren. Teilweise wurden bisher allerdings Stoffe in die Gewässer eingebracht, über die nur lückenhafte toxikologische Erkenntnisse vorliegen. Jetzt hat ein Arbeitskreis erste Ergebnisse toxikologischer Prüfungen vorgelegt: Einige Stoffe wurden als toxikologisch unbedenklich eingestuft, während vom Einsatz anderer Substanzen abgeraten wurde. Grundsätzlich sollten möglichst wenig Versuche durchgeführt und nur geringe Mengen vom Stoffen in die Gewässer eingebracht werden.

Hydrologen setzen für Markiereungsversuche bestimmte Farbstoffe, Salze oder auch mit Acridinorange gefärbte Bärlappsporen und winzige fluoreszierende Polystyrolkügelchen ein. Sporen und Kunststoffkügelchen sind dazu da, die Ausbreitung von Bakterien und anderen Mikroorganismen zu simulieren, die dem Menschen gefährlich werden könnten. Allein in Baden-Württemberg beispielsweise wurden in den letzten 15 Jahren zwischen 20 und 30 Versuche in jedem Jahr durchgeführt und dabei jeweils mehrere Kilogramm Markiereungsmittel eingesetzt.

Allerdings wurden bisher Substanzen in die Gewässer eingebracht, über deren Giftigkeit (Toxizität) für Lebewesen bislang nur lückenhafte Daten vorlagen. Die für die Zulassung der Versuche zuständingen Behörden haben daher beantragte Versuche in der Vergangenheit zum Teil abgelehnt oder nur mit starken Einschränkungen genehmigt.

Wegen dieser Unsicherheiten hat das Umweltbundesamt, Institut für Wasser, Boden- und Lufthygiene (WaBoLu), 1994 einen Arbeitskreis einberufen, dem Fachleute aus dem Umweltbundesamt, dem Geologischen Landesamt Baden-Württemberg, dem Deutschen Verband für Wasserwirtschaft und Kulturbau (DVWK), dem Deutschen Verein des Gas- und Wasserfaches e. V. (DVGW), der Bundesanstalt für Gewässerkunde, der Arbeitsgemeinschaft leitender Medizinalbeamtinnen und -beamter der Länder (AGLMB) und weiterer Institutionen angehören. Ansprechpartner ist Dr. Ruprecht Schleyer von der Außenstelle Langen des Umweltbundesamtes.

Erste Ergebnisse toxikologischer Studien und die Sichtung der schon vorhandenen Daten ergeben, daß gegen den maßvollen Einsatz folgender Stoffe im Grundwasser keine humantoxikologisch begründeten Bedenken bestehen: die Farbstoffe Uranin, Eosin, Sulforhodamin B, Amidorhodamin G, Pyranin und Natriumnaphthionat und die Salze Strontiumchlorid sowie mit Einschränkungen Lithiumchlorid (weniger als 0,5 mg/l Lithium bei Trinkwasser). Beim Einsatz von Natriumbromid können bei der Behandlung des Trinkwassers mit Ozon oder Chlor gesundheitsrelevantes Bromat oder bromorganische Verbeindungen entstehen, was ausgeschlossen werden muß.

Von der Anwendung der Farbstoffe Rhodamin WT, Rhodamin B, Rhodamin 6G, Tinopal CBS-X und Tinopal ABP flüssig dagegen rät der Arbeitskreis wegen toxikologischer Bedenken oder wegen unzureichenden Datenmaterials vorerst ab. Für diese Stoffe sowie für Bärlappsporen und Polystyrolkügelchen führt der Arbeitskreis weitere Untersuchungen durch. Für den Einsatz in Oberflächengewässern müssen die Markierungsmittel auch auf ihre Ökotoxikologie hin untersucht werden. Der Arbeitskreis weist darauf hin, daß prinzipiell ein Minimierungsgebot für die Zahl der Versuche und die Menge der eingesetzten Stoffe besteht. Zu erwartender Nutzen und möglicher Schaden sind bei jedem einzelnen Markierungsversuch sorgfältig abzuwägen.

Martin Knez

THE 15th SPELEOLOGICAL SCHOOL (LANDEK ZDROJ, POLAND, FEBRUARY 12-18,1996)

The co-workers of the Karst Research Institute ZRC SAZU visited the jubilee 15th Speleological School in Poland. In a typical Sudetes town Landek Zdroj we passed professionally interesting week from 12 to 18 Febuary.

The town Landek, as it is called by the natives for short, lies in a mountainous area of the western Silesia where the peaks reach the altitudes from 800 to 1200 m. The highest among them is Snieznik, 1425 m a.s.l. At its foot the most famous cave in Poland, the Bear Cave (Jaskinia Niedzwiedzia) is located. In the Snieznik area gneisses and marbles prevail and water incised deep valleys in them. The Bear Cave developed in poorly recrystallized marbles.

The Speleological School was organised, as all the previous, by researchers from the Geomorphology Department, University of Silesia. Headed by world famous karstologist and glaciologist Prof. M. Pulina Doc. A. Tyc took care for this week. The Scientific Protective Committee at the Bear Cave and the Provincial Found of Environmental Protection and Water Management of the Walbrych province cooperated at the organisation.

The scientific Committee was represented by distinguished professors and researchers of karst and Arctic regions: A. Jan, M. Pulina, J. Głazek, J. Jania, S. Kozlowski and A. Rožkowski of the Silesian University, of the Wroclaw and Poznan Universities and National Geological Institute, Warszawa.

The organisers of the jubilee Speleological School tried to gather the highest possible number of experts related to speleology and karstology, and to glaciology from Poland and abroad. More than 50 representatives responded from Poland, Czech Republic, France, Russia, Slovakia, Ukraina and Slovenia, or in other words, from Bordeaux in the west to Irkutsk in the east.

As usually, also this meeting included invited papers, papers of participants and exhibition of posters. During the meeting an excursion to the Polish finest cave, Bear Cave, was organised.

Program of talks covered various topics, from applicative to entirely theoretical papers, from researches of lithosphere over GIS to various aspects of speleogenesis, datation of flowstone age by the TL, ESR, 14C, U/Th methods to Radon measurements in caves, researches of glaciers on Svalbards to tectonic grabens in Nigeria, from human impact on karst to protection of some karst areas. Each particular day was dedicated to a defined topic: karst hydrology, problematics of human impact on karst, speleogenesis, cave sediments, glaciology and regional problems and karst protection in Poland.

There were about 30 papers altogether. Slovenia was represented by four researchers with the following titles: The initial development of Škocjanske jame within the area of collapse doline Velika Dolina (M. Knez); Collapse Chamber in Postojnska jama and its relation to geological structure (S. Šebela); Mineral composition of cave mechanical sediments and their origin (N. Zupan Hajna); The complete karst model (F. Šušteršič).

All the lecturers placed great emphasis on fact that without understanding the karst law relation environment protection, safeguarding of water potentials and other measures are practically impossible. The papers showed the results and need for further development of science.

The evenings were made agreable by slides and video-films. The beauties of Ural and caves in ice of polar regions of Svalbards still remain within our recollection.

Our papers well represented Slovenia and I think that to attend the 15th Speleological School was not only interesting and agreable but also instructive.

The organisers plan to publish the given papers in a special publication.

Tanja Čelhar

INTERNATIONAL SYMPOSIUM ON "RESEARCH, CONSERVATION, MANAGEMENT" (1.-5. MAY 1996, AGGTELEK - JÓSVAFŐ, HUNGARY)

Between April 30 and May 8, 1996, I took part in the International Symposium on "Biodiversity monitoring and other research in nature conservation areas as the basis of nature management"; "Research, Conservation and Management" for short. The main organizer of the meeting was the Aggtelek National Park in cooperation with the Speleological Institute of the National Authority for Nature Conservation, the Ministry of Environment and Regional Policy in Budapest, CEE-WEB - Central and East European Working Group for the Enhancement of Biodiversity at Miskolc, Slovak Karst Protected Landscape Area, SEA, Banská Bystrica.

The symposium was held in the Hotel Cseppkő and the buildings of the Aggtelek National Park Directorate in Aggtelek and Jósvafő. Aggtelek and Jósvafő, two small villages, are situated in north-east Hungary, about 250 km from Budapest and quite near to each other, only 7 km.

The subject of the symposium was the results of biodiversity monitoring and other research conducted in nature conservation areas and its applicability to detect the adverse changes early, to follow the effects of the applied management methods, to implement the old conservation strategies and to elaborate new ones. Nowadays the three concepts given by the title of the symposium are completely inseparable. The protection of a valuable area, a vanishing habitat or rare species is unimaginable without the knowledge of the basic attributes of the object, the conditions of its survival, etc. In our quickly changing world where only small patches of untouched nature can be found, management is the primary condition of nature protection. At the very best management means closing and guarding, but in most cases active management is necessary to keep up a diverse and worth-conserving system or to approach the appropiate near-natural conditions. The most important part of nature management are the exploring investigation and the state assesment of the conserved object. This could help to set up the management strategy and to predict the results. It could be the basis of further monitoring to follow the changes. Nature protection would be unthinkable without the unselfish work of our researchers and experts.

The symposium brought together the researchers and the experts of nature conservation to present their results, to communicate, to share experiences and to work out new strategies.

The aims of the symposium were to review the current and recent works on the above fields and to discuss new approaches and potential future developments in view of the problems of nature protection facing the changing world of today, especially questions related to adequate implementation of the Convention on Biological Diversity.

The main symposium started in the afternoon of 1st of May with the Opening Lectures and Welcome Party. It ended on 5th of May with a Plenary discussion and Closing words. An excursion to the territory of Slovak Karst Landscape Protection Area and the Aggtelek National Park was organized on 3rd of May. The other days started with a plenary lecture with discussion afterwards. The rest of the days were devoted to shorter contributions and poster sessions.

Two main sessions were planned: one for presenting the results of the research, monitoring and management of the wildlife for conservation purposes and the second dealt with the results of the investigation, monitoring and management of the abiotic values (e.g. caves) in protected territories. As part of the last session I presented my poster with the title: "The Speleological Researches for Protection and Safeguarding of Škocjanske jame". It deals with karst researches in this region; the Karst Research Institute tries to determine the "natural equlibrium" and to gather the basic ecological assessments based on the actual knowledge ("null state") of Škocjanske jame with only partial possibility of ascertaining the original, i.e. natural state. Helped by such data one would contemporaneously or at given intervals compare the main parameters in the cave with the "null state" and determine whether the caves are appropriately safeguarded, does the ecology regenerate or even improve, or are the conditions worse so that additional measures have to be taken.

The lectures, abstracts of papers and the text to posters, as well as the guide-book for all excursions, were already published in a special volumes before the symposium.

The post-symposium field trip from 6.-8. of May was organised to visit other Hungarian national parks: Bükk and Hortobágy National Park and several interesting caves of the Slovak and Aggtelek Karst (Rakoczi cave in Bodvarako, Baradla cave in Aggtelek, Gombasek cave and Zadiel Gorge in Slovakia). Bükk (Beech) National Park measures 150.000 ha and its characteristic is "original beech forest" which is protected by law. We visited the birds rehabilitation centre of the Hortobágy National Park with mostly raptors and owls. The last night of the post-symposium excursion we slept in a real castle in Tiszafüred.

My participation at the Conference was made possible by the Karst Research Institute ZRC SAZU and Ministry of Science and Technology of the Republic of Slovenia. Without their help my active participation at this important Symposium would not have been possible.

GEOLOGY OF THE SURROUNDINGS OF VILLAGES JÓSVAFŐ AND AGGTELEK

The Aggtelek National Park is situated in the Aggtelek-Rudabánya Mountains, NE-Hungary. Its territory consists of segments of widely different geological history. Originally these segments were situated far away from each other. They became juxtaposed in the course of the Cenozoic era as a result of large scale horizontal movements of the Earth's crust. The earliest known events of the geological history of the area date back to the Late Paleozoic, when after a long-lasting continental period subsidence and a gradual transgression of the sea began. The geological record shows that climate was hot and dry at that time, and along the coastline in the shallow lagoons aridity resulted in the evaporation of sea water. During the driest periods anhydrite, gypsum and other evaporite minerals had been precipitated. When - from time to time - the climate became more humid and wet, clay minerals of continental origin accumulated on the sea bottom. Due to its plasticity this sedimentary complex exerted a strong influence on subsequent tectonic events. Under the influence of mountain building processes, huge rock masses could glide and therefore be displaced on the surface of the evaporite beds, which have acted as natural lubricants and therefore promoting the movements. Large blocks could collide with each other, they became folded and piled up, and thus the mountains were formed. The understanding of such complex deformation processes is as difficult as deciphering a cryptogram. Also the efficacy of the two is largely similar: though the essential might be figured out, many of the details remain a secret forever. Starting with the beginning of the Mesozoic era the gently sloping continent has been gradually overridden by the sea. After the evaporites, the first sediments deposited in the coastal belt of the subsiding basin were sands, silts and clay, transported by inflowing rivers originating in the continent. A great number of shells and other creatures were in the sand. Later on, as with the advance of the sea the water became deeper and deeper, deposition of calcareous sediments set in and less fine clastic material could reach the place from the far-away continent. A thick sequence of carbonate sediments (consisting of limestones, calcareous marls and marls) was formed, with thin claybeds intercalated in the limestone, testifying that the finest land-derived material still was able to reach the basin. In the meantime the sea-arm became isolated from the open sea by an underwater topographic barrier. As a result of the closure, sea water became impoverished in dissolved oxygen in the deeper parts of the lagoon. Episodically oxygen-rich water, rich in swimming and floating organisms, could enter the isolated lagoon through the barrier. This water, however, could not subside to the bottom of the embayment: instead it was spread over the surface of the anoxic water mass. Therefore the oxygen-rich water never reached the bottom of the gulf. Without oxygen, bottom-dwelling organisms could not survive in the deeper parts of the basin, so they could not destroy the fine organic detritus deposited together with the clay and silt. Rocks formed of these oxygen-poor sediments are therefore black (rich in organic matter). This long-lasting dynamic equilibrium was upset by endogenic forces originating deep in the Earth's interior. Continental plates were broken up and their pieces forced apart by the intrusion of ophiolites (kinds of basaltic magma), rising up along fractures or rifts, and resulting in the birth of new oceanic crust in the place of the former continent. In the ever deepening water of the embryonic ocean the precipitation of carbonates was shut down because of undersaturation of the sea water in respect of carbonates. During such periods skeletons of carbonate-secreting organisms get quickly dissolved as after the death of the animal they begin to settle in the water column. As a consequence, in such cases there is no carbonate deposition in the sea bottom. Instead silica (called chert by the geologists) may occur, sometimes alternating with carbonates. Remnants of such chert and "cherty-limestone" beds are described from the upper Bódva valley. Meanwhile, most of the present area of the National Park still remained a continental fragment, where conditions similar to that described above persisted for a long period of time. Finally also the rate of subsidence of this fragment has been accelerated, as a result of which reefs (strictly dependent on shallow water) could not survive. They became covered by a fine mud consisting of tiny little skeletons of floating unicellular organisms characteristic of the open sea. The most important group of these organisms are the Radiolarians, the skeletons of which are made of silica instead of carbonate. Deep water sedimentation continued also in the Jurassic period. The results of shallow water sedimentation on distant carbonate banks were transported into the deep sea by underwater slumps. Their products, called olistolites, are of great interest here. Olistolites are huge blocks of rocks found in an alien sedimentary environment (in this case embedded in sediments of the open sea). Traces of volcanic eruptions of an island arc, characteristic of the subduction of oceanic crust into the underlying mantle are also present in the Jurassic sedimentary complex here. Towards the end of the Mesozoic, in Cretaceous to early Cenozoic times, the area became uplifted and subject to intense erosion. The climate permitted the formation of red clay (terra rossa), and/or bauxite. After that, in Oligocene-Miocene times the area was again flooded by the sea. The sediments of this period are known, however, from very few places only. They were almost all eroded from the surface and are preserved only underground. Towards the end of the Miocene a large freshwater lake, the Pannonian lake - was formed the sediments of which comprise clays, sands, gravel and - along its margins - also coal seams. Overlying various kinds of older rocks, these Pannonian sediments are exposed along the rims of the limestone area and within small basins in between the hills, as for example in the vicinty of Bódvaszilas. Since Pannonian times the area has been subject to more or less continuous uplift. The resulting erosion stripped the Cenozoic cover of the limestone and dolomite complex. The eroded material of the older rocks was deposited as alluvial gravel and sand in the valleys. Part of the surface became covered by fine airborn dust which - on weathering -was converted into red clay. Occasionally in this the red clay blanket, reworked fragments of the old Mesozoic bauxite can also be found. The youngest geological formations are: slope scree, alluvial fans, young unconsolidated alluvial sediments of the present-day valley bottoms and the sandy-silty, sometimes gravelly fillings of the caves.

THE FAUNA AND FLORA OF THE AGGTELEK AND SLOVAK KARST

The most important features of the Aggtelek and Slovak Karst are its marginal and transitional position. Biogeographycally it is situated in the overlap of the Carpathian and Pannonian flora-sector and as an independent flora-district, Tornense came into existance here, in specific karstic conditions. Most of the territory is covered by Middle-European deciduous forest, but many differences from this forest type can be observed. Edaphically unwooded or less closed stands can occur only on steeply fractured slopes and dolomite ridges. It is worth mentioning those areas where the extensive use (grazing, mowing) over centuries made it possible for specific secondary, but near-natural associations to develop. In spite of the fact that they are not primeval, they are also included in the biosphere reserve because of their significant species diversity. The extraordinary high habitat and species diversity of the territory is showed by the series of completely antagonistic faunal and floral elements and relic species. There are several north-carpathian, east-carpathian-south-balkan and boreo-mountain species living in the extrazonal beech forests of the northern hillsides, cool dolinas and the ravine forests of deeply incised valleys. Some illyr-carpathian elements increase the variety of the rockforest fragments on the steep rocky slopes. The stepp and forest-stepp (ponto-pannon and subponto-south-siberian) species are dominant in the fauna and flora of the grasslands and the underwoods of the scarcely wooded calciphilous oak forests. The oak forests of the warm southern hillsides, the shrub forests with pubescent oak and the rocky grasslands are rich in submediterranian, pontomediterranian and balkan representatives. The vegetation (with heather, juniper and robur oak) which is quite similar to the West-European Heide vegetation occur on the covered karst and it makes the picture more colourful with its character (completely different from the karst vegetation). According to the list (not final) based on the data of museums and the literature and the results of complex ecological survey: there are nearly 1500 plant species (70 species protected in Slovakia and about 110 protected in Hungary). Tornaian yellowdrop (*Onosma tornense*) is registered in the World Red Data Book and 4 other plant species are included in the European Red Data Book. In the territory 42 fish, 13 amphibian, 9 reptile, 178 (127 nesting) bird and 57 mammals species had been identified so far. The avifauna includes 23 species that are endangered at the European scale. One of the mammals, European ground squirrel (*Citellus citellus*) is a seriously endangered species, registered within Bern Convention.

EXCURSION TO SLOVAK KARST

Gombasek cave was discovered in the year 1951. The cave is open to the public, and a national nature monument. Characteristic are the 2-3 m long straws (long, thin dripstone formations). Limestone production is clearly evident on the adjacent slope of Plesivec plateau.

Zadiel Gorge; national nature reserve, most beautiful gorge in Slovak Karst and formated by Blatnicá brook. Length of the gorge approx. 2200 m, depth around 300 m, width of bottom in some places is only 10 m, entire rise in elevation 205 m, the walls of the gorge in places are vertical interesting characteristics include the morphological formation Cukrová cone, unique plants and animals, and the inversion of vegetation zones due to local climatic conditions. An information trail is also present.

The waters of the Blatnisky Potok pounded on the limestone plateau massif for millions of years. In that time they broke the way up to the Turna basin and created a monumental georgе of the Szádelői (Zadiel) valley. For its specially botanic and zoologic values it was declared a state and later national nature reserve. Its area is 214,73 hectares and is located in the cadaster area Borka and Háy. The nature reserve documents the influence of water upon the morphology of landscape, the evolution of flora and fauna in the postglacial period and the influence of the terrain relief on the occurrence of species.

GEOMORPHOLOGY

From the morphologic point of view the Slovak Karst is a conspicuous unit, which is beyond the whole landscape picture of the West Carpathians and consists of a system of plateaux edged by the steep slopes bending to the bottoms of adjacent basins, or canyon-like valleys and gorges. The most beautiful morphologic phenomenon of the Slovak Karst is undoubtly a gorge of the Szádelői (Zadiel) valley. The water of the Blatnicky Brook cut into the limestone rocks, in which its riverbed is still deeper. A gorge was created by step-by-step collapse of ceilings of the passages and caves. The walls of the gorge were firstly shaped by vertical erosion. A slight sign of the original bridge over of the valley can be seen on its upper end. The length of the proper gorge is about 2200 m, and its depth is about 300 m, when right side is some 50 meters higher than the left one. The width on the botton of some of its places is only 10 meters, the lowest point of the gorge above the Szádelői (Zadiel) village is 270 meters above sea level and its mouth in upper part is in the height of 475 meters. Total elevation is thus 205 meters. The gorge runs from north to south; its walls are in some places almost vertical. In the upper two thirds they widen in a V shape. On both its sides can be seen rock ridges going vertically, in higher parts extremely weathered and creating numerous spires. Among these valley ribs hollows can be found, in the higher part these are covered with forest growth, changing over in the low part to the broken rocks, which at the valley create talus in places. Attention is attracted by a cone rock shaped by the erosive activity of water. The rock was named a Sugar Loaf for its shape. The Blatnicky Brook flows alternately in the right and left sides of the road and creates small waterfalls and cascades. In the gorge's walls the traces of previous action of running water can be seen. Water with its pressure and with the help of rock fragments polished in the walls different bowls and hemispherical pits, so- called pressure giant pots. While on the right side of the gorge spread the forest plateau of Horny vrch (the Upper Hill), on the left side is the Zádielska planina (the Szádelői (Zádiel) Plateau), which is mostly bare with groups of broad-leaved growth. A few smaller caves were found in the Szádelői (Zádiel) valley, of which the most important are the Kostrová, Královska and Bobková caves.

EXPOSED CARBONATE ROCKS

The most characteristic sign of the karst surface are exposed carbonate rocks and calcareous fields. Vegetation is varied especially in the spring, when there is still enough moisture in the soil. First flowers are usually *Draba lasiocarpa* and *Pulsatilla slavica* and *Pulsatilla grandis*, later flowers *Potentilla arenaria*, *Aster alpinus* and *Iris pumila*. On the rocks is the scented *Dianthus lumnitzeri*. With its eye-catching appearance is *Dracocophalus austriacum and* the shrubby ones *Chamaecytisus hirsutus* and *Genista pilosa*. *Sedum sexangulare* and *Sempervirum tectorum* are adapted to the extreme conditions. In the chinks of limestone rocks *Asplenium ruta-muraria* and *A. trichomanes* take refuge. The typical character of the limestone surface of plateau is given by grassy growths of *Carex humilis* and *Festuca pallens*. On the karst plateaux not only characteristic flora, but specific fauna was developed as well. Of reptiles is worth mentioning a lizard *Lacerta viridis* and *Lacerta muralis*. Butterflies are represented in great numbers, and very rare is *Saga pedo* and Praying mantis *Mantis religiosa*.

FLORA

The Szádelői (Zádiel) valley is an important finding place of rare species, some of which found their refugium in the glacial period, and others have their north border of distribution here. Plant communities in the gorge document an inversion of vegetation zones. On sunny margins at the elevation about 600 m above sea level, plant communities with important xerothermic species can be found, such as: *Scorzonera austriaca*, *Bupleurum affine*, *Aurinia saxatilis*, *Melica ciliata*, *Aconitum anthora*, *Allium flavum* and others. On the bottom of the valley, where cold and moist air gathers, dealpine kinds occur, such as: *Bellidiastrum michelii*, *Phyllitis scolopendrium*, *Valeriana tripteris*, *Saxifraga* *paniculata*, *Campanula carpatica*, *Primula auricula*, *Aster alpinus*, *Arabis alpina*, *Crepis jacquinii* and others. In the upper part of the valley *Petasites hybridus* is abundant. On the vertical slopes *Cyanus triumfettii* grows, in late summer *Anthericum ramosum*, in broken rocks *Campanula carpatica*; of ferns *Gymnocarpium dryopteris* and *Cystopteris fragilis;* on soaked places of broken stones *Lunaria rediviva* is in great numbers. While on the elevated spots and rocky ridges the original European larch tree and Scots pine is preserved; in gorges we can find autochthonous yew, which has here one of the lowest situated sites of its natural occurrence in this country.

FAUNA

Contingent upon the climatic conditions were developed zoocoenoses characteristic of the steppe and forest-steppe zone in the region of the Szádelői (Zádiel) valley. On the damp and cool places, specially on the bottom of the gorge, the alpine and subalpine species found the optimum conditions, as the plants did. Important group of fauna, alas only sporadic, includes birds, whose names have been for long years in the list of protected species. Before anything else is an eagle *Aquila heliaca*, which can be sometimes spotted circling above the valley, exploiting the air currents. No less rare is a falcon *Falco cherrug* and *Falco peregrinus*. More frequent in the Szádelői (Zádiel) valley is a raven *Corvus corax*, less common is a stork *Ciconia nigra*. All these birds, regularly nest in the Szádelői (Zádiel) valley in great numbers in the past. Of the mammals it is necessary to mention *Lynx lynx*, *Felis silvestris*. *Meles meles* and as the case may be also *Martes martes* and *Martes foina*; of the even-toed ungulates the red-deer, roe-deer and wild boar are common. Of an interest are the animals perfectly adapted to the conditions underground, as is for example the troglobiot *Mesoniscus graniger*. In rocky holes and caves live the bats *Rhinolophus ferrumequinum* and *Rhinolophus euryale.*

FOREST ASSOCIATIONS

Primeval forest growth gave way in the past to the booming grazing, and shallow soil loosened by grazing cattle was gradually washed away. The extreme conditions are best tolerated by bushy communities, which we rank among *Corneto-Quercetum*. Of the original woody species we can find *Quercus pubescens*, *Q. petraea*, *Q. cerris*, *Fraxinus ornus*, *Cerasus mahaleb*, *Acer tataricum*. Bushy character vegetation obtains thanks to *Cornus mas*, *Prunus spinosa*, *Crataegus monogyna*, *C. laevigata*, *Euonymus verrucosus*, *Spiraea media* and others. In some places *Staphylea pinnata* occurs. Significant components of the herbaceous synusion are the species of steppe and forest steppe character. Of grasses the sedges *Carex humilis* and *C. michelii* and *Festuca valesiaca* are very well represented.

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Metka Petrič

INTERNATIONAL SYMPOSIUM "KARST-FRACTURED AQUIFERS - VULNERABILITY AND SUSTAINABILITY" (KATOWICE - USTROŃ, POLAND)

From 10th to 14th June, 1996 the international symposium "Karst-Fractured Aquifers - Vulnerability and Sustainability" was held at the health resort Ustroń by Katowice in Poland. It was organized by the Department of Hydrogeology and Engineering Geology of the University of Silesia in Sosnowiec; it was held under the patronage of the International Association of Hydrogeologists (IAH). There were 61 participants from 13 countries (China, Croatia, France, Germany, Ireland, Italy, Israel, Poland, Russia, Slowakia, Slovenia, Switzerland and the USA). The Slovenian coloures were represented by me, Metka Petrič from the Karst Research Institute ZRC SAZU in Postojna.

The symposium started with the opening ceremony on June 10th, 1996, in the morning. The participants were greeted by introductory speeches by the chairman of Scientific Committee prof. dr. Andrzej Rožkowski, by the rector of the Silesian University prof. dr. Andrzej Jankowski, by the representative of the Ministry of Environment Protection, Natural Resources and Forestry dr. Jacek H. Jezierski, by the president of IAH prof. dr. John Moore, and by the president of the Karst Commission at IAH prof. dr. Heinz Hötzl. After the official introduction the professional part of the symposium began.

The presentations were divided into five topical themes. The first one was dedicated to the groundwater protection in karst areas, and to systems and methods of preserving the karst aquifers in various countries. The second theme treated the human impact on the karst environment. The authors tried to answer to the question what the consequences of the intensive exploitation of underground water on the state of aquifer systems are - from the qualitative as well as from the quantitative point of view. Discourses in the session on groundwater management in karst areas presented practical researches how to solve the problems of water supply. Also with these speeches a special attention was given to the protection of water sources against pollution. More general problems regarding karst hydrogeology were included in the fourth group. There were shown characteristics and specialities of numerous karst aquifer systems in different parts of the world. In the fifth group research methods in karst-fractured aquifers were spoken about. Among others the use of hydraulic and geophysical methods in karst hydrogeology was shown. I spoke about the study of the rainfall - runoff relations in the experimental karst basin.

The organizer offered also the opportunity to illustrate the themes with posters. So on six panneaus there were primarily presented the pollution problems and the quality of underground water in Upper Silesia. The afternoon of the 11th June was filled locally, too. For this day was preserved for the visit of the health resort complex at Ustroń. The hosts informed us first with the basic hydrogeological characteristics of the area, then with the methods of draining the used medicinal salty water back into the aquifer. Eventually we visited the most important resort premises, and the computer guided pumping station for the underground water.

During the symposium there were held various meetings of the Karst Commission at IAH. Most of the time was dedicated to the preparation of a new book on the karst hydrogeology, one of the next IAH publications.

The second part of the programme was reserved for excursions. On Wednesday, 12th June there were two all day long excursions. The main destination of the first one was the lead and zinc mine Olkusz, lying 30 km east of Katowice. I took part, however, in the excursion to the territory of Tarnowskie Gry in the northern part of the Upper Silesia. We first visited the lead, zinc and silver mine where the ore was excavated from the 12th to the beginning of the 20th century. The consequence of the years long mining is a dense network of galleries, shafts and drainage system in the Middle Triassic carbonate rocks. Very interesting are also the hydrogeological conditions, for two of the aquifer zones are separated by an intermediate layer of poorly permeable rocks. The upper aquifer part is equipped with horizontal drainages which drain water to the near river, while the water from the lower zone is pumped. We went to see also Staszic, the oldest of the pumping stations in Upper Silesia. Here a relatively pure water is pumped. But a much greater ecological problem is represented by the outflows of 65 coal mines in the area. About 500 m^3 of waste water from these mines flows into rivers every minute. Because of that the rivers are very polluted. Another unpleasant consequence of the years long mining is the subsidence of the surface above the mines. According to the quantity of the excavated material the surface subsides from some centimetres to one meter a year.

The afternoon excursion of 13th June took us to the hilly area Beskidy, which is built with Cretaceous and Tertiary flysch sediments. We visited the spring area of two rivers, Visla and Sola which together with their tributaries represent the main source of drinking water for the provinces Katowice and Bielsko-Biala. Of a really great interest were the wells of salt water with a high concentration of Na, Cl, J and Br in the surrounding of the town Sol. In the evening the symposium was officially closed. The next morning I took part in the post-congress excursion to Krakow and to the salt mine Wieliczka.

The given lectures have been collected in the final publication. In the introductory part of the book it is written that the purpose of the symposium was to offer the participants possibilities to exchange opinions and ideas on the characteristics of the karst-fractured aquifers, the presentation of their studies, and their protection.The majority of the participants would certainly agree that this purpose was completely achieved.

Nadja Zupan Hajna

INTERNATIONAL CONFERENCE “CLIMATE CHANGE: THE KARST RECORD”, BERGEN

At the Geology Department, University of Bergen, Norway a conference on climatic changes recorded in karst has taken place between August 1 and 4 coorganized by Karst Waters Institute, West Virginia, USA. The main topic discussed there was the importance of absolute dating of flowstone by 234U isotope and definition of paleoclimatic conditions during the speleothem growth on the base of oxygen and carbon isotopes.

The Conference was attended by 72 karst researchers from all over the world; they presented their work by lectures or posters. There were 48 lectures altogether, 12 on the first day, 19 on the second and 17 on the third and 22 posters. The introductory papers were given by distinguished karst scholars, Prof. D. C. Ford: Dating Cave Deposits and Prof. H.P. Schwarz: Paleoclimate inferences from stable isotopic studies of speleothem, both from McMaster University, Hamilton, Canada and Prof. W. Dreybrodt: Chemical kinetics, speleothem growth and climate from University of Bremen, Germany.

From Slovenia three representatives were present, two of them from the Karst Research Institute ZRC SAZU. Andrej Mihevc gave a lecture entitled Pleistocene to Holocene climatic record in speleothems on the SE edge of the Kras plateau in Slovenia. My first lecture was The valuation of absolute speleothems dating from Slovenia and the second, with co-author Andrej Kranjc Paleogeomorphologically interesting detail from the Ist Island.

The first day the lectures covered stratigraphy and chronology of flowstone from a theoretical point, mostly dealing with U/Th datations by mass spectrometry, luminiscence and speleothem growth. The second day morning dealt with stable isotopes and paleoclimatic records during the speleothem growth, stratigraphy of cave sediments and paleomagnetism. The afternoon was dedicated to cave biology and paleontology. The third day the lectures covered regional karst researches and analyses of cave sediments.

From July 30 to 31 an excursion - Geomorphology and Quaternary geology of inner part of Sogne fiord, south Norway was organized. In two days we visited typical landscape consisting of fiords and high plateaus.

The second day of the excursion through the Dummdalen valley, 1080 to 960 m a.s.l., was interesting in particular. In this glacial valley a layer of Cambrian-Ordovician marbles, some metres wide, several times crosses the stream that runs through the valley. At the contact with marbles water sinks, flows underground and reappears at the contact of marbles and shales. In lower part of the valley some shorter active caves developed. The caves have several entrances, they developed in several levels, the main water flow is in flooded passages, the upper levels are dry at low water level and flooded when the water is very high. The second type of caves developed in the slope of the valley where the marble layer reaches the slope's surface. These caves are mostly phreatic tubes cut by younger vadose chimneys on many places. The caves in the Dummdalen valley are the largest karst caves of the southern Norway.

Rajko Pavlovec

MONOGRAFIJA O POMEMBNOSTI LEZIK PRI NASTAJANJU KRASA

Mladi raziskovalec z Inštituta za raziskovanje krasa ZRC SAZU dr. Martin Knez je napisal obsežno delo o problematiki nastajanja kraških pojavov (**Vpliv lezik na razvoj kraških jam. Primer Velike Doline, Škocjanske jame.** - Zbirka ZRC, 14, 186 str., 81 slik, 18 preglednic, 26 tabel slik, ISBN 961-6182-12-9). Vprašanje nastajanja kraških jam je že dolgo živo. Velik del speleologov in morda še bolj geologov se je navduševal nad tektonskimi pojavi, ob katerih naj bi voda začela prodirati v globino. Drugi so iskali vzrok v različnosti karbonatnih kamnin. Tretji so videli kraške pojave tesno povezane z lezikami, vendar takšna razlaga doslej ni bila dovolj podprta z dokazi v naravi. Martin Knez se je lotil prav tega, pri čemer je kritično upošteval še druge faktorje. To pojasnjuje že kar v uvodu, ko pravi: "Osnovno vprašanje, na katerega sem skušal odgovoriti, je izšlo iz popolnoma laičnega spoznanja v Veliki Dolini v Škocjanskih jamah. Vsak pozornejši obiskovalec namreč opazi, da se jamski rovi, njihovi fragmenti in drugi sledovi podzemnega zakrasevanja ne pojavljajo poljubno razmetani v stenah, ampak so zbrani vzdolž majhnega števila lezik. Ker podobna skladanja opazimo tudi v nekaterih jamah Notranjske, je bilo vprašanje, ali gre pri tem za širšo zakonitost, in kje so njene korenine, samoumevno".

Marsikdo se bo ob branju Knezove monografije vprašal, zakaj se je podal prav na področje Škocjanskih jam. To sam pojasnjuje. Po eni strani so kljub svoji slavi Škocjanske jame v geološkem smislu relativno slabo raziskane. V njih je plastnatost izrazita, bilo je pričakovati zanimiva opazovanja prav v zvezi z lezikami in njihovem pomenu za nastajanje krasa. Škocjanske jame ima M. Knez tudi za tipičen vzorčni model kraških pojavov na matičnem Krasu.

Razlog, da se je M. Knez odločil prav za Škocjanske jame in predvsem udornico Veliko Dolino, pa je bil tudi preučevanje tektonskih in litoloških podatkov, speleografija Škocjanskih jam in okolice, opazovanja lezik in hidrografskih razmer danes in v preteklosti. Knez loči lezike, ki so bile deformirane ob prelomih, gubah ali medplastnem zdrsu, in lezike, ki niso bile deformirane, vendar pa so neprevodne za vodo. Pri tem je M. Knez prišel do mnogih drobnih, vendar zanimivih podatkov in razlag. Osnova nastajanja kraškega prostora je ta, da voda skozenj prenika, da kamnino topi, raztopino odnaša, a s tem ne zamaši vodnih poti. Ob upoštevanju številnih podatkov iz okolice Škocjanskih jam je prišel do številke, da je malo več kot en jamski vhod na kvadratni kilometer. Največ kraških pojavov je v turonijskih apnencih. V vremskih plasteh ni veliko kraških pojavov. To razlaga s specifično sedimentacijo v času nastajanja vremskih plasti.

Martin Knez nadalje razpravlja o oblikovanju udornic, kar je zelo kompleksen pojav. Razni avtorji ga sicer malo različno razlagajo, vendar je vzroke za nastanek udornic gotovo treba iskati v tektonskih elementih, v poškodovanosti kamnin (v razpoklinskih conah), v debelini plasti pa celo v krioklastičnih pojavih in drugem.

Kot dokazno gradivo in kot osnovo svojih izvajanj je M. Knez pregledal več sto vzorcev in mikroskopskih preparatov. Najbolj pomembne dele opazovanega terena je prikazal tudi v geoloških stolpcih, v katerih so poleg osnovnega profila podatki o plastovnih značilnostih in teksturah, o fosilih, o kalcitnih žilah in poroznosti. Takšnih stolpcev je osem. Navedene so tudi podrobnosti o pogostosti ortokemov, alokemov, raznih fosilov, bioklastov in druge, kar bi v kakršnikoli obliki pomagalo pri reševanju osnovnega vprašanja nastajanja krasa. Posebej zanimive so seveda razpoke in kalcitne žile, zlasti v neposredni okolici nosilnih lezik. Tako je Knez poimenoval lezike, ki so bistveno pripomogle k nastanku freatičnih kanalov. Kakor mnoge druge, je tudi te Knez prikazal na številnih diagramih. Navaja tudi rezultate meritev množine kalcijevega karbonata. Vsi ti in še številni drugi podatki in opazovanja so ga pripeljali do zelo prepričljivih sklepov o nastajanju kraških pojavov. Takole pravi: "Samoumevna se mi zdi misel, da je vendar že davno dokazano, da se jame razvijajo tako ob tektonskih deformacijah kot tudi po lezikah. Takšno mnenje povzema neko neopredeljeno, navidezno predznanje in je verjetno prav zato dolgo odvračalo pozornost speleologov od nekaterih postavk. Šele detaljne raziskave postrežejo z na prvi pogled malenkostnimi ugotovitvami, ki pa vendarle prinašajo preciznejše in predvsem konkretnejše odgovore". Iz tega izvaja M. Knez trditev, da osnovni podatki in zapažanja niso na makroskopskem nivoju, ampak v podrobnih raziskavah. Pravi, da so se začetni kraški procesi odvijali na mikroskopski ravni, čeprav so pozneje lahko nastali ogromni podzemni prostori.

Na koncu zelo jasno postavlja trditev, da bo treba v bodoče makrotektonsko in mikrogeološko znanje sestavljati, združevati in dopolnjevati. V preteklosti so razmišljali predvsem o značaju kamnine in morda še o zdrobljenih conah. Martin Knez pravilno ugotavlja, da so doslej premalo pozornosti posvečali medplastnim zdrsom ali poškodovanim lezikam. Prav tako trdi, da se na začetku razvoja krasa matične kamnine in lezike obnašajo različno.

Velika vrednost Knezovega dela je v tem, da se je naslanjal skoraj izključno na geološke podatke, da je vse natančno preveril in preizkusil, in da skoraj ni golega vizuelnega opisovanja vidnih pojavov. Knez sam pravi, da je v svoja razmišljanja vključil geološki čas od nastanka kamnine do prvega kopnega, do tektonskih deformacij in današnjega površja. Takšen pogled je izredno kompleksen in je zagotovo pripeljal do pomembnih rezultatov.

Martin Knez je naredil pionirsko delo v pogledu nastajanja krasa. To, kar so nekateri teoretično razpravljali ali slutili, je potrdil in dopolnil s številnimi dokazi. Knezova monografija ni samo osnovno delo za vse bodoče tovrstne raziskave, ampak je izredno dobro dokumentirana s podatki, diagrami, slikovnim gradivom, tablami in drugim, tako da je to resno znanstveno delo. Obsežna literatura je imeniten pripomoček za podobne študije.

Ob koncu lahko rečemo, da smo monografije dr. Martina Kneza izredno veseli zaradi njene bogate in nove vsebine. Še posebej smo veseli zato, ker prihaja ta monografija iz naših krajev, iz rojstne dežele krasa.

A MONOGRAPH RELATED TO THE INFLUENCE OF BEDDING-PLANES ON KARST ORIGIN

Dr. Martin Knez, a researcher from the Karst Research Institute ZRC SAZU wrote a comprehensive work dealing with karst phenomena origin (**The influence of bedding-planes on development of karst caves.** An example of Velika Dolina, Škocjanske Jame.- Zbirka ZRC, 1996, 14, 186 p. 81 figs. 18 diagrams, 26 tables of figures, ISBN 961-6182-12-9). The question of cave origin is actual for a long time. An important number of speleologists, maybe geologists even more, argued for tectonic phenomena along which the water was supposed to infiltrate into depth. Others searched the reasons in variability of carbonate rocks. The third found karst phenomena tightly connected with bedding-planes but such an explanation was not enough supported by the evidences in nature. Martin Knez set to study this last hypothesis but he critically considered all other factors. He explains it in the introduction already when he says: "The basic question I wished to answer derived from an entirely laymen recognition in the Velika Dolina in Škocjanske Jame. Each thoughtful visitor perceives that cave passages, or parts of them and other traces of the underground karstification do not appear scattered on the walls at random but they are gathered along small number of bedding-planes. As similar accordance may be found in other caves of the Notranjska karst the question arose whether it is a general lawfulness and, obviously, what is its reason".

Reading the book of Knez someone may ask why he set to work at Škocjanske Jame. He explains it himself. On one hand Škocjanske Jame were relatively poorly studied from the geological point of view in spite of their fame. The bedding there is well pronounced and it was expected that the observations would give interesting results related to bedding-planes and their importance for karst development. Also M. Knez considers Škocjanske Jame as a typical model of karst phenomena in the classical Karst.

Deciding Škocjanske jame and for the collapse doline Velika Dolina in particular led M. Knez to study tectonic and lithological data, speleography of Škocjanske Jame and vicinity, observation of bedding-planes and hydrographical properties today and in past. Knez differs between bedding-planes that were distorted along the faults, folds or interbedded slides and bedding-planes that were not distorted and are impervious for water. By such a way Knez achieved several tiny, yet very interesting data and explanations. The basic feature of karst means that water percolates through the rocks, dissolves the rocks and transports the solution without blocking the water conduits. Considering numerous data around Škocjanske Jame he calculated that there is slightly more than one cave entrance per square kilometre. Most of karst phenomena occur in Turonian limestones. In the Vreme beds there are not many karst phenomena. This may be explained by specific sedimentation during the development of the Vreme beds.

In continuation Martin Knez discusses the formation of collapse dolines which is a very complex phenomenon. Various authors explain it in different ways, as reason for a collapse doline origin must be searched, without doubt, in tectonic elements, in lithology (fissure zones), in thickness of beds and even in cryoclastic occurrences and in other.

Martin Knez examined more hundred samples and microscopic thin-sections to argument and to found his conclusions. The more important parts of studied terrain he presented in a geological column which displays basic profile data about bedding properties and textures, fossils, calcite veins and porosity. There are eight such columns. He also quotes details about the frequency of orthochems, alochems, various fossils, bioclasts and others that might in any form help to solve the basic question of karst origin. Fissures and calcite veins in immediate vicinity of formative bedding-planes are particularly interesting. Knez named formative bedding-planes those bedding-planes that essentially helped to initiate phreatic channels. These also are shown in numerous diagrams. He also cites the measurement results about the level of calcium carbonate. All these and numerous other data and observations gave very persuasive conclusions related to karst phenomena origin. These are his words: "I find obvious a thought that it was from ever proved that caves develop along tectonic deformations and also along bedding-planes. Such an opinion implies undefined, apparent knowledge and probably this is the reason that the attention of speleologists was for such a long time diverted from some facts. Only detailed researches that offer by first sight trifle facts, can yield more precise and mostly more concrete answers." Thus M. Knez concludes that basic data and observations do not exist on macroscopic level but in detailed researches. He says that the initial karst processes started to develop on microscopic level although later huge underground spaces may derive.

At the end he clearly sets up an affirmation that in future macrotectonical and microgeological knowledge must be combined, associated and complemented. In past the character of the rocks and maybe broken zones were in foreground. Martin Knez correctly states that in past too little attention was focused on interbedded slides or damaged bedding-planes. Also he claims that at the very beginning of karst origin parent rock and bedding-planes acted differently.

A great value of Knez work consists in fact that he almost entirely used geological data, that he precisely checked them and that there is almost none pure visual description of phenomena. Knez himself says that he included into his research geological time since the origin of the rock to the appearance of land, to tectonical deformations and to actual surface. Such view is very complex and surely leads to important results.

The research of Martin Knez means a pioneer work related to karst origin. He confirmed and complemented by numerous proofs the theoretical ideas or premonitions of others. Knez's monograph is not only a basic work for all the researches of the kind to come but also very well documented work with data, diagrams, figures, tables and other; it is a serious scientific work. An exhaustive references list is an additional resource for similar studies in future.

At the end one may say that we are very glad that this monograph was published due to its rich and new content. In particular we are glad that this work comes from our places, from native land of the classical Karst.

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