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SLOVENSKA AKADEMIJA ZNANOSTI IN UMETNOSTI
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VSEBINA

HALF A CENTURY OF ACTA CARSOLOGICA: FROM SLOVENE KARST TO GENERAL KARSTOLOGY

I have in hands some old issues from 1970 to 1980 of Journal published by the Karst Research Institute ZRC SAZU and I can tell you that this is a highly scientific journal since its first number but I see also transformations and editorial progress achieved by Acta carsologica.

In the first two decades the Journal essentially published works concerned with karst of south-western Slovenia giving us a comprehensive knowledge of certain areas and opening new problems. Let me mention some monograph's contributions of I. Gams about the Cerknica polje (1970), F. Habe about the underground world of Predjama (1970), A. Kranjc about the Kočevje polje (1972) and R. Gospodarič about the sediments in Križna jama (1974) and cave sediments of Taborska (Županova) jama (1987) and articles of P. Habič about Cerknica lake (1974), Mrzlek karst spring (1982), geomorphology of Suha Krajina (1988). These works and many others … bear witness about the activity of researchers of Postojna and we used them as the reference literature related to Slovene karst.

A turning point occurred about 1990. Because of international meetings organized by or together with the Karst Research Institute of Postojna Acta carsologica opened to international contributors; geographical field of researches was considerably enlarged and important thematic issues were published. We, the French, were the first to take advantage with the proceedings of the French-Slovene Round Table « Le Karst des moyennes montagnes méditerranéennes » (24-27 juin 1991 – coinciding with the independence of Slovenia) published in Acta carsologica XX, 1991. Among the consecutive thematic issues about the international meetings let us mention the proceedings of « *Man on karst* » by I. Gams at Postojna in 1993 (XXIV, 1995, 591 p.), and *Alcadi 96* consecrated to history of speleology (XXVI/2, 1997, 508 p.) and symposium in Ljubljana in 1999 « *Groundwater pollution in Karst* » (29/1, 2000). Annual meetings of International Karstological School, the first one being in Lipica in 1993 organized by the Karst Research Institute provided excellent thematic issues: specially interesting is the one of the 10th Classical Karst (31/3, 2002) giving new methods about the paleokarst studies and also the 11th with prevailing topic about the karst terminology (32/2, 2003). Let us cite also 33/2, 2004 oriented towards new researches of Dinaric karst, to problems of dating and vulnerability of karst systems.

Referring to the last published volumes one can see all the variety of contributions. A lot of other authors joined Slovene and nearby European authors. It is a plea-

UN DEMI-SIÈCLE D'ACTA CARSOLOGICA : DU KRAS SLOVÈNE À LA KARSTOLOGIE GÉNÉRALE.

Ayant eu en mains quelques numéros des années 1970-80 de la Revue éditée par l'*Inštitut za raziskovanje krasa,* dans le cadre des publications de l'Académie des Sciences et Arts de Slovénie, je peux ici témoigner de son grand intérêt scientifique dès les premiers numéros et des transformations et progrès éditoriaux d'*Acta carsologica.*

Dans les deux premières décades, la Revue a publié essentiellement des travaux sur les karsts du Sud-Ouest de la Slovénie, en nous donnant une connaissance approfondie de certains secteurs, et en posant les éléments de problématiques nouvelles. Citons parmi les monographies celle d'I. Gams sur le poljé de Cerknica (1970), de F. Habe sur le monde souterrain de Predjama (1970), d'A. Kranjc sur le poljé de Kočevje (1972), de R. Gospodarič sur les sédiments dans la Križna jama (1974) et les remplissages de la grotte de Tabor (1987) et les articles de P. Habič sur le lac de Cerknica (1974), la source Mrzlek (1982), la géomorphologie de la Suha Krajna (1988). Ces travaux, et tant d'autres…, témoignant de l'activité des chercheurs de Postojna, nous servent de référence sur les karsts slovènes.

Un tournant a été pris vers 1990. Grâce aux rencontres internationales, organisées par ou avec l'Institut de Postojna, *Acta carsologica* s'est ouverte aux contributeurs extra-slovènes; le champ géographique d'investigation s'est considérablement élargi, et des numéros thématiques importants en sont issus. Nous français, avions été les premiers à en bénéficier, avec la publication des actes de la Table-ronde franco-slovène « Le Karst des moyennes montagnes méditerranéennes » (24-27 juin 1991 – coïncidant avec l'Indépendance de la Slovénie…), publiés dans *Acta carsologica* XX, 1991. Parmi les numéros thématiques consécutifs à des rencontres internationales, on retiendra celui des actes du symposium « *Man on karst* » dirigé par I. Gams à Postojna en 1993 (XXIV, 1995, 591 p.), celui *d'Alcadi 96* consacré à l'histoire de la Spéléologie (XXVI/2 , 1997, 508 p.) et celui du symposium de Ljubljana en 1999 « *Groundwater pollution in Karst* » (29/1, 2000). Les réunions annuelles de l'*International Karstological School*, à partir de celle de Lipica en 1993, programmées par l'Institut de Postojna, ont donné lieu à de très bons numéros thématiques: celui consécutif à la 10ème « *Classical Karst* » (31/3, 2002) est particulièrement intéressant sur les méthodes nouvelles dans l'étude des paléokarsts, de même celui la 11ème, dont le thème directeur était la terminologie karstique (32/2, 2003). Citons aussi le n° 33/2, 2004, particulièrement orienté sur les recherches nouvelles dans les karsts dinariques, sure for a geographer to find in every new volume recent information about the Alpine and Dinaric regions and also texts about less known karsts, as for example Bulgaria, Turkey, Iran and even more distant (China, Cuba). Thus, progressively enriched by different contributions about many research topics, Acta carsologica succeeded to attract international audience in karstological domain, scientific speleology, and history of underground explorations. Even more, certain articles treat the problems of applied research, such as protection of sites and karst waters, very important topics for Slovenia, but also very useful for readers…

With increase in number of authors and research topics the thickness of volumes increased also. They are better and better edited, figures and photographs in colour: pleasure at reading is combined with scientific interest. It is difficult to express our gratitude and felicitations to A. Kranjc and his colleagues from the Karst Research Institute ZRC SAZU, to workers and responsibles for this publication over the years and our thanks go to the Slovene Academy of Sciences and Arts for sponsoring and financing. Our wish is that this journal, edited by our Slovene friends thrives in future.

Jean NICOD

les problèmes de datation et la vulnérabilité des systèmes karstiques.

En se référant aux derniers numéros parus, on voit toute la variété des contributions. Aux auteurs slovènes et européens proches se sont joint bien d'autres. C'est un plaisir pour un géographe de trouver dans chaque tome des informations nouvelles sur les régions alpines et dinariques, mais aussi des textes sur des karsts moins connus, comme ceux de Bulgarie, de Turquie et d'Iran ou plus lointains (Chine, Cuba…). Ainsi, progressivement enrichie de contributions variées sur de nombreux thèmes de recherche, *Acta carsologica* a pu acquérir une audience internationale dans les domaines de la karstologie, de la spéléologie scientifique et de l'histoire de l'exploration du monde souterrain. De plus, divers articles traitent de problèmes de recherche appliquée, comme la protection des sites et des eaux karstiques, thèmes très important pour la Slovénie, mais ailleurs aussi de grande utilité…

Avec la progression du nombre des auteurs et des champs de recherche l'épaisseur des volumes s'est accrue… Ils sont de mieux en mieux édités, avec des figures et des photos en couleurs: l'agrément de la lecture se conjugue avec leur intérêt scientifique. On ne saurait trop mesurer notre gratitude et nos félicitations à A. Kranjc et à tous ses Collègues de l' *Inštitut za raziskovanje krasa ZRC SAZU,* artisans et responsables de cette publication au cours des ans, et nos remerciements à l'Académie Slovène des Sciences et des Arts d'en avoir assuré le patronage et le financement. Et nous ne pouvons que souhaiter que l'audience de cette revue éditée par nos amis slovènes s'accroisse encore!

Jean NICOD

COBISS: 1.01

TECTONIC INCEPTION IN CALEDONIDE MARBLES
TEKTONSKA INCEPCIJA V KALEDONSKIH MARMORJIH

Trevor FAULKNER[1]

Abstract: UDC: 551.24:551.44(48)
Trevor Faulkner: Tectonic inception in Caledonide marbles
A fundamental difference between caves in sedimentary limestones and those formed in a repeatedly-glaciated 40000 km^2 region in central Scandinavia that contains over 1000 individual marble outcrops and has nearly 1000 recorded karst caves is the metamorphic grade of the karst bedrock and its negligible primary porosity. Allied to this is the fine-scale foliation and consequent lack of 'bedding-plane' partings. Indeed, the foliation is commonly vertical in the western part of the study area, where sub-horizontal openings must be along joints or other fractures. The deepest cave is only 180 m deep, despite outcrop vertical ranges reaching over 900 m. Caves tend to cluster together and are positioned randomly in a vertical dimension, whilst commonly remaining within 50 m of the overlying surface. Additionally, despite some stripe karst outcrops being several tens of kilometres in length, there are no regional scale caves, and karst hydrological system distances are invariably shorter than 3.5 km. Because the caves are relatively short and epigean and there is a complete absence of long, hypogean, cave systems, speleogenesis by the (chemical) inception horizon hypothesis is unlikely.
A tectonic inception model is derived that proposes that it is only open fracture routes that could provide the opportunity for dissolution and enlargement into cave passages in the Caledonide marbles. It is hypothesised that the dimensions of these fractures are related to the magnitude, and perhaps to the frequency, of local earthquakes and commonly-small tectonic movements that arose mainly from the isostatic rebound that accompanied deglaciation at the end of each major Pleistocene glacial. The openings formed along *inception surfaces* between the limestone and adjacent aquicludes and at *inception fractures* that are entirely within the limestone and are commonly (though not universally) parallel to, or orthogonal to, the foliation. The model builds on reports of a 'partially detached' thin upper crustal layer in similar settings in Scotland and is supported by observations of later neotectonic movements, as indicated by sharp edges and slickensides in most present relict cave passages and sporadically on the surface.
Keywords: Caledonide, epigean, foliation, ice margin, inception fracture, inception surface, marble, near surface aquifer, neotectonics, seismicity, tectonic inception, stripe karst, Weichselian.

Izvleček: UDC: 551.24:551.44(48)
Trevor Faulkner: Tektonska incepcija v kaledonskih marmorjih
V centralni Skandinaviji je več kot tisoč izdankov marmorja v katerih je znanih preko tisoč jam. Razlika med temi jamami in tistimi v apnencih, je pogojena s procesi metamorfoze in zanemarljivo primarno poroznostjo prvih. S tem je povezano drobno plastenje (foliacija) in posledična odsotnost lezik. Najgloblja jama je globoka 180 m, kljub temu, da vertikalni razpon izdankov znaša do 900 m. Jame največkrat najdemo v skupinah in so v vertikalnem merilu precej naključno porazdeljene, pri čemer jih redko najdemo več kot 50 m pod površjem. Kljub temu, da so nekateri izdanki pasastega krasa dolgi več deset kilometrov, zelo dolgih jam ne poznamo, kraški hidrološki sistemi pa ne presegajo dolžine 3.5 km. Ker so jame kratke in blizu površja, je kemijska incepcija manj verjetna. Zato predlagam model tektonske incepcije, ki predvideva, da so jame v kaledonskih marmorjih nastale zgolj vzdolž sistemov odprtih razpok, pri čemer je dimenzija in frekvenca teh razpok povezana z magnitude tektonskih premikov, ki so nastali kot posledica izostatičnega uravnoteženja ob umikih ledenikov po ledenih dobah. Sistemi takih razpok so nastajali vzdolž incepcijskih površin med marmorji in neprepustnimi plastmi in vzdolž incepcijskih razpok v marmorjih, ki so vzporedne ali pravokotne s plastenjem. Model gradim tudi na poročilih o delno odcepljenem tankem vrhnjem delu skorje v podobnih okoljih na Škotskem. Model podpirajo tudi opažanja kasnejših neotektonskih premikov, na katere kažejo ostri robovi in tektonska zrcala v jamah in na površju.
Ključne besede: Kaledonidi, plastenje, rob ledenikov, incepcijska razpoka, incepcijska površina, marmor, plitvi vodonosnik, neotektonika, seizmičnost, tektonska incepcija, pasasti kras, Weichelij.

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INTRODUCTION

Central Scandinavia is a repeatedly-glaciated 40000 km^2 region that contains over 1000 individual Caledonide marble outcrops and over 1000 karst caves with a total passage length >72 km, within an area about the size of Switzerland (Fig. 1). A factual review of data assembled into karst and cave databases (Faulkner, 2001 and 2005a) revealed that cave development has been predominantly phreatic, so that, commonly, just a single vadose streamway underlies upper-level relict phreatic passages with few vadose elements, creating an *upside-down* morphology. Recharge to the karst is primarily allogenic and discharge commonly remains unsaturated with calcite; autogenic recharge is relatively insignificant, mainly occurring during the spring snowmelt. These caves have their own morphological style, recognisable right across the area, which differentiates them from caves formed in 'classical' karsts in sedimentary limestones. A key question to address is "Why do these caves exist at all?"

THE INCEPTION PROBLEM

The Inception Horizon Hypothesis (IHH; Lowe, 1992; Lowe and Gunn, 1997) proposed that the initiation of proto-conduits occurs as a syngenetic cave formational process during diagenesis. The long, slow, *non-karstic*, inception phase is driven by capillarity, earth tides or ionic diffusion at great depth and over great distances *within stratigraphical partings* or *adjacent porous or fractured rocks*. Eventually, chemical dissolution increases conduit sizes to explorable dimensions. How does this hypothesis stand in relation to the karsts and caves of the study area?

LACK OF PRIMARY POROSITY

Most of the high (up to amphibolite) -grade metalimestones of the study area exhibit little memory of their original diagenesis, after their subduction and metamorphism to marble at elevated temperatures and pressures: any proto-conduits formed syngenetically during diagenesis were closed as the rock experienced chemical and physical changes in lithology. The recrystallisation to metacalcite produced a rock with a fine-scale foliation and a primary porosity that can be regarded as negligible, even over the long timescales available for 'conventional' inception. The same applies to any mica schist, amphibolite, granite or gneiss lying adjacent to the marble: these rocks could not have sufficient primary porosity to act as aquifers carrying water to the limestone surface.

LACK OF STRATIGRAPHICAL HORIZONS

The foliation is commonly vertical in the western Helgeland Nappe Complex (HNC; Fig. 1), but caves in such vertical stripe karst (VSK; foliation dip 81–90^o) commonly display morphologies similar to those in horizontally-bedded limestones, with many horizontal passages orthogonal to the foliation (Faulkner, 2005a), despite the lack of inception horizons to guide their formation along particular bedding plane partings. There are also no consistent systems of sills or other intrusions to act as inception horizons, so that the horizontal openings must be along joints or other fractures.

LACK OF REGIONAL-SCALE SYSTEMS

The IHH suggests that inception takes place over extremely long timescales, at great depths and over great distances. There is no evidence that such a mechanism has taken place in the study area, despite some of the *'stripe karst'* outcrops exceeding 50 km in length. There are no regional-scale caves; there are no known allogenic or autogenic sink-to-rising hydrogeological drainage systems longer than the 3.5 km that occurs at Vallerdal on the border between Norway and Sweden; and there is no evidence of very deep cavities or wells in the metacarbonates. The steep foliation and metamorphic history have left many completely separate stripe karsts. Their contained caves are, by necessity, commonly short (mean length = 85 m) and completely unrelated to each other internally, even if proximate in the field, so that regional-scale inception is not possible.

EXISTENCE OF SHALLOW SYSTEMS

Despite the large vertical range (VR) of some of the metalimestone outcrops (up to 956 m), the deepest cave is only 180 m deep, and only four others are more than 100 m deep. The mean cave VR is only 8.8 m and it rarely exceeds 15% of the local outcrop VR. Thus, the caves are commonly extremely epigean and there is a total absence of long, hypogean, cave systems. It is self-evident when visiting such systems (e.g. a short shallow 'through cave' that carries a stream along a vadose passage from one

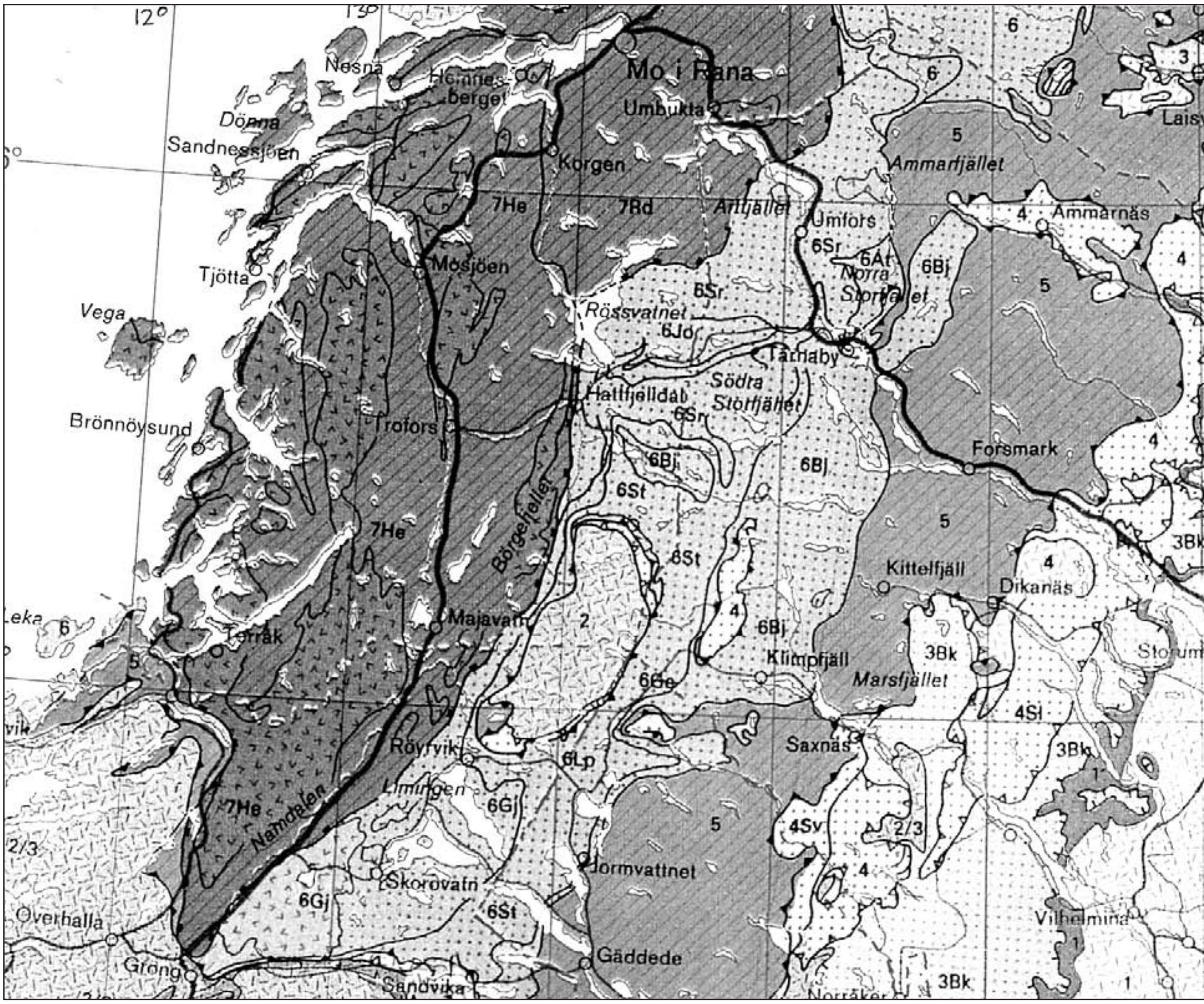

Fig. 1: Tectono-stratigraphic map of central Scandinavia, from Gee and Sturt (1985). The numbers indicate the area's various allochthons and nappes. Most nappes contain metacarbonate outcrops that are commonly aligned N–S and decrease in size (along with a common reduction in metamorphic grade) in an easterly direction. Caves are only recorded in metalimestone outcrops in the Uppermost Allochthon (7; i.e. in the Helgeland Nappe Complex, HNC and the Rødingsfjell Nappe Complex, RNC) and in the Køli Nappes of the Upper Allochthon (6). Small marble outcrops occur in the Seve Nappes of the Upper Allochthon (5) and in the Lower Allochthon (3), without recorded caves. The Middle Allochthon (4) does not contain metacarbonates.

entrance to another) that such passages have no relationship to any deeper, regional-scale, hydrogeology, even if it existed. Whereas it could perhaps be considered as a possibility that *all* such short and shallow caves are the lowest remnants of much longer systems formed deep below landscapes that have since been eroded away, this seems most unlikely as the carbonate outcrops would not have been consistently longer in the past than at present.

THE IMPLAUSIBILITY OF THE IHH TO EXPLAIN INCEPTION IN SOME METALIMESTONES

From the four arguments presented above, the IHH cannot explain the inception of the overwhelming majority of caves in the study area. However, elements of the Hypothesis may explain parts of the inception process in some caves, or groups of caves. For example, inception that is *guided* along sub-horizontal aquicludes within the foliation of marbles in low angle karst (LAK; foliation dip 0–30°) seems likely, as at **Ytterlihullet** in Bryggfjelldal. Similarly, inception along-strike at lithological boundaries within lower grade metacarbonates in angled stripe karst (ASK; foliation dip 31–80°), as at **Korallgrottan** in Sweden, is also feasible. However, even in these examples, another mechanism is needed to explain an initial porosity.

THE TECTONIC SOLUTION

Despite the difficulty in utilising the IHH to explain the inception of the studied caves, these caves exist and their origins must post-date the last phase of metamorphic activity. The consistent style of the caves suggests that a consistent set of processes guides their inception, development and eventual destruction. Two major clues to the inception process were noted in analysing the cave morphologies: externally, their epigean association with the landscape, and internally, the dominance of relict phreatic passages.

ASSOCIATION OF CAVES WITH LANDSCAPE

All cave passages in both VSK and ASK lie within 50 m of the overlying surface. Even in **Ytterlihullet** (LAK), all parts of its streamway are ≤93 m below the surface. Its stream resurges, flows along a short surface valley, and then sinks again in the same limestone outcrop before finally resurging some 200 m above the base of the limestone, and some 300 m above the valley floor. Thus, this cave and most other active caves act in harmony with local hydrology and have an intimate, *epigean*, association with their local landscape. It seems safe to assume that these caves evolved in association with the shaping of their local topography, whose dominating process is the cycle of glaciation and deglaciation that has been repeated many times since the late Tertiary.

RELICT PHREATIC PASSAGES

The absence of relict vadose caves shows that all relict caves in the area developed phreatically, as did nearly all the higher-level abandoned passages in the active caves. However, it is not possible to imagine present circumstances, even during spring melt, when most of these relict caves could be flooded to create phreatic conditions for their enlargement. It *may* be possible to envisage earlier landscapes where these passages were submerged under meteoric conditions, but a much simpler explanation is that these passages enlarged subglacially or during deglaciation phases, when whole valleys could be inundated by glacial meltwater.

THE TECTONIC INCEPTION MODEL

The development (and destruction) of the present suite of karst caves can therefore be addressed by considering the way that glaciation has eroded the land surface, and perhaps provided sufficiently aggressive meltwaters to enlarge passages by dissolution. But these processes cannot explain the actual inception along proto-conduits. Without such openings, glacial meltwaters would not penetrate into high grade metalimestone, even under pressure.

The *Tectonic Inception Model* hypothesises that, through several separate, but commonly related, mechanisms, the stress release arising from the isostatic rebound and surface erosion that accompanied deglaciation at the end of each glacial cycle, plus longer-timescale plate tectonics, caused the formation of tectonic fractures in the upper (epikarstic) part of the limestone (Fig. 2). Thus, openings are created along *inception surfaces* between the limestone and adjacent aquicludes (which may include dolostones), and by *inception fractures* that are entirely within the limestone, but are commonly (though not universally) parallel to, or orthogonal to, the foliation. This model builds on the observations that "*the continuing seismic and tectonic activity* (in similar settings) *in Scotland may be best understood in terms of a 'partially detached' thin upper crustal layer*" (Davenport *et al*., 1989, p 191) and that near-surface limestones are not very ductile and produce brittle fractures during folding, faulting and removal of overburden stress by erosion (e.g. Doré and Jensen, 1996, pp 426–427). It is also assumed that the maximum thickness of permafrost during glaciation is c. 100 m. Rock above this level is subjected to more severe temperature cycling and freeze-thaw processes than rock below it, and is therefore more likely to form inception fractures when triggered by seismicity. The practical expression of these processes was provided by Boulton *et al*. (1996, p 403), who noted from pumping tests that the crystalline basement rocks of the Scandinavian shield (primarily non-carbonates) have "*a surface horizon of fractured bedrock about 100 m thick which has a hydraulic conductivity of* $10^{-6} ms^{-1}$". This provides a *near surface aquifer* that is commonly found in crystalline rocks worldwide (Gustafson and Krasny, 1994).

The idea of tectonic speleogenesis in karst rocks has a precedent, because Riggs *et al.* (1994) proposed this at

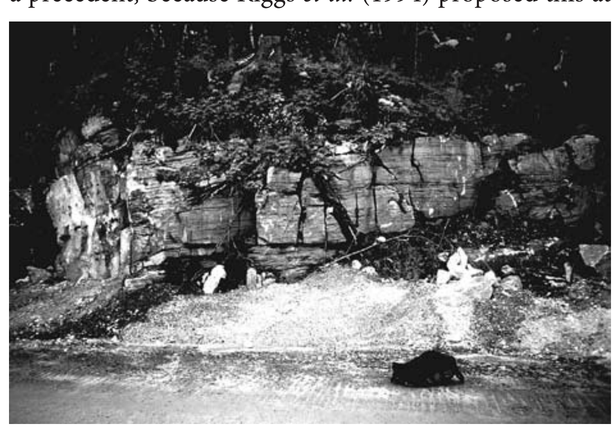

Fig. 2: Marble at Indråsen quarry, Velfjord: Shattered nature of the epikarst in high-quality metalimestone altered by contact metamorphism.

Devils Hole, Nevada, although without subsequent dissolution. The only known paper to discuss the importance of fracturing by stress release in the development of cave passages in sedimentary limestones was by Sasowsky and White (1994), who anticipated some of the processes described herein, but for a non-glacial setting in Tennessee.

THE GLACIAL / TECTONIC CYCLE

Because the tectonically-induced inception fractures are commonly produced at the *end* of each glaciation, there may not always be sufficient time for phreatic passages to enlarge to explorable dimensions during the remaining time of that particular deglaciation. Hence, the cyclic processes of glaciation, deglaciation and tectonic opening combine together to develop cave passages: tectonic inception provides fractures that permit the circulation of meltwaters that can be chemically aggressive even without dissolved CO_2 (Faulkner, 2004a and b; 2005a), both during that deglaciation and during the next glacial and deglacial phases. As the cycle repeats itself, passages near the surface enlarge and become removed by glacial and fluvial erosion (as noted by Isacsson, 1994, at **Korallgrottan**), and new passages form at geologically lower levels.

FORMATION OF TECTONIC FRACTURES

Tectonic inception (and indeed any *inception* hypothesis) is not easy to *prove*. Tectonic fractures may be too narrow to observe visually and may no longer be recognisable after karstic dissolution and enlargements to explorable passages. Thus, the Tectonic Inception Model is supported by several lines of evidence for Caledonide tectonism and fracture formation in the following sections. The *hydrogeology* of fractured rock, including fractured metalimestone, was considered separately by Faulkner (2003 and 2005a).

CALEDONIDE EVIDENCE FOR TECTONIC ACTIVITY

Faulkner (1998) reviewed recent ideas on the importance of tectonic activity to cave development in sedimentary limestones. The idea that tectonism *sensu lato* has influenced karst cave development in Norway has been suggested, or hinted at, by several authors. Thus, Hoel (1906, p 8) raised the possibility that **Aunhattenhullet 1, 2 and 3** and **Langskjellighattengrotta** in Velfjord in the study area were formed by "dislocations". Horn (1947: McGrady translation, 1978, p 135) noted that the Norwegian coastal area at the Arctic Circle is still unstable tectonically, which should favour joint formation, or the widening of old joints. Kirkland (1958) thought that collapsed blocks on the floors of chambers in the Svartisen area could have resulted from movements along faults and from seismic disturbances. Lauritzen (1989a, 1989b and 1991b, p 122) suggested that cave passages in Norway are almost always guided by the line of intersection between two planes (but see section 4). His statistical analysis revealed that commonly shear fractures (faults and shear joints) and less commonly tension fractures are utilised as primary guiding voids for speleogenesis. Onac (1991) noted caves formed by gravitational mass movement near Narvik, and the influence of tectonic faults in guiding subterranean streams.

Randall *et al*. (1988) reported on the hydrogeological framework of the NE Appalachians (USA), a region with a comparable metamorphic Caledonide geology. They noted high hydraulic yields from fractured nonporous bedrock, especially from wells that intersect contacts between different lithologies. Earlier work was quoted that showed that fractures decrease in size and frequency some 50–75 m below the surface. The watertable configuration in uplands nearly replicates the topography throughout the region, so that inter-basin flow systems involving significant flux have not been shown to exist, as in central Scandinavia. Carlsten and Stråhle (2001) reported that open, and partly-open, fissures were found in a borehole at Bodagrottorna in non-carbonate rock on the Swedish Baltic coast at depths at least down to 150 m, in an area that was very active seismically in the early Holocene.

TECTONIC MECHANISMS

Seismic and aseismic tectonic processes that create fractures can arise from several separate mechanisms. The evidence for considerable isostatic uplift during the melting of the 2–3 km-thick Weichselian icesheet is well documented. That part of the evidence for uplift that is associated with caves includes Sjöberg (1981a and b), who discussed 50 elevated caves in east Sweden formed by cobble abrasion at the coast of the Baltic, and Sjöberg (1988) who discussed elevated coastal caves in central Norway. That seismic tectonic activity accompanied the uplift was documented by: Husebye *et al*. (1978); Mörner (1980); Stephansson and Carlsson (1980), who discussed a Caledonian Zone of seismicity; Anderson (1980), who suggested that the maximum number of earthquakes after deglaciation would occur just inland along the coast, especially in regions of large elevation differences perpendicular to the coastline; Sjöberg (1987), who classified Swedish neotectonic cave types as occurring a) in split roches moutonées, b) in collapsed mountain slopes, and c) in sub-horizontally displaced mountain tops, and who postulated that talus caves in Sweden were formed by earthquakes caused by the early and rapid Holocene uplift that Mörner (1979) estimated at 20–50 cma^{-1}; Sjöberg (1996a), who dated the formation of scree and talus caves by a huge tectonic event at 9400–9200a BP; Sjöberg (1996b) and Mörner (2003), who recorded that the Swedish nuclear industry now accepted that Sweden suffered heavy earthquakes immediately after the Weichselian glaciation; Sjöberg (1996c), who listed Swedish Holocene earthquakes with magnitudes from 5–8 and showed how the formation of seismotectonic caves could be dated by studying soft sediment deformation in varved clay, as also discussed by Sjöberg (1999a and b); Kejonen (1997), who described seismotectonic crevice caves in Finland that developed from 12–8 ka BP; and by Mörner (2003) who presented 15 papers to demonstrate that Scandinavia was an area of high seismic activity at the time of deglaciation.

Mörner *et al.* (2000) noted that palaeoseismic events occurred in the Stockholm area about every 20 *varve years* from ~10490 to ~10410a BP, and listed 15 events in Sweden with magnitudes between 6 and >8 from ~12500 to ~1000a BP, some being associated with tsunamis. Because the records came from the whole of Sweden, no region was aseismic during the deglaciation period. The formation of the Bodagrottor talus cave (close to the borehole discussed in section 3.1) by the 'blowing-up' of a roche moutonée occurred at 9663a BP, by the dating of a varve that arose from a synchronous earthquake-generated tsunami that swept across the Baltic sea 33 varve-years after local deglaciation. From the size of the individually moved blocks, this earthquake may have had a magnitude >9–10. A map produced by Mörner *et al.* (2000) shows that each seismic event occurred as the ice margin passed overhead, commonly from west to east during deglaciation. Thus, from all this evidence, it is sensible to suggest that some fractures in the metacarbonates of the Caledonides were caused by surface strain release, or by deeper seismic activity, associated with the fast, early Holocene, uplift, at a time roughly coincident with the passing of the ice margin.

The uplift was not necessarily uniform, even at a local scale. Differential uplifts caused crevasses and other changes of slope, particularly along ridges. Braathen *et al.* (2004) described four types of failure of rock slopes that occur especially in valley shoulder locations, where Faulkner (2005a) showed that cave dimensions are maximised. Additionally, Warwick (1971), Ford and Ewers (1978) and Lauritzen (1986) suggested that pressure release at the sides of valleys could create fracture zones, including after melting of the local valley glacier (e.g. Fig. 3).

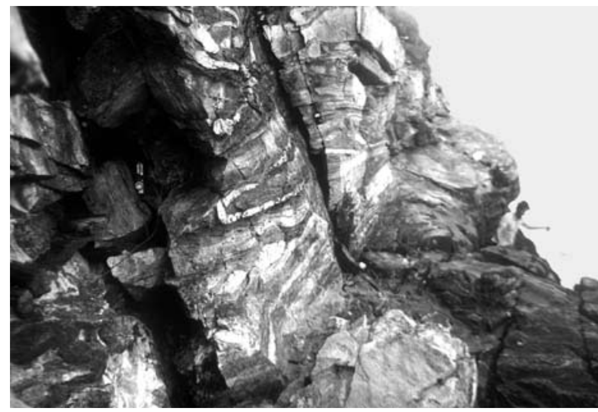

Fig. 3: Entrance to Johngrotta, Tosenfjord: Tectonic openings caused by pressure relief at side of fjord. Caving lamp for scale, at entrance to 15 m-long fissure.

Rohr-Torp (1994) found excellent linear relationships (R^2>0.85) between the local present rate of uplift (which itself is positively correlated with the total Holocene uplift) and the mean and median of both borehole yield and the reducing depth required to achieve an adequate yield, at sites across southern Norway. Concluding that young tectonic events have rejuvenated old fractures, he proposed a simple rule to predict the typical yield of a randomly-placed drilled well in Precambrian rocks in Fennoscandia: the yield is 180 Lh^{-1} at a place with 0mma^{-1} uplift from a well at 80–85 m depth, increasing by 100 Lh^{-1}, from a required depth of 6 m less, for each extra mma^{-1} of uplift. Present study area uplift rates vary from 2.5–5.5 mma^{-1}, going inland. The fracture patterns and dimensions that may support this groundwater storage and flow in Norway were discussed by Banks *et al.* (1996) and by Gudmundsson *et al.* (2002). Ford (1983, p 157) referred to this mechanism in Canada as *"isostatic groundwater pumping"*.

Thorson (2000) noted that there is now a blurring between the study of basic tectonics, and the study of *glaciotectonics*, and further, that seemingly trivial changes in stress may be sufficient to nucleate earthquakes, especially if there is a change in *crustal pore pressure*. Muir-Wood (2000, p 1410) stated that, at deglaciation, the tectonic strain energy that was accumulated during the whole period in which the icesheet had been in place "*can be liberated in a major seismic outburst*". Stewart *et al.* (2000) noted that horizontal plate motions normally drive crustal deformation, but with the onset of glaciation, this style is overprinted by the glacial stress, and new horizontal crustal motions increase outwards from the icesheet centre. They showed that subglacial water penetrates into the crust below enhanced icemelt in topographic hollows, increasing the pore-water pressure, and that large icesheets stabilise underlying crustal faults, whereas deglaciation destabilises the faults. Periods of cover by maximal Scandinavian icesheets represent times of seismic quiescence, due to the muffling effect of the weight of ice, as the land is gradually compressed and isostatically depressed (Johnston, 1987). In Fennoscandia, faulting is linked to zones with very steep ice gradients, or to the final stages of recession, when the bulk of seismic activity probably occurs within a few hundred years. During the similar deglaciation of Scotland, local movements were caused by differential glacial load flexure stresses (Davenport *et al*., 1989; Ringrose *et al*., 1991), at places with the steepest ice gradients (Stewart *et al*., 2000). Johnston (1987) also noted that artificial reservoirs can trigger earthquakes by increasing hydrostatic pressure. It occurs to this author that local deglacial earthquakes may similarly be triggered by the formation of ice-dammed lakes. Fjeldskaar *et al*. (2000) suggested that stress-generating mechanisms can be grouped into three classes: first-order stresses across *Fennoscandia* that arise from the longer-term plate tectonic NW–SE compression ridge-push forces caused by oceanic spreading from the Atlantic Ridge; second-order stresses that are limited to *Scandinavia*; and third-order stresses that relate to *local* features (e.g. topography) and rarely extend beyond ~100 km.

Any of the above mechanisms may result in fractures open to the surface. They may fill with water in summer, so that any winter freezing would subject the rock to increased stress. The magnitude of any widening is proportional to the sub-zero (°C) temperature at the surface (Matsuoka, 2001). Although most widening is reversed on thawing, there is a tendency for the fracture to be permanently enlarged, and then to admit a higher volume of water during the next freezing cycle. The temperature cycling of rocks of differing lithologies that have unequal coefficients of thermal expansion would also promote fracture enlargement along contact zones. Indeed, Gudmundsson *et al*. (2002, p 64) stated that "*stresses tend to concentrate at the contact between dyke rock and the host rock and generate fractures that may conduct groundwater*". Thus, tectonism commonly leads to a growth in the size of the near-surface fracture network, even without invoking karstic processes. If ice-dammed lakes completely froze in winter or during a period of local permafrost, then submerged fractures would also be subjected to further stress and widening.

Another mechanism to increase fracturisation is *hydrofracturing* (e.g. Gudmundsson *et al*., 2002). This process forces groundwater upwards through bedrock at gaps in permafrost, which may apply to metacarbonates during parts of the glacial cycle. At the base of a 500 m-deep ice-dammed lake, the excess pressure would be 50 atm. Thus, water can be injected into fractures that may occur within any underlying metalimestones, and, according to Banks *et al*. (1996, p 230), such pressures in a borehole may be sufficient to stimulate already fractured bedrock and to create new fractures. Lubrication by water would also amplify the effects of local seismicity.

There is no reason to suppose that the concentrated seismic creation of fractures during the Weichselian deglaciation was unique: similar processes must have occurred during the demise of all previous Cenozoic glacials (and perhaps stadials). However, from the speleothem chronozones proposed for Norway (Lauritzen, 1991a), there are long intervals of several 10 ka when speleothems did not grow, and full glacial coverage can be inferred. It therefore seems likely that the largest magnitude earthquakes only occurred once per 100 ka glacial cycle.

NEOTECTONICS

In addition to the postglacial uplift, there are two main sources of evidence of *neotectonics* in Scandinavia: the recent earthquake record, and the observation of movement along faults (e.g. Husebye *et al*., 1978; Olesen, 1988; Bungum, 1989; Olesen *et al*., 1992 and 1995). Local instrumentation can now record small earthquakes of magnitude 2, as summarised on a neotectonics map by Dehls *et al.* (2000a). The seismic events tend to follow N–S alignments at depths commonly focused above 15 km at the Atlantic Ridge, along the Continental Shelf edge, along the Norwegian coast, rather randomly along the border and onto the Swedish shield, and along the Swedish Baltic coast.

Many earthquakes have occurred in northern Norway and along the coast of southern Norway since 1750 AD, but lower frequencies and magnitudes coincide with the study area, which occupies a 'saddle' position between higher mountain ranges. Central Scandinavia probably acted as a focus for ice flow during late Cenozoic glaciations. With thinner icesheets, there was less stress relief and lower seismicity at each deglaciation. Additionally, increased ice flow increases glacial erosion, leading to less surface relief and less differential stress, and the increased sedimentation on the Vøring Plateau, off the coast of the study area, may have a dampening effect. The historical record of significant, but comparatively smaller and less frequent neotectonic earthquakes in the study area (Fig. 4) *may* be representative of relative seismic activity during the whole Holocene, although, following the 'pulse' of deglaciation seismotectonics, the style of seismicity does change, as noted by Stewart *et al.* (2000, p 1381): "*Whereas present-day seismicity is concentrated around the margins of the former icesheet, on deglaciation, earthquakes predominated at the centre of the rebound dome*". However, neotectonic earthquakes do follow the *Rana Fault Complex* south along the coast of the study area, and the largest recorded Northern European near-shore earthquake, of magnitude 5.8, occurred on 31 August 1819 AD in Rana, just north of the study area. Some 10000 micro earthquake shocks were recorded instrumentally at Meløy, 70 km north of the study area, during 10 weeks in 1978 (Bungum *et al.*, 1979). These were up to magnitude 3.2, were heard and felt locally, and caused cracks in walls and chimneys.

The documented active postglacial faults are commonly NE–SW-trending reverse faults that lie within a 400 km x 400 km area in northern Fennoscandia (e.g. Arvidsson, 1996). Their lengths and maximum scarp heights vary from 3–150 km and from 1–30 m. Fault offsets range up to 13 m (Dehls *et al.*, 2000b). A magnitude 4 earthquake occurred near one of these faults in 1996, when large amounts of groundwater poured out of the escarpment. The fault length to offset ratio indicates that the structure itself resulted from an earthquake with a magnitude above 7. The work of Olesen *et al.* (2004, p 17) *"supports previous conclusions regarding a major seismic 'pulse' (with several magnitude 7–8 earthquakes) which followed immediately after the deglaciation of northern Fennoscandia".*

The earthquakes may not just be caused by isostatic rebound after the removal of ice. They may also indicate the opportunity for adjustment to glacial erosion after the 'muffling' effect of the ice cover has gone. The 2 km-wide W–E Båsmoen Fault zone is just north of the junction between the HNC and the Rødingsfjell Nappe Complex (RNC) and can be traced for 50 km along Ranafjord (Fig. 4). It has a maximum displacement of 10 m, escarpments up to 80 m, provides evidence of recent movements (30–40 cm between 8780 and 3880a BP: Hicks *et al.*, 2000), and was associated with the 1819 earthquake. The Rana area was the subject of an in-depth seismic study, NEONOR, from 1997–1999, when some 267 local earthquakes were recorded with magnitudes up to 2.8 by Hicks *et al.*, (2000), who stated (p 1431): *"The Rana area has a significant amount of the total seismic activity in onshore northern Norway"* and concluded that postglacial uplift is the most likely cause for this continuing high level of seismic activity.

Muir-Wood (2000) discussed postglacial very shallow stress-relief phenomena, known as 'pop-ups', which are prevalent along the margins of the Laurentian icesheet, but relatively unknown in Scandinavia. However, Roberts (2000) reported offset structures in boreholes at road-cuts that are regarded as stress-relief features initiated by blasting. Within road tunnels there is anecdotal evidence that civil engineers report the sounds of rock moving, and 'rock bursts' occur when rocks fall from the roof, after blasting is complete. At the surface, crushed rocks and slipped blocks and notches on skylines may indicate postglacial movements along faults and nappe boundaries.

Olesen *et al.* (2004, Appendix A) included 54 classified claims of neotectonic movements from onshore mainland Norway, prior to new evidence discussed here (section 3.4). The earthquakes and fault movements are commonly parallel manifestations of neotectonic activity that arise from both glacial isostatic uplift and the longer-term plate tectonics. Olesen *et al.* (1992) reported that the earliest detectable displacement in Finnmark (the northernmost county in Norway), is of *Proterozoic* age, indicating an extremely long-lived fault zone. Such fault zones and their adjacent sub-parallel accommodation faults lie parallel to the strike of the foliation, and give low resistivity readings *due to ingress of water into fractures*. Whereas the plate tectonic processes constitute the most important fault-generating mechanism in Finnmark, stress relief could still have been *triggered* during the deglaciation period.

There are no known *extensive* faults wholly within the study area, which, as noted above, is less seismically active, although Olesen *et al.* (1995) showed an earthquake zone that extends NE across the north of the study area, passing through Mosjøen and Korgen (Fig. 4). Because the Weichselian icesheet had melted by 8500^{14}Ca BP, the present pattern of neotectonic seismic activity corresponds more to the *horizontal* stress field. As well as being concentrated at the centre of the rebound dome, the earthquake pattern from 10000–8500^{14}Ca BP was probably aligned along the mountain ranges, and represented the *vertical* isostatic rebound.

A conclusion from this review of neotectonic activity is that the seismic and aseismic creation and enlargement of near-surface fractures continued throughout each interglacial, to supplement the more intense fracture sets produced at each deglaciation. These processes probably combine to create a spectrum of fracture apertures, lengths, frequencies and interconnectivities within the metalimestones. Such fracture systems may include subsystems that vary from being too small to transmit water, to those that are great enough to permit turbulent flow (without requiring karstic dissolution) over path lengths that in the study area reach up to 3.5 km.

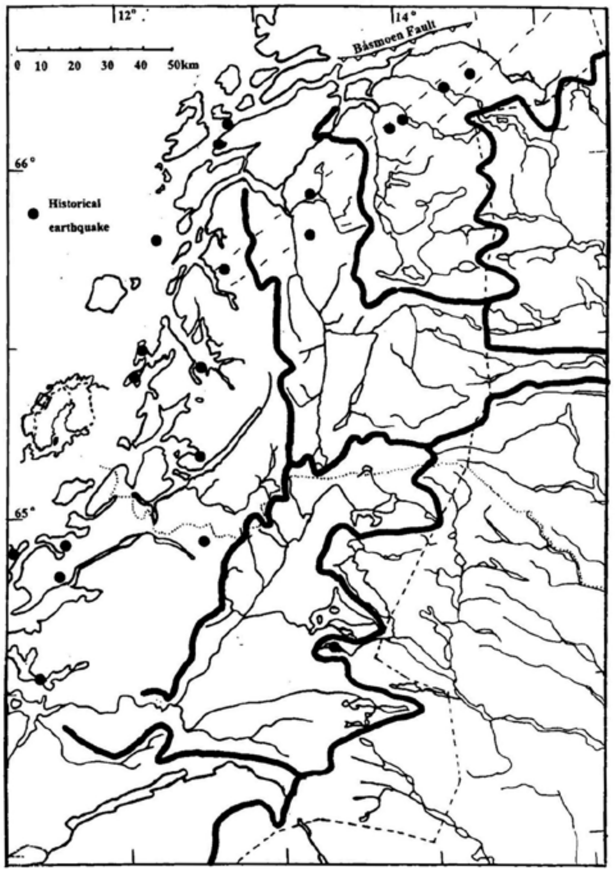

Fig. 4: Historical earthquakes in the study area (Various sources).

EVIDENCE FOR TECTONIC ACTIVITY FROM THE STUDY AREA

None of the 54 claimed examples of Norwegian neotectonic movement (section 3.3) lie within the study area. The lithologies of affected or adjacent rocks are rarely given, but there is no indication that any are in carbonate rocks. Thus, a list of 56 possible examples of tectonic movements in metalimestones presented by Faulkner (2005a, Appendix D1) may be the first recorded for the study area, and the first observed in both exokarstic and endokarstic situations. Altitudes range from near sea level to 770 m. Elgfjell provides many good examples. Most underground observations are intended to provide direct evidence of movement, after formation of the observing passage, rather than direct evidence of tectonic inception.

Only one observation concerns fallen, broken or curved stalactites and stalagmites, which can be diagnostic of earthquakes and relative roof movement. A few more unrecorded examples probably do exist, but speleothems are rare in the study area anyway, and most of those that do exist are small and probably grew in the Holocene, *after* the large earthquakes occurred. Speleothems that grew in earlier interglacial periods have commonly been removed by subsequent deglacial outflows. The few chambers with roof spans greater than c. 6 m commonly contain fallen blocks, which almost universally comprise limestones with clean, sharp, angular surfaces. This suggests that they fell after any deglacial deposition, and are situated high enough above streamways not to have been eroded by Holocene flood waters. Only two of the chambers are lit by daylight from nearby entrances, so that only these two may experience severe, seasonal, frost action. The others are not in entrance areas, and their disturbance by seismic shock seems the best explanation (e.g. Fig. 13). Human intervention is most unlikely, because of the common inaccessibility. However, all the large chambers are within 30 m of the overlying surface, and most within 15 m, so that a second possible process is downward flexing of the roof by the weight of an overriding icesheet (providing the cave was not filled by ice or water), as proposed by Warwick (1971), and upward flexing when the ice melted. A third explanation based on the freezing to a total ice fill during glacial conditions also cannot be ruled out.

It is the author's opinion, made after field trips to marble caves in central Scandinavia, northern America and Scotland, that evidence of small Holocene tectonic movements (e.g. bedrock movement that displays sharp edges or slickensides, without subsequent calcite dissolution or deposition) can be found in all relict passages in metalimestones in the Caledonides. Movements in VSK seem to occur in either vertical or horizontal slabs that are typically 1–3 m thick. The movements, presumably caused by W–E compressive stress, are commonly horizontal, normal to the strike, and have typical moved distances of only a few centimetres (and, rarely, several tens of centimetres), as expressed at the surface and within cave passages. The horizontal movement of vertical slabs of limestone 1–3 m thick is compatible with the survey leg length of many caves in the study area, suggesting that joint systems (in, e.g., VSK) are produced by this process (Figs. 5 and 6). Longer straight passage elements, and very wide, but low, passages, may arise from the horizontal movement of horizontal slabs of limestone (Figs. 7, 8 and especially 9 and 10). These observations agree with those of Olesen *et al.* (2004, p 13): *"the Norwegian bedrock consists of individual blocks that, to some degree, move independently of each other"*. According to Mörner (2003, p 72), a passing seismic wave can cause bedrock to lift up and then sink back, whilst the ground is being severely shaken. This probably happened at **Cliff Cave** in Jordbrudal (Figs. 9 and 10). Because most tectonic movements are of only a few centimetres, explorable cave passages are unlikely to be truncated along faults, and few such blind passages are known in the area.

Fig. 5: Scallop in Elgfjellhola: 11cm tectonic movement at scallop (highlighted), which occurred after formation of the passage, probably synchronously with movement in the nearby Paradox Cave (Fig. 6).

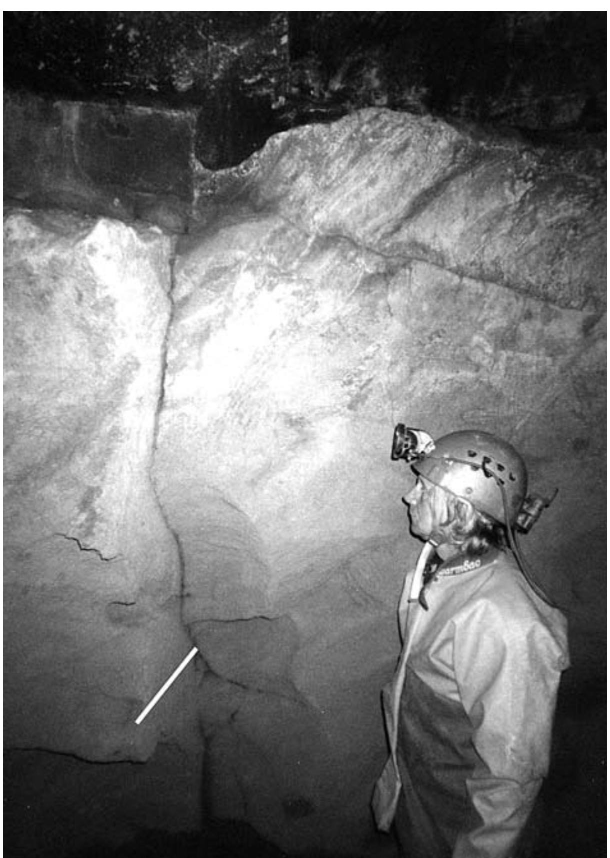

Fig. 6: Slickensides in Paradox Cave, Elgfjell: Tectonic movement of ~20 cm after enlargement of passage to its present size.

A possible alternative explanation is that there has not been any movement, but that differential erosion or corrosion has given the appearance of movement.

Fig. 7: Kidney Lake Cave, Jordhulefjell: Relict phreatic passage, with ~2 m diameter. A prominent horizontal tectonic movement bisects the passage, probably resulting from seismic amplification, because the cave lies in a ridge. Although this movement occurred after the passage enlarged to it present size, cave inception probably took advantage of a similar movement at the end of the Saalian deglaciation. Photo by P. Hann.

Fig. 8: Horizontal tectonic movement on Elgfjell: Mass movement outward (after glacial smoothing) of 2 m-thick slab of metalimestone, with proto-conduits at upper fracture.

This could arise particularly if the apparent movement is aligned with the foliation. However, the photographic evidence for tectonic movements discussed above is compelling. The evidence provided at **Elgfjellhola** (Fig. 5) is particularly convincing, because the movement is *across* the foliation, is seen all the way around the passage walls, has a 1 mm-thick fault gauge wafer protruding up to 50 mm, and includes an 11cm step across a wall scallop. The evidence of protruding fault gauge wafers at surface sites (e.g. Fig. 11) that appear to cross-cut karren and stream channels suggests that these movements occurred in the Holocene, after the transport of ice across the area. The wafers could have been extruded beyond the faces of the limestone blocks by the seismic movements, or else Holocene chemical dissolution of the surface has left the more resistant wafers exposed to a height that indicates

Fig. 9: Cliff Cave entrances: Shattered cliffs and towers of limestone near the Rockbridge, Jordbrudal.

Fig. 10: Cliff Cave entrance from inside: Horizontal opening of c. 1 m to both left and right that split floor of phreatic passage to create a box-like profile. This is the largest known tectonic movement in the study area.

Fig. 11: Diverging flow on Elgfjell: Diverging flow of coffee across vertical fracture with fault gauge, suggesting that movement occurred after the surface flow was established.

Fig. 12: Fountain at Litl Hjortskar, Svenningdal: Spring at high stage from metalimestone fractures 1 m above level of adjacent stream.

the extent of local surface lowering, or wall retreat in a cave. The wafers are calcitic, with polished surfaces and unknown dissolutional characteristics.

The observed tectonic movements in karst caves commonly follow the plane of the supposed inception fracture. Additionally, caves commonly display a high concentration of joints and fractures (c.f. the epikarst in sedimentary limestones) that lie parallel to, or normal to, the plane of foliation, and in some cases at other angles. These openings may not show lateral movement, but the variable degree of sharpness or smoothing by dissolutional water indicates that they probably represent a general settling upwards of large superficial carbonate blocks after seismic shocks. The sporadic lines of speleothems beneath roof joints indicate 'failed' vertical inception fractures, which transmit water more readily in vadose rather than phreatic conditions.

Fig. 13: The Blockpile, Kvannlihola 2: Well-away from freeze-thaw influences, this collapse likely occurred during early Holocene earthquakes.

Fig. 14: Secret Stream Cave, Elgfjell: Primarily a tectonic cave, formed at junction of mica schist and marble. The mica schist has split and rotated upwards. The pick-axe is a relic of small-scale mining activity.

EVIDENCE FOR TECTONIC INCEPTION

It is self-evident that if tectonic caves can form in non-carbonate rocks, such as the entrance to **Secret Stream Cave** in mica schist (Fig. 14), then, despite metalimestone perhaps being slightly more ductile than some other local lithologies, there almost certainly exist natural conditions that promote the creation of tectonic caves in marbles, as listed by Faulkner (2005a). Such caves may be recognised by their angular or triangular passage profiles, especially at roof level. (Sediments, clastic materials and fallen rock may provide a flatter, sub-horizontal, floor). Whereas the movements along fractures in caves primarily formed by karstic dissolution are commonly small (the c. 1 m movement in **Cliff Cave**, Figs. 10 and 11, is exceptional), the movements at purely *tectonic* caves could be much greater. It is also self-evident that if a limestone tectonic cave later became part of a drainage route, under vadose or phreatic conditions, then normal karstic chemical and mechanical erosion processes would apply, and, over time, the passage would enlarge. If the drainage was phreatic, then eventually the evidence of its tectonic inception could dissolve away. Even in vadose conditions, the signs of an original tectonic movement may be destroyed in all but the highest, perhaps inaccessible, levels. The only known examples in the study area of caves in metalimestone that possibly enlarged tectonically to explorable dimensions and later enlarged significantly by karstic processes are the adjacent caves **Nordlysgrotta** and **Marimyntgrotta** in Velfjord, which may also have passages truncated by tectonic movements (Faulkner, 2005b).

Whenever a Caledonide karst passage has been studied by the author, it has always been found to follow either the contact between metalimestone and another, non-carbonate, rock, or a narrow (commonly horizontal in VSK) fracture plane in the limestone. Because there are likely to be rheological differences between rocks of differing lithologies, tectonic fractures are particularly likely to form at lithological contacts, under all conditions of seismic and aseismic tectonic movement. It is not necessary to have intersecting fractures for tectonic inception: apertures are uneven, and channel flow follows the widest part of the opening (Hanna and Rajaram, 1998). Nor is movement along the plane of the fracture necessary: a separating aperture adjacent to, or within, the limestone is sufficient. Such local rock splitting, especially vertical, may arise near the surface from deglacial and erosional unloading, without necessarily being triggered by seismic or aseismic processes.

CONCLUSIONS

On the basis of the accepted facts of seismic and slow tectonic activity in Scandinavia (section 3), it is argued here that all the solutional karst caves of the study area were initiated by tectonic inception. Tectonic activity creates fractures and some of these fractures must be open, as shown by the extreme cases of explorable tectonic caves. For the vertical stripe karsts in the HNC (at least), it seems probable that horizontal movements produce sublinear sections of horizontal and vertical fractures with apertures that match the mm- and cm-scale banding of the foliation. The availability of chemically aggressive waters during meteoric and glacial conditions (Faulkner, 2005a) that can pass easily through connected fissures that lie close to the surface, and that commonly have high hydraulic gradients (Fig. 12), promotes karstic enlargement. Indeed, just as it seems impossible for karst caves to exist in the metalimestones of the study area without tectonic inception (section 1), it also seems impossible for them not to exist, given the tectonic history and the availability and flow regimes of chemically aggressive waters. Hence, all the karst caves are hybrids. After tectonic inception, conduits enlarged by dissolutional karstic processes, some with marine modification, and some with observable tectonic modification subsequent to inception. Monogenetic cave types in metacarbonate rocks are limited to wholly tectonic caves, wholly sea caves (formed by wave action), and jettegryter (rock-mills, formed by mechanical action during deglaciation).

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HYDROCHEMIC CHARACTERISTICS AND TECTONIC SITUATION OF SELECTED SPRINGS IN CENTRAL AND NW YUNNAN PROVINCE, CHINA

HIDROKEMIČNE ZNAČILNOSTI IN TEKTONSKI POLOŽAJ IZBRANIH IZVIROV V OSREDNJEM IN SZ YUNNANU, KITAJSKA

Stanka ŠEBELA[1] & Janja KOGOVŠEK[1]

Abstract UDC 556.3:54(510)

S. Šebela & J. Kogovšek: Hydrochemic characteristics and tectonic situation and of selected springs in central and NW Yunnan province, China

The Yunnan Province lies on the eastern rim of the collision zone between the Indian plate and Eurasia. This region is characterized by complex Cenozoic structures and active seismotectonics. In the year 2004 the areas north from Kunming and the NW part of Yunnan were studied. The measurements of the temperature, conductivity and the analyses of carbonate, phosphate and nitrate were performed in Quinglongtan spring and in the accumulation lake that is situated lower than the spring. The springs are situated in the wider zone of the Xiaojiang fault along which left horizontal movements are taking place. Along the wider zone of the Zhongdian fault between the town of Zhongdian and the Yangtze River on the south there are more springs. Tiansheng Qiao (T = 57.5°C) and Xiageiwenquan (T = 48,3 – 66.8°C) are thermal springs along which tufa is deposited. The Baishuitai spring has high mineralization and lower temperature (T = 11.1 – 13.3°C) and deposits calcium carbonate in the form of gours. All studied springs are connected with active fault zones. The studied areas mostly represent the contact areas between carbonate and non-carbonate rocks.

Key words: springs, tectonics, travertine, Yunnan, China.

Izvleček UDK 556.3:54(510)

S. Šebela & J. Kogovšek: Hidrokemične značilnosti in tektonski položaj izbranih izvirov v osrednjem in SZ Yunnanu, Kitajska

Provinca Yunnan leži na vzhodnem robu kolizijske cone med Indijsko in Evrazijsko ploščo. Za to ozemlje so značilne zapletene kenozojske strukture in aktivna seizmotektonika. V letu 2004 smo proučevali ozemlja severno od Kunminga in SZ del Yunnana. Meritve temperature, specifične električne prevodnosti in analize vsebnosti karbonatov, fosfatov in nitratov smo opravili na izvirih Quinglongtan in v nižje ležečem akumulacijskem jezeru. Izviri se nahajajo v širši prelomni coni Xiaojiang, ob kateri se vršijo levi zmiki. V širši prelomni coni Zhongdian preloma med mestom Zhongdian in reko Yangtze na jugu se nahaja več izvirov. Tiansheng Qiao (T = 57,5°C) in Xiageiwenquan (T = 48,3 – 66,8°C) sta termalna izvira, ob katerih se odlaga lehnjak, Baishuitai pa je močno mineraliziran izvir z nižjo temperaturo (T = 11,1 – 13,3°C), ki odlaga kalcijev karbonat in gradi ponvice. Vsi ti izviri so vezani na aktivne prelomne cone. Izbrani predeli večinoma predstavljajo kontakt med karbonatnimi in nekarbonatnimi kamninami.

Ključne besede: izviri, tektonika, lehnjak, Yunnan, Kitajska.

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INTRODUCTION

Exposed karst areas in China comprise about 900.000 km^2 and the karst area in Yunnan includes 110.900 km^2. The Yunnan region in southwest China is located in the boundary area between the active Tibetan Plateau to the west and the stable South China platform to the east. This region is characterized by complex Cenozoic structures and active seismotectonics.

The studied area is part of the Three parallel rivers of Yunnan Protected Areas, which is inscribed in the UNESCO's World Heritage List. The area represents geological history of at least 50 million years associated with the collision of the Indian Plate with the Eurasian Plate, the closure of the ancient Thethys Sea, and the uplifting of the Himalayan Range and the Tibetan Plateau.

The site consists of 15 protected areas (in eight geographic clusters) in the mountainous northwest of Yunnan Province and extends over a total area of 1.698.400 ha, encompassing the watershed areas of the Yangtze (Jinsha), Mekong (Lacang) and Salween (Nu Jiang) rivers. The rivers pass through steep gorges, in places up to 3.000 m deep. At their closest the three gorges are 18 km and 66 km apart.

Our research work in this region was performed within the Slovene-Chinese project with Yunnan Institute of Geography from 18-29th October 2004. In the previous years most researches were oriented to the area around Kunming (Lunan) and SE from Kunming (Xichou, Qiubei, Guangnan) (Figure 1). Shilin, fengcong, fenglin, karst caves were studied (Knez & Slabe 2002; Šebela *et al.* 2004) and water tracing tests were performed (Kogovšek *et al.* 1997; Kogovšek & Liu Hong 2000). In the year 2004 it was the first time that the areas of NW Yunnan were visited and some thermal and non-thermal springs with tufa deposits related to active tectonics were studied.

TUFA DEPOSITS

Tufa as a general name covers a wide variety of calcareous freshwater deposits, which are particularly common in late Quaternary and Recent successions. Tufa is the product of calcium carbonate precipitation under a cool water regime and typically contains the remains of micro- and macrophytes, invertebrates and bacteria. The term travertine is restricted to all "freshwater" thermal and hydrothermal calcium carbonate deposits dominated by physico-chemical and microbial precipitates, which invariably lack in situ macrophyte and animal remains. Tufas are usually distinguishable from travertines, even in ancient deposits, by the comparatively high diversity of contained plants, including macrophytes, and animals (Ford & Pedley 1996).

In China's vast karst landscapes there are many tufa deposits. They are known in Sichuan, Guizhou, Guangxi and Tibet Provinces. Some of the tufa cascades in Guizhou are broadly comparable with the Plitvice barrages (Ford & Pedley 1996). Frančišković, Bilinski *et al.* (2003) analysed the tufa from Guangxi. One tufa sample originated in the Pleistocene, and the others in the Holocene.

The travertines in China are divided into two major geochemical groups: the meteogenes and thermogenes. The thermogenes are essentially hydrothermal deposits, where $CaCO_3$ is precipitated from high-CO_2 groundwaters. Most of this CO_2 comes from deep within the crust as a result of magmatic degassing or limestone decarbonation with DIC (dissolved inorganic carbon) values typically >>10 mM/l. They are usually found in tectonically and/or volcanically active regions (Pentecost & Zhang 2001).

Tibet, in spite of its cold dry climate and high altitude, has a scatter of tufa deposits, mostly either calcareous crusts on colluvium or associated with geothermal springs (Waltham 1996).

TECTONIC SITUATION

Tectonic development of the SE Asia includes the Indian subcontinental collision, which represents the penetration of a rigid block (representing India) into layers of plasticine in a partly confined block (Asia) (Tapponnier *et al.* 1982). The Red River Fault zone (Figure 1) is the major geological discontinuity that separates South China from Indochina. Today it corresponds to a great right-lateral fault, following for over 900 km the edge of four

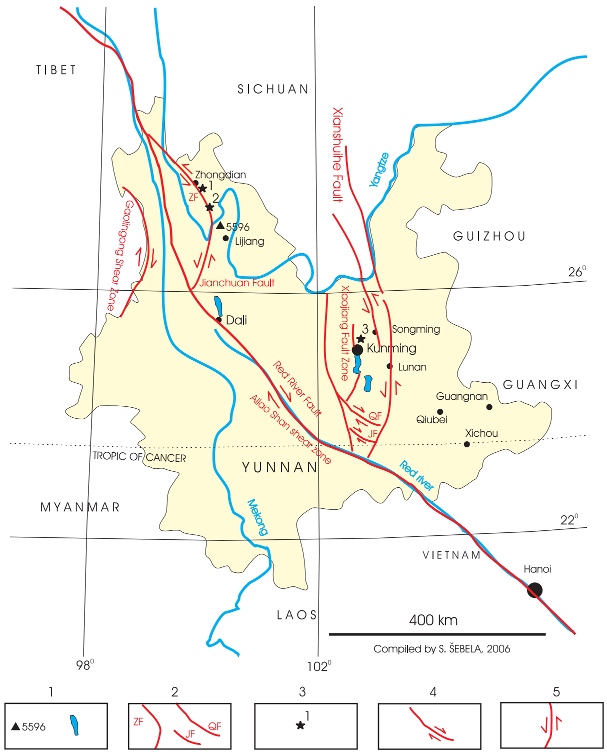

Fig. 1: Tectonic situation of Yunnan (after Burchfield & Wang 2003). 1 = Yulong Snow mountain 5596 m above sea level; lake, 2-ZF = Zhongdian fault, JF = Jianshui fault, QF = Qujiang fault, 3 = studied areas, 1 = Tiansheng Qiao and Xiageiwenquan springs, 2 = Baishuitai tufa deposits, 3 = springs north of Kunming, 4 = right-lateral slip along the fault, 5 = left-lateral slip along the fault.

Slika 1: Tektonske razmere Yunnana (po Burchfield & Wang 2003). 1 = Yulong Snow mountain 5596 m nad morjem; jezero, 2-ZF = Zhongdian prelom, JF = Jianshui prelom, QF = Qujiang prelom, 3 = raziskovana mesta, 1= izviri Tiansheng Qiao in Xiageiwenquan, 2 = Baishuitai ponvice, 3 = izviri severno od Kunminga, 4 = desni zmik ob prelomu, 5 = levi zmik ob prelomu.

narrow (<20 km wide) high-grade gneiss ranges that together form the Ailao Shan-Red River metamorphic belt (Leloup *et al.* 1995).

The movement along the Red River Fault has been dominantly right lateral since the close of the Tertiary. The best evidence comes from offsets of tributary streams of up to 5-6 km in the last 2 to 3 Ma (amounting to slip rates of 2-5 mm/yr). No significant earthquake has occurred along the fault in the last 2000 years (Allen *et al.* 1984). Tapponnier *et al.* (1982) surmise reversal of movement on the Red River Fault from the initial left-lateral sense during the first 20 to 30 Ma following the onset of the Indian collision. A different regional stress pattern now favors adjustment by dextral slip. The orientation of the fault is consistent with N-S shortening and E-W extension.

Geological relations near the NW termination of the Ailao Shan suggest the Red River fault had a minimum of 14 – 48 km of right-lateral displacement in pre-Pliocene (and presumably post -17 Ma) time and only 5-6 km of displacement in Quaternary time (Allen *et al.*, 1984; Wang *et al.*, 1998). Active right-lateral displacement on the eastern part of the Red River fault zone is interpreted to be caused by a segment of the fault zone being rotated counterclockwise by shear related to the left-lateral Xiaojiang fault system (Wang *et al.* 1998).

Stating that the Red River fault has been displaced by the Xiaojiang fault, it can be concluded that with respect to its present kinematics, the eastern part of the Red River fault does not accommodate large motions nowadays (Michel *et al.* 2000). The northwest-striking Jianshui and Qujiang faults (Figure 1) and probably the Zhongdian fault show evidence for different amounts of middle Cenozoic (pre-Pliocene and post-early Paleogene) left-lateral displacement that range from 6-25 km. The age and orientation of the left-lateral faults suggest that the faults are related to a regional deformational event associated with important left-lateral shear on the Ailao-Shan shear zone (Burchfiel & Wang 2003).

The Zhongdian fault (Figure 1) appears to have undergone only left-lateral displacement, some of which may be middle Cenozoic in age and some post-Miocene in age. Active displacement on the Zhongdian fault is interpreted to mark the eastern boundary for a small crustal fragment that rotates clockwise around the eastern Himalayan syntaxis (Burchfiel & Wang 2003).

Active right-lateral movement on the Jianshui fault (Figure 1) can be documented by numerous geological (offset structures) and geomorphic (deflected rivers and pull-apart basins) features. Active right-lateral displacement of the Quijiang fault is demonstrated by numerous scarps and offset Holocene feature and seismic activity (Burchfiel & Wang 2003).

SE of Zhongdian the Zhongdian fault passes through a series of basins filled with Quaternary sediments and the analysis suggests left-lateral stream deflections indicating the fault is active. The fault bends south at the Jinsha River and merges with the active left-lateral Jianchuan fault (Burchfiel & Wang 2003).

Quaternary basins and lakes north of Dali and within the southern part of the Xiaojiang fault zone are areas of local active extension (Wang & Burchfiel 2000). Only the Jianshui fault and possibly the Quijiang fault contain evidence for right-lateral reactivation of older left-lateral faults (Burchfiel & Wang 2003). The Xiaojiang fault system is at least 2-4 m.y. old, and possibly as old as 6-8 m.y., which suggests rapid right-slip did not begin on the

Quaternary Jianshui and Quijang faults until left-lateral shear within Xiaojiang fault system was well underway (Burchfiel & Wang 2003).

The Pliocene-Quaternary sedimentary fill in pull-apart basins associated with left-lateral Xianshuihe-Xiaojiang fault system indicated that this fault system was initiated by at least 2-4 Ma (Wang *et al*. 1998).

Kunming is moving due south with respect to Sundaland-South China indicating sinistral movement along the Xiaojiang fault system with a rate of 11 ±4 mm/yr. The Xianshuihe-Xianjiang fault system suffers pure sinistral strike slip faulting in its central part with respect to South China (Michel *et al.* 2000).

SEISMICITY

In the broad sense, strike-slip faults and earthquakes in SW China result from the eastward motion of the Earth's crust that is driven by the collision of the Indian and Eurasian continental plates beneath the Himalaya Mountains and the Tibetan Plateau to the west.

There is an obvious difference between the southern segment and northern segment of the Red River Fault from the viewpoint of modern seismicity. The most disastrous earthquakes occurred in the northern segment. Feigl *et al*. (2003) report that the Red River Fault did not slip faster than 1 or 2 mm/yr between 1994-2001 near Thác Bà, Vietnam.

A strong earthquake occurred in Lijiang area in Yunnan Province on February 3, 1996 (M = 7.0). The epicenter was determined to be in the seismically active region of the Hengduan mountains, which belong to the Alpine-Himalaya seismic belt.

Kunming is situated in the middle and southern part of seismically active Xiaojiang-Fault. In the year 1833 earthquakes (M = 8.0) were located in the area of Songmin (Figure 1).

The focal mechanisms of the 1966 earthquakes on the N-S-striking Xiaojiang fault imply left-lateral slip along it. A normal component of slip on the roughly N-S faults south from Kunming has created several Quaternary half-grabens, some of them filled by lakes (Tapponnier & Molnar 1977).

An earthquake of M = 7.7 occurred on the Quijiang fault in 1970 (Tunghai earthquake). The event produced a 60-km-long surface break and with a maximum right-lateral displacement of 2,7 m (Liu *et al*. 1988; Ma, 1989).

SPRINGS NORTH FROM KUNMING

Upper Devonian, Carboniferous and Permian shallow-water carbonates build the south China tower karst, south from Kunming. Near Kunming basalt rock is interbedded with the Upper Permian limestones.

Within the frame of the fieldwork the accumulation lake and Quinglongtan spring (Figure 2) north from Kunming were studied on 21st October 2004. The water from several springs is lead to a common channel that runs into the accumulation lake that was made for irrigation and water supply of Kunming. The springs are located in the wider zone of Xaojiang fault (Figure 1), which is still tectonically active.

The measured temperature and conductivity (SEC) of the three main springs showed that the water from the springs belong to the same source (temperature 14.7°C and SEC 277 μS/cm). The water in the accumulation lake was warmer (19.4°C), while the SEC measurement was within the values of the Quinglongtan spring. The carbonate concentration in accumulation lake and in the springs was low; just 135 mg $CaCO_3$/l (2.7 mekv/l) what means it was a little bit lower than total hardness (146 mg $CaCO_3$/l or 2.92 mekv/l, Figure 3). In Tianshengan area we measured such low values of hardnesses in karst springs at high hydrological conditions (Kogovšek 1998).

The phosphate concentration in accumulation lake and in the spring was under the detection limit of the method (<0,01 mg PO_4^{3-}/l), the nitrate concentration was 4,6 or 4,4 mg NO_3^-/l, what shows good water quality.

Fig. 2: Qinglongtan spring (one of the several springs) north from Kunming (photo by J. Kogovšek).

Slika 2: Qinglongtan izvir severno od Kunminga (foto J. Kogovšek).

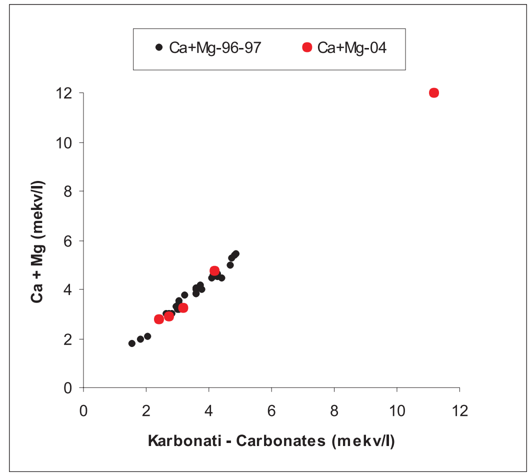

Fig. 3: Total and carbonate hardness of sampled springs in year 2004 and sampled karst waters in Tianshengan area in the years 1996 – 97 at different hydrological conditions.

Slika 3: Celokupna in karbonatna trdota vzorčevanih izvirov v letu 2004 in vzorčevane kraške vode na področju Tianshengan v letih 1996-97 v različnih hidroloških pogojih.

SPRINGS NORTH FROM LIJIANG

The water supply for the Lijiang derives from the nearer Zhenzhuquan spring (Figure 4), where the water is cached in a smaller lake that is regulated for tourism. Part of the water is accumulated into the channels that run through the Lijiang town. On the principal spring there is a pumping area (Figure 5) that is still used for water supply of the Lijiang. During our visit on the 24th October 2004 we met many natives who come to take the water from the spring. The water temperature was 14.8°C, SEC 370 µS/cm, carbonate hardnesses 158 mg $CaCO_3$/l (3,16 mekv/l), and the total hardness 162 mg $CaCO_3$/l (3,24 mekv/l). These measurements fall well with characteristics of groundwater and karst springs in Tianshengan area near Stone forest (Kogovšek *et al.* 1997, Kogovšek 1998). The water had good quality regarding the low chloride concentration (1 mg Cl^-/l), the nitrate concentration (1,3 mg NO_3^-/l), and the o-phosphates (< 0.01 mgPO_4^{3-}/l).

Fig. 4: Zhenzhuquan spring near Lijiang (photo by J. Kogovšek).

Slika 4: Izvir Zhenzhuquan pri Lijiangu (foto J. Kogovšek).

Yulong Snow Mountain (5596 m) consists of Paleozoic carbonate rocks and in the eastern area of Tertiary clastic rocks with marlites and calcareous rocks (Huang Chuxing 2004). Bai Shui He river that runs on the northern slope of the mountain showed the temperature of 9,6°C (23rd October 2004), low SEC (196 µS/cm), low carbonate hardness (109 mg $CaCO_3$/l or 2.17 mekv/l) and just 1 mg NO_3^-/l. The pH measurement showed value 8.2.

Fig. 5: The pumping area at Zhenzhuquan spring (photo by J. Kogovšek).
Slika 5: Črpališče na izviru Zhenzhuquan (foto J. Kogovšek).

Fig. 6: Xiageiwenquan thermal spring (photo by J. Kogovšek).
Slika 6: Termalni izvir Xiageiwenquan (foto J. Kogovšek).

SPRINGS SOUTH FROM ZHONGDIAN

About 42,2% of the Zhongdian County represents carbonate surface. Most of the carbonate rocks are from Devonian and Cretaceous. Some are from lower Permian and the middle and lower Triassic (Huang Chuxing 2004). In the wider zone of the Zhongdian fault near the town of Zhongdian and Yangtze river there are more tectonic depressions that are developed inside carbonate rocks but border also to other rocks as magmatic, sandstones and marbles. In such cases we don't deal with the true karst poljes. All depressions are related to active tectonic faults that are NW-SE oriented with active sinistral horizontal movements.

In the area of the active Zhongdian fault there are more springs (Figure 1). Some are thermal springs others have lower temperature and many of them precipitate tufa deposits. The spring waters are supposed to come from the depths. During our field studies we visited the Xiageiwenquan thermal springs, Tiansheng Qiao thermal spring, and Baishuitai tufa deposits. All three locations are tourist attractions.

Xiageiwenquan (Figure 6) is situated about 10 km east from the Zhongdian town and represents about 10 smaller and bigger thermal springs in the distance of 300 m. In the area there are older and younger still active travertine deposits. The area is built of Triassic limestones, sandstones and mudstones. Yuan Daoxian (2002) mentioned 9 springs with discharges between 0,5 to 1 l/s and temperature between 36,6 and 67,4°C. The SEC values of the springs were between 1676 and 2660 μS/cm.

Our measurements taken on the 26th October 2004 detected the temperature being between 48,3 and 66,8°C, and minimal discharges. The SEC values were from 1260 to 1510 μS/cm (measurements were performed with WTW instrument LF 90 at ref. temperature 20°C).

Tiansheng Qiao is situated some km south from Xiageiwenquan, along the active sinistral horizontal Suoge-Xuejiping fault on the western side of the Jinsha river. The fault is a deep and wide fault formed in the early stage of Permian but still active today. A hot liquid of the gabbro plasma effuses up through this fault. And it is the precondition to form tufa landscapes (Huang Chuxing 2004).

The attraction of the Tiansheng Qiao is the natural bridge with Shuodugang river running below it (Figure 7). The limestone natural bridge is 40 m high, 10 m wide and 15 m long. In the area there is also the Tiansheng Qiao thermal spring with travertine deposits. Huang

Fig. 7: Natural bridge of Tiansheng Qiao (photo by J. Kogovšek).
Slika 7: Naravni most Tiansheng Qiao (foto J. Kogovšek).

Chuxing (2004) speaks about sulphur springs, formed in different stages. The east side is from the earlier stage and the west side from the later stage. Travertine deposits at a relatively high speed with the estimated sedimentation 1-5 cm/year. By comparison with other in the surrounding areas the travertine of Tiansheng Qiao did not form earlier than 5000 years ago.

The thermal water of the Tiansheng Qiao spring is accumulated into the thermal pools (Figure 8) used by

Fig. 8: Thermal spring of Tiansheng Qiao is accumulated into the pools (photo by J. Kogovšek).

Slika 8: Termalni izvir Tiansheng Qiao je speljan v bazene (foto J. Kogovšek).

tourists. The Shuodugang river had (25th October 2004) the temperature of 10°C and low SEC (115 µS/cm). The water of the thermal spring had the temperature of 57,5°C and high SEC (1805 µS/cm), high carbonate concentration (20 mekv/l) higher chloride values (27 mg Cl^-/l) and the sulphate values of 26 mg SO_4^{2-}/l. High SEC value means high concentration of dissolved substances. The water probably contains other substances but our analyses were limited to the analyses mentioned above.

The scenic spot is the gathering place between the surface and underground water, and also the converging place of the N-S trending Suoge-Xuejiping fault and another E-W trending fault (Huang Chuxing 2004).

Baishuitai spring contain high mineralizated waters with regular temperatures. Baishuitai is situated about 20-30 km north from the Yangtze river. The area is built of Triassic rocks (limestones and sandstones) as well as of Permian rocks and Quaternary (delluvium) rocks.

Because the spring water is oversaturated it deposits dissolved mineral substances. In this sense the slopes are covered by mostly white tufa. The tufa dams and gours (Figure 9) are covering the areas of Lower and Middle Triassic limestones. The water resurges from different springs. The spring area is covered by deciduous trees, which are the source for pollution and also the food for

Fig. 9: Tufa gours of Baishuitai (photo by J. Kogovšek).

Slika 9: Baishuitai ponvice (foto J. Kogovšek).

algae growth. The springs are decorated with Buddhist symbols. Many people visit the spring area and walk over the tufa deposits what causes dams' destruction. The park administration is trying to protect the area.

The springs' temperature is between 11,1 and 13,3°C. The SEC measurements showed a little bit over 1000 µS/cm what means that the water has a lot of dissolved carbonates. Total hardness was 600 mg $CaCO_3$/l (12 mekv/l) and carbonate concentration 560 mg $CaCO_3$/l (11,2 mekv/l). The ratio Ca/Mg of the water was equal to 4,4, what shows that the Mg values are 4,4-times lower then the Ca and that the water is coming from the hinterland. The water had low nitrate and phosphate concentrations and 40 mg SO_4^{2-}/l of sulphates.

The temperature and conductivity measurements of the water in the gours along the water flow showed the

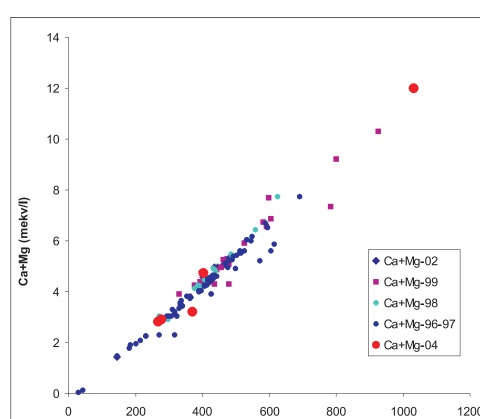

Fig. 10: SEC and total hardness of karst waters from different parts of Yunnan (Kogovšek 1998) and in the article mentioned springs.

Slika 10: Specifična električna prevodnost in celokupna trdota kraških voda iz različnih delov Yunnana (Kogovšek 1998) in v članku omenjenih izvirov.

increase of temperature and lowering of the SEC values, what is typical of intensive carbonate precipitation. At the bottom of the slope the water is led into the channel that runs to the nearest village where it is used for water supply and irrigation. Total hardness of this water was only 240 mg $CaCO_3$/l (4,8 mekv/l), with 210 mg $CaCO_3$/l belonging to carbonates (4,2 mekv/l). The ratio Ca/Mg was 3, suggesting mainly the calcium carbonate precipitation (from 1 liter of water up to 360 mg $CaCO_3$ was deposited) while magnesium remains in the solution. The same results were obtained in tufa precipitation at Podstenjšek spring in Slovenia (Kogovšek 2006). The lower concentration of sulphates (5 mg/l) compared with the values of the higher spring shows partial sulphate precipitation only. These are our first results, which should be expanded, as the nice and attractive gours need to be protected from numerous visitors. Liu Zai-Hua *et al.* (2004) reported about researches of geochemical indicators (saturation index, pH, CO_2 partial pressure) in calcite-precipitating stream and channel at Baishuitai.

Baishuitai tufa deposits in Yunnan are comparable with the Plitvice travertine dams in Croatia. They are probably thermogene (Pentecost & Zhang 2001).

CONCLUSIONS

The Yunnan Province lies on the eastern rim of the collision zone between the Indian plate and Eurasia. This region is characterized by complex Cenozoic structures and active seismotectonics.

The Quinglongtan spring (T = 14,7°C and low values of SEC, carbonate and total hardnesses) are situated north from Kunming. Similar values were detected in the area of Tianshengan, Yunnan at high hydrological conditions. The Zhenzhuquan spring near Lijiang had the same temperature but higher values of the SEC and hardnesses.

Quinglongtan and Zhenzhuquan springs and accumulation lake had low levels of phosphate (under 0,01 mg PO_4^{3-}/l) and low nitrate concentrations (from 1,3 to 4,6 mg NO_3^-/l) and are showing good water quality. The springs are situated inside the Xiaojiang fault zone along which sinistral horizontal movements are still active (Figure 1). Most probably they are karst springs.

In the wider zone of the Zhongdian fault between Zhongdian town and the Yangtze river there are more tectonic depressions, which are developed inside carbonate and non-carbonate rocks. In this sense they are not the true karst poljes. All depressions are developed inside NW-SE and N-S oriented active fault zone with sinistral horizontal movements.

In the wider zone of the Zhongdian fault there are more springs related to active tectonics. Tiansheng Qiao (T = 57,5°C) and Xiageiwenquan springs (T = 48,3 – 66,8°C) are thermal springs with tufa deposits. Baishuitai is very mineralized spring with lower temperature (T = 11,1 – 13,3°C), which deposits mostly calcium carbonate. The ratio of Ca/Mg decreases along the precipitation path, what means that Mg remains in solution. Also the sulphates are partly precipitating. Baishuitai travertines are probably thermogene (Pentecost & Zhang 2001).

Because carbonate tufas are very sensitive to water and climate Huang Chuxing (2004) performed the geomorphological investigations to provide scientific basis for the protection of tourist tufa resources of Tianshengqiao.

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HIDROKEMIČNE ZNAČILNOSTI IN TEKTONSKI POLOŽAJ IZBRANIH IZVIROV V OSREDNJEM IN SZ YUNNANU, KITAJSKA

POVZETEK

Kitajska provinca Yunnan je tektonsko zelo zanimiva, še vedno je tudi tektonsko zelo aktivna, kar dokazujejo močni potresi. Leži na stičišču dveh velikih tektonskih plošč Azijske na severu in Indijske na jugu, ki se podrivata ena pod drugo. Prelom Ailao Shan – Red River je eden najbolj izrazitih prelomov na Kitajskem. Današnje gibanje ob prelomu je desnozmično za 2-8 mm na leto. Prelom najprej sledimo zahodno od mesta Dali, potem pa se nadaljuje proti JV Yunnana po dolini Rdeče reke (Slika 1). Sledimo ga vse do obale vietnamskega morskega zaliva Tonkin v Južnokitajskem morju.

Kunming se nahaja v Xiaojiang prelomni coni, znotraj katere se vršijo levi zmiki. V okviru terenskega dela 18. do 29.10.2004 smo si severno od Kunminga ogledali akumulacijsko jezero in više ležeči izvir Quinglongtan (Slika 1, točka 3), ki prispeva vodo v akumulacijo. To so zgradili za oskrbo Kunminga s pitno vodo in za namakanje. Meritve temperature in specifične električne prevodnosti (SEP) treh glavnih izvirov Quinglongtan so pokazale, da gre za isto vodo (temperatura 14,8ºC in SEP 277 μS/cm). Voda v akumulaciji je bila toplejša (19,4ºC), po SEP pa je le minimalno odstopala od vrednosti izvira Quinglongtan. Vsebnost karbonatov je nizka (135 mg $CaCO_3$/l) tako v izvirni vodi kot v akumulaciji in je bila le malo nižja od celokupne trdote (146 mg $CaCO_3$/l). V izviru in v akumulaciji je bila koncentracija fosfatov pod mejo detekcije (<0,01 mg PO_4^{3-}/l), koncentracija nitratov pa je bila 4,6 oz. 4,4 mg NO_3^-/l, kar kaže glede na omenjena parametra dobro kakovost vode.

SZ del Yunnanan je premrežen s številnimi prelomnimi conami. Severno do Dalija se od preloma Red River odcepi še ena močna prelomna cona. V skrajnem SZ delu Yunnana se ta prelom imenuje po tibetanskem mestu Zhongdian, ki leži na nadmorski višini nekaj čez 3.000 m. Prelom Zhongdian, ob katerem se vršijo levi zmiki, poteka vzporedno z dolino reke Yangtze, nato pa se obrne proti jugu, v smeri mesta Dali, kjer se razširi v širšo prelomno cono. Mesto Lijiang, ki je v UNESCO-vi kulturni dediščini od leta 1997 je 3.februarja 1996 stresel močan potres z magnitudo M = 7.0 po Richterju. Mesto se nahaja v širši prelomni coni generalne smeri sever-jug, ki povezuje Zhongdian prelom z Red River prelomom.

Mesto Lijiang se z vodo oskrbuje iz bližnjega izvira Zhenzhuquan (Slika 4), kjer so vodo zajezili v majhno jezerce, ki je turistično zelo obiskano. Del vode je speljan po kanalih skozi mesto, pred časom je bil to verjetno način oskrbe mesta z vodo. Na glavnem izviru je črpališče (Slika 5) za oskrbo mesta s pitno vodo. Ob našem obisku smo srečali številne domačine, ki so prišli na izvir po vodo. Dne 24.10.2004 je bila temperatura izvira 14,8ºC, SEP 370 μS/cm, karbonatna trdota je bila 158 mg $CaCO_3$/l, celokupna pa 162 mg $CaCO_3$/l. Voda je imela nizko vsebnost kloridov, nitratov (1,3 mgNO_3^-/l) in fosfatov in je bila glede na te parametre dobre kakovosti.

Bai Shui He reka, ki priteka z območja Yulong Snow mountain (5596 m), je imela temperaturo le 9,6ºC, nizko SEP (196 μS/cm) in nizko karbonatno trdoto (2,17 mekv/l), pH = 8,2 in je vsebovala le 1 mg NO_3^-/l.

V širši prelomni coni Zhongdian preloma med mestom Zhongdian in reko Yangtze je več tektonskih depresij, ki so razvite v apnencih, mejijo pa tudi na nekraške kamnine, kot so magmatske kamnine, peščenjaki. Tako ne gre vedno za prava kraška polja. Vse depresije so vezane na aktivne prelomne cone, ob katerih se vzdolž prelomov smeri SZ-JV vršijo levi zmiki.

V širši prelomni coni Zhongdian preloma se nahaja več izvirov, ki so močno mineralizirani in izločajo del raztopljenih snovi. Nekateri so termalni, drugi pa nimajo povišane temperature. Glede na raziskave kitajskih znanstvenikov gre za izvire, kjer voda prihaja na dan iz velikih globin. Izmed številnih izvirov je potrebno poudariti tri: naravni most s termalnim izvirom Tiansheng Qiao (Slika 1, točka 1), Xiageiwenquan (termalni izviri) (Slika 1, točka 1) in Baishuitai (ponvice) (Slika 1, točka 2). Vsa tri mesta so dobro obiskane turistične točke.

Xiageiwenquan se nahaja 10 km južno od Zhongdiana in obsega več termalnih izvirov, ob katerih najdemo starejše in mlajše plasti sige. Tudi ti izviri so vezani na aktivne tektonske prelome. Toplo vodo uporabljajo v terapevtske namene. Dne 26.10.2004 smo izmerili temperaturo na treh izvirih in ugotovili, da dosega voda od 48,3 do 66,8ºC ter da vsebuje obilo raztopljenih snovi, saj je bila izmerjena količina raztopljenih snovi – SEP od 1260 do 1510 μS/cm.

Tiansheng Qiao se nahaja ob aktivnem levo zmičnem Suoge-Xuejiping prelomu na zahodni strani reke Jinsha. Naravni most (Slika 7), pod katerim teče reka Shuodugang, je zgrajen iz apnenca in je 40 m visok, 10 m širok in 15 m dolg. Neposredno ob naravnem mostu je termalni izvir Tiansheng Qiao, ki izloča travertin. Odlaganje travertina naj ne bi bilo starejše kot 5.000 let.

Voda termalnega izvira Tiansheng Qiao je imela 25.10.2004 temperaturo 57,5ºC, zelo visoko SEP (1805 μS/cm), visoko vsebnost karbonatov ter povišane vrednosti kloridov in sulfatov. Verjetno vsebuje še številne druge snovi, vendar so bile naše meritve in analize omejene le na zgoraj omenjene parametre. Topla voda z izvira odteka v bazen v sklopu »toplic« (Slika 8), kjer ponujajo različne terapevtske usluge. Neposredno ob bazenu tekoča reka Shuodugang je imela tedaj temperaturo 10ºC in nizko SEP.

Tudi **Baishuitai** izvir je vezan na aktivno tektoniko. Ker je voda na izvirih prenasičena, izloča ob polzenju po pobočju raztopljene mineralne snovi. Tako je celotno pobočje pokrito z belo prevleko, ki ga krasijo manjše in tudi zelo velike ponvice (Slika 9). Ponvice so se oblikovale na širšem področju spodnje in srednje triasnega apnenca. Voda izvira v več izvirih, del pa je priteka po manjšem kanalu iz višjega izvira. Izvirno področje je delno poraslo predvsem z listavci, tako da je odpadlo listje vir onesnaževanja oz. vir hrane za različne alge, ki motijo belino pobočja. Svoje dodaja tudi turistični obisk. Očitno se tega do določene mere zavedajo upravljalci, saj so na nekaj mestih napeli vrvi, ob našem obisku pa so se zanimali kaj merimo.

Meritve so na več izvirnih točkah pokazale, da je temperatura izvirov med 11,1 in 13,3ºC. Meritve SEP, ki so dale vrednosti celo nekoliko nad 1000 μS/cm, so nakazale, da izvirna voda vsebuje veliko raztopljenih karbonatov, kar so potrdile kasnejše analize vode. Celokupna trdota je znašala 600 mg $CaCO_3$/l, od tega je bilo kar 560 mg $CaCO_3$/l karbonatov. Razmerje Ca/Mg vode je bilo enako 4,4. Voda je imela nizke vsebnosti nitratov in fosfatov, vsebnost sulfatov pa je bila 40 mg SO_4^{2-}/l. Meritve temperature vzdolž pobočja in v ponvicah so pokazale segrevanje vode in upadanje SEP in razmerja Ca/Mg ter vsebnosti sulfatov, iz česar smo sklepali na intenzivno izločanje kalcijevega karbonata ter delno sulfatov, medtem ko magnezij ostaja v raztopini. Podobno smo ugotavljali tudi za izvir Podstenjšek v Sloveniji. Do dna pobočja se je iz enega litra vode izločalo povprečno 360 mg $CaCO_3$. Voda je speljana nato po kanalu do bližnje vasi, kjer jo uporabljajo kot pitno vodo in vodo za namakanje.

COBISS: 1.01

MONITORING THE FLOOD PULSES IN THE EPIPHREATIC ZONE OF KARST AQUIFERS: THE CASE OF REKA RIVER SYSTEM, KARST PLATEAU, SW SLOVENIA

SPREMLJANJE POPLAVNIH VALOV V EPIFREATIČNI CONI KRAŠKEGA VODONOSNIKA: PRIMER REKE REKE, KRAS, JZ SLOVENIJA

Franci GABROVŠEK[1] & Borut PERIC[2]

Abstract UDC 556.3 (497.4-14)

Franci Gabrovšek & Borut Peric: Monitoring the flood pulses in the epiphreatic zone of karst aquifers: The case of Reka river system, Karst plateau, SW Slovenia

The Reka river sinking into Škocjan caves (Škocjanske jame) is the main allogenic input into the aquifer of Classical Karst. So far the subsurface flow of the Reka river between Škocjan caves and the spring of Timava in Italy has been reached in five caves. Two were recently discovered in Slovenia. Continuous logging of water levels and temperatures in four of these caves was established in spring 2005. The paper presents and briefly discusses the first results obtained in three of them. The results are indicating a fast passage of a flood wave along a well developed conduit system.

Key words: karst hydrology, aquifer, flood pulse, Reka, Kras, Slovenia.

Izvleček UDK 556.3 (497.4-14)

Franci Gabrovšek & Borut Peric: Spremljanje poplavnih valov v epifreatični coni kraškega vodonosnika: Primer reke Reke, Kras, JZ slovenija

Reka Reka, ki ponika v Škocjanske jame, je najpomembnejši alogeni vir, iz katerega se napaja kraški vodonosnik. Doslej so med Škocjanskimi jamami in izviri Timave v Italiji našli pet jam, kjer je mogoče priti do podzemnega toka Reke. Dve so pred kratkim odkrili v Sloveniji. Pomladi leta 2005 se je začelo stalno spremljanje nivoja in temperature vode v štirih od teh jam. Članek predstavlja in na kratko obravnava prve rezultate, pridobljene na treh merilnih mestih. Rezultati kažejo na hitro potovanje poplavnega vala po dobro razvitem sistemu kraških kanalov.

Ključne besede: kraška hidrologija, vodonosnik, poplavni val, Reka, Kras, Slovenija.

INTRODUCTION

The Kras (Classical Karst) plateau has been attracting researchers for more than a century. Its aquifer is as complex as a karst aquifer can get. A more than 300 m deep vadose zone, huge underground cavities, all possible flow regimes, complex recharge and discharge conditions and complex evolution, enough to believe that the system is far from being resolved. This paper presents the first results of an ongoing effort to put a new stone into the puzzle of the aquifer of Kras.

Fig. 1 presents a generalized map and a cross-section of the Kras plateau and its surroundings. It shows the main geological formations, caves with the active underground flow and the measurement points presented in this paper.

Kras belongs to the Adriatic-Dinaric tectonic plate in the region of the Outer Dinarids (Kranjc, 1997). The folds sink towards NW under Soča alluvium. The same direction is also followed by the main draining conduits from SE of the plateau. The area is mostly composed of Cretaceous and Tertiary carbonate sediments.

The depth of the unsaturated zone reaches more than 300 m. Many caves, remains of an old drainage network, can be found along its complete vertical profile.

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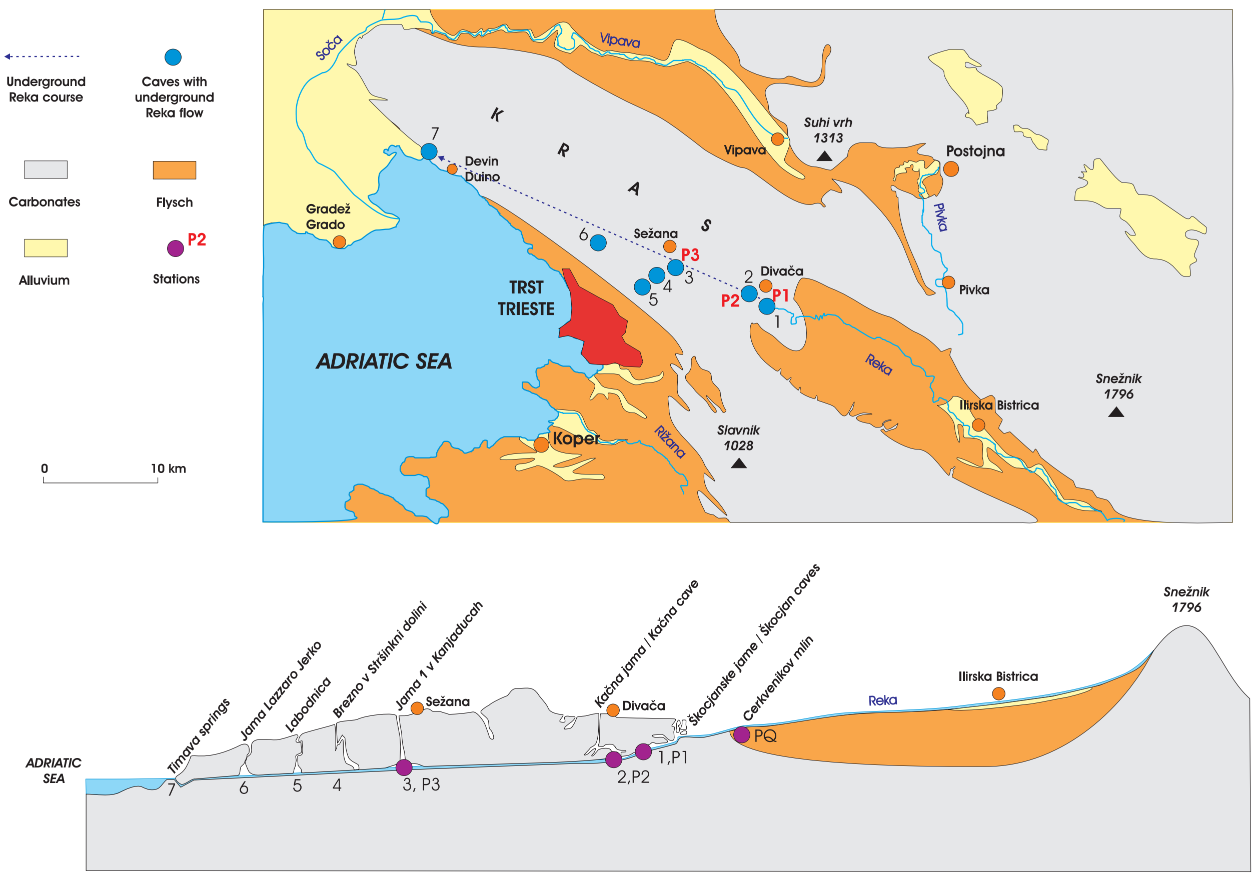


Fig. 1: Simplified map and cross-section of the Kras plateau with main geological formations, caves and measurement points presented in this study.

Below the piezometric surface, the structure of the aquifer is largely unknown. An indicator of a well developed conduit system was a sudden collapse in the Reka stream near Gornje Vreme in 1980, at the flysch-limestone contact, where around 1 m^3/s still disappears underground (Brilly *et al.*, 2002).

The focus of our study is epiphreatic zone, characterized by a high flow variability of the Reka river which is the main allogenic input to the aquifer. The river flows about 50 kilometers on impermeable flysch rocks, continues for another 7 kilometers as a surface flow on a limestone terrain, and starts its underground course at Škocjan caves. It emerges at the Timavo springs in Trieste Bay. The air distance between Škocjan caves and springs of Timavo is around 33 km. Based on the data of the Environmental Agency of the Republic of Slovenia for the period 1961–1990, the average discharge of the Reka River is 8.26 m^3/s. The ratio between low and high waters reaches 1 to 1700 with the maximum measured discharge 305 m^3/s, and minimum 0.18 m^3/s. The springs of Timavo have an average discharge of 30.2 m^3/s. Beside main spring, the aquifer discharges through the many other smaller springs in the vicinity, many of which are bellow the sea surface.

Efforts to reach Reka between Škocjan caves and the springs of Timavo have long history (Kranjc, 1997). At the moment we know five caves leading to the active subsurface flow: Kačna cave and Labodnica/Grotta di Trebiciano are well known and have already been thoroughly investigated. Recently, three additional caves were pushed down to the depths of active Reka flow: Lazzaro Jerko in Italy; Jama 1 v Kanjaducah and Brezno v Stršinkni dolini in Slovenia. The river has also been reached through Brezno 3G, which turned out to be another entrance of Kačna cave.

In Škocjan caves and Kačna cave it is possible to follow several kilometers of the underground river, while only small fragments are accessible in other caves as the confining siphons are not far apart, therefore further exploration is left to cave divers.

For more information on geology, speleology, hydrogeology and history of exploration and research of Classical Karst and its aquifer refer to (Cucchi *et al.*, 2000; Galli, 1999; Kranjc, 1997; Mihevc, 2001).

Cuchi and Zinni (2002) reported on the continuous monitoring of physical parameters of the subsurface Reka flow. They have measured level, temperature and specific electric conductivity in Škocjan caves, Grotta di Trebiciano/Labodnica, Lazzaro Jerko and Timavo springs. Based on more than 100 flood events, a distinction was made between three principal types of flood waves, characterized by the presence or absence of inflow from the sources that feed the Timavo river system: namely the Reka River, Brestovica basin and Soča-Vipava rivers basin. The temperature and conductivity changes between Škocjan caves, Labodnica/Trebiciano and Lazzaro Jerko cave indicate that the underground flow is fast (even more than 800 m/h) and continuous. Their results indicate a "direct drainage" along Škocjan-Labodnica/Trebiciano-Lazzaro Jerko. They proposed that the aquifer of Classical Karst is at the 3rd state of the Ford-Ewers's speleogenetic model (Ford & Ewers, 1978).

OBSERVATION POINTS

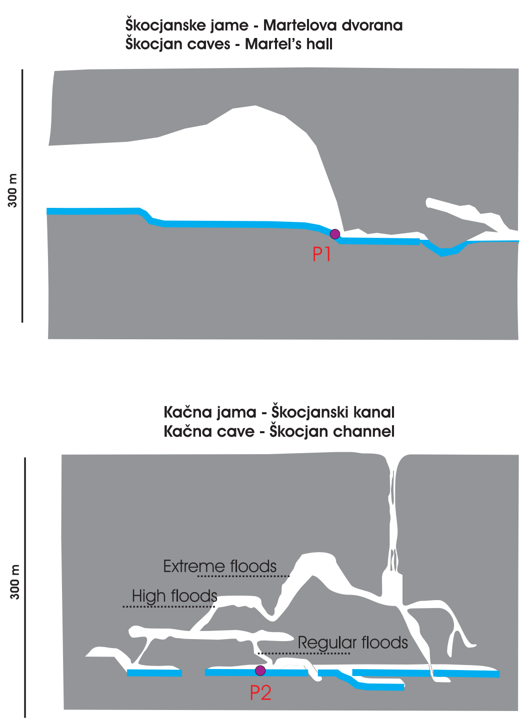
Except in Škocjan caves, the underground flow of Reka is not easy accessible. To reach it one must descend between 250 and 330 m down vertical shafts and steep galleries.

New entrances are rarely found. During the flood events when the water rises and squeezes the air from the voids and fractures, an intense airflow can be detected at some spots at the surface. These are the spots where cavers start following narrow leads through the vadose zone and hope to enter an easy passage to the river. Normally it takes years of digging and climbing to succeed. Except in Škocjan caves and Kačna cave, all the discoveries have been done this way.

Between February and October 2005, data loggers were placed in Škocjan caves, Kačna cave, Jama 1 v Kanjaducah and Brezno v Stršinkni dolini. Data from the first three caves have been retrieved so far and are presented in this paper. The distance between Škocjan caves and Kačna cave is about two kilometres. The direct distance from Kačna cave to Jama 1 v Kanjaducah is about seven kilometers (see Fig. 1).

The instruments were fixed to the underground river banks. In Škocjan caves and Kačna cave the micro location was chosen so that the instruments cannot be damaged by larger pieces of flotsam.

Fig. 2 shows simplified sketches of the caves with the positions of measurement points. In Škocjan caves it was fixed at Martel's lake (**P1**) at the end of 2.2 milions m^3 large Martel's chamber, in Kačna cave at rapids in Škocjanski kanal passage (**P2**), in Kanjaduce (**P3**) and Brezno v Stršinkni dolini it is located at terminal sumps at the end of the caves.



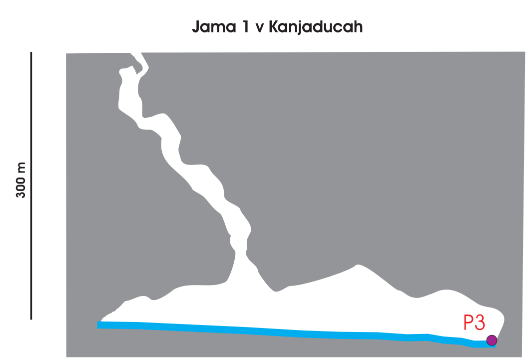


Fig. 2: Simplified sketches of the caves with positions of the measuring points. Flood levels based on flotsam occurrence (Mihevc, 2001) are marked in Kačna cave. Maps of Škocjan caves and Kačna cave were obtained from the Karst Research Institute archive and Slovenian cave cadastre. Map of Jama 1 v Kanjaducah was obtained from the web site of Sežana caving club (http://www.brlog.net/jds/kanjaduce.htm).

INSTRUMENTS

To log water level and temperature we use TD Diver produced by Van Essen, a Schlumberger company, Holland (Fig. 3). Instruments measure and record pressure and temperature. Recently we have introduced instruments (CTD Diver) which additionally log specific electric conductivity. The instruments are autonomous, the autonomy being guaranteed by the life span of internal batteries which is 8-10 y (depending on measurement frequency) and internal memory which can hold up to 24000 readings (TD). They are easy to program by the enclosed software. The sampling interval is between 5 seconds and 99 hours, sampling can be linear, logarithmic or event based. We used the instruments with the measurement range of 100 m. Precision of the level measurements is 0.1% of the full range, i.e. 10 cm in our case. Precision of temperature sensor is 0.1°C. Data from the instrument can be retrieved to computer via optical bridge as shown in Fig. 3.

Fig. 3: Datalogger in the office, connected to the computer via optical reader (left) and fixed to the wall of the terminate lake of Jama 1 v Kanjeducah (P3) (right).

The pressure sensor is a ceramic transducer therefore the measured level value is the sum of water and air pressure converted to a water column. For small level fluctuation (e.g. decimeter scale), the levels should be compensated with the barometric measurements of the surrounding atmosphere. Since we are interested in the large scale oscillations, we have not done that.

RESULTS AND DISCUSSION

The main input to our system is the sinking stream of Reka therefore the flow hydrograph at the station Cerkvenikov mlin provided by Slovene Environmental Agency is taken as an input data into the system. As mentioned, there is a considerable leakage from Reka into the karst aquifer before to the arrival at Škocjan caves which is neglected in the course of discussion. One should also consider the dispersed and concentrated input to the conduits from the karst surface along the entire pathway. The latter was reported by divers who conducted research in the terminal siphons of Škocjan caves.

Results for the entire period are shown in Fig. 4. During the spring, four flood events with the level rise of several meters occurred. A dry period followed with some small scale events in August.

Fig. 5 presents larger events in a weekly time window. Upper graphs show levels, whilst lower graphs their time derivatives, i.e. rising and dropping rates in m/h. Top axes give dates, bottom axes give time in hours elapsed since the recording started in Škocjan caves (February 18th, 2005). Note that the flow at Cerkvenikov mlin is in units of 10 m^3/s.

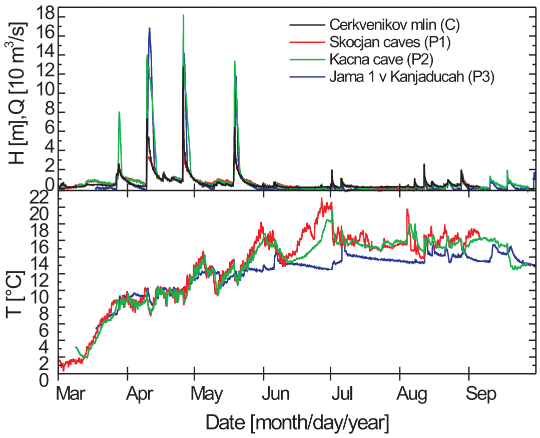


Fig. 4: Upper figure presents flow rates at Cerkvenikov mlin (C) and levels at points P1-P3 during the whole period. Lower figure shows temperatures at measurement points. Colour code is valid for both graphs.

First event (Fig. 5a), starting on March 27th, is compiled of two flood pulses with time lag of a day with peak flow rates at 15 and 25 m^3/s respectively. The level response to the first pulse was of similar magnitude in all three caves. Second pulse with 25 m^3/s did not make a considerable difference in Škocjan caves (P1) and Kanjeduce (P3), yet the level in Kačna cave (P2) rose for almost 7 meters. Slow increase of the input flow resulted in a slow increase of the levels. In Kačna cave (P2) the rate of level increase reached 0.9 m/h.

Second event (Fig. 5b) on April 9th , started with a 60 m^3 pulse which dropped to 20 m^3/s in 3 days. Long recession of input flow resulted in long recessions of levels in P1 and P2. This is the only event when the levels at P3 are above those at P2. One could attribute this to the unknown recharge along the pathway between Kačna cave and Jama 1 v Kanjaducah.

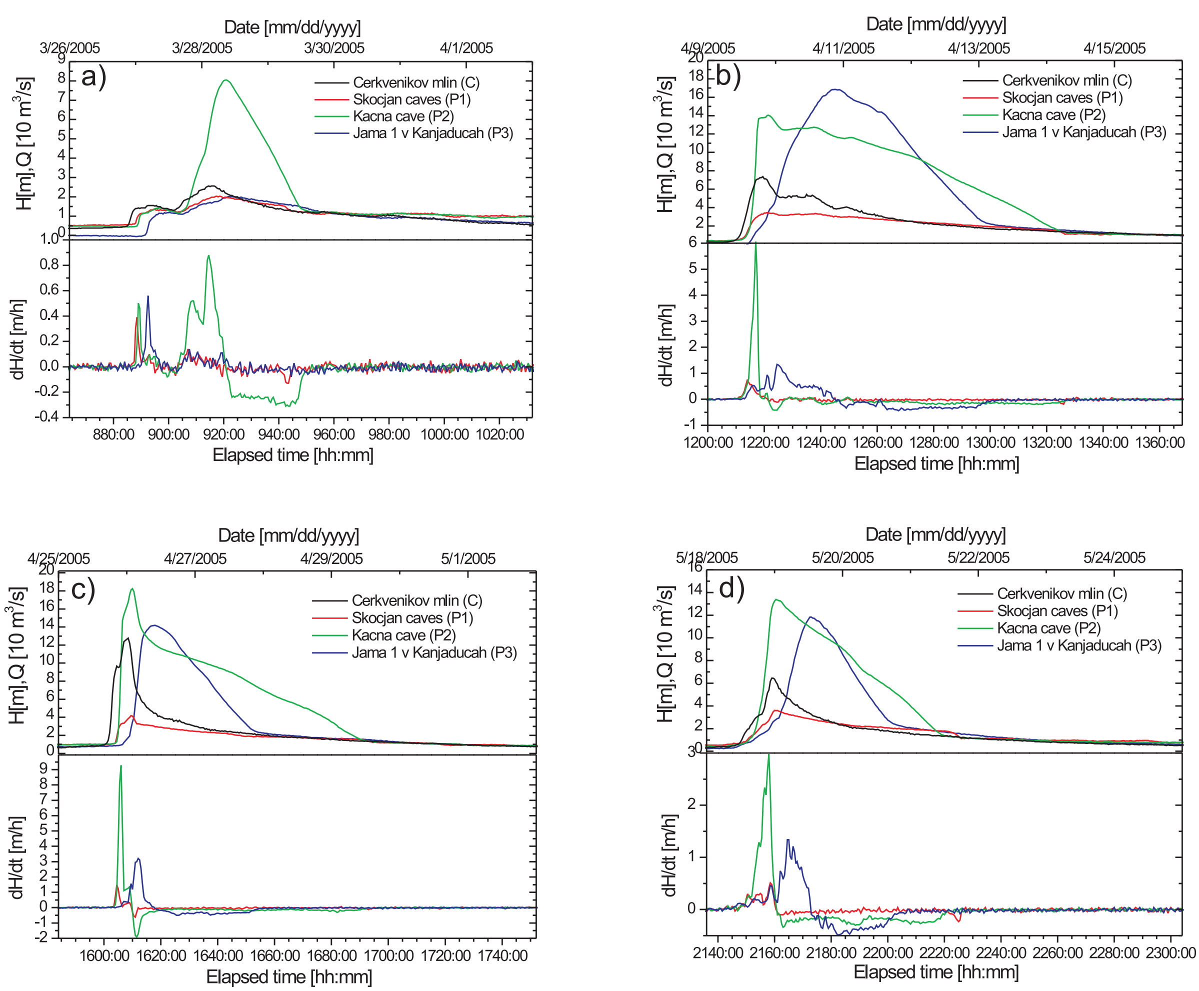


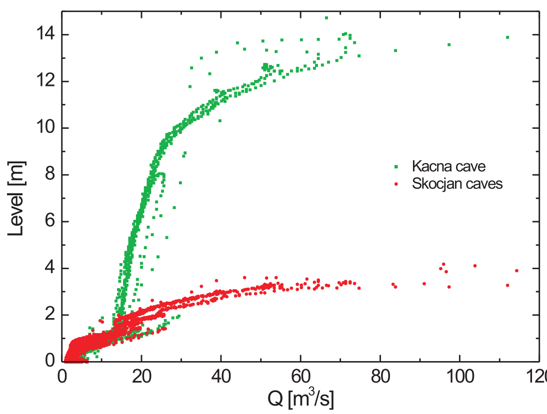
Fig. 5: The evolution of levels and level changes during for major flood events. Colour codes are valid for upper and lower graphs.

Third event (Fig. 5c) on May 25th was the largest. It comprises a single pulse with a maximum flow of 120 m^3. The responds at P1 and P2 is vigorous. At P2 (Kačna cave) the rate of level rise reached 9 m/h. Maximum level at P1 (Škocjan caves) is 4 m, at P2 18 m and at P3 14 m. How undisturbed the flood wave passed the way to P2 can be seen from the kink in the rising limb of hydrograph which is nicely preserved in the level hydrograph at P2.

Fourth event (Fig. 5d) is similar but smaller compared to the third event and needs no further discussion at this point.

There were several small flood events following the dry period in August. One of them is shown in the Fig. 15. All levels show a sharp rise suggesting that the passage of the pulse through the system is little affected by the restrictions.

The next step we take is to plot our results versus input. Therefore, Fig. 6 presents the levels at all points in dependence on the flow rates at Cerkvenikov mlin. We shifted the levels back in time with respect to flow to consider the travel time between Cerkvenikov mlin and particular measuring point. Therefore, the flow rates at time *t* are plotted with the levels at time *t+ T,* where *T* is the average value given in the Tab. 1. The choice is rather intuitive and although dubious for several reasons, the results are satisfactory for the first estimation.



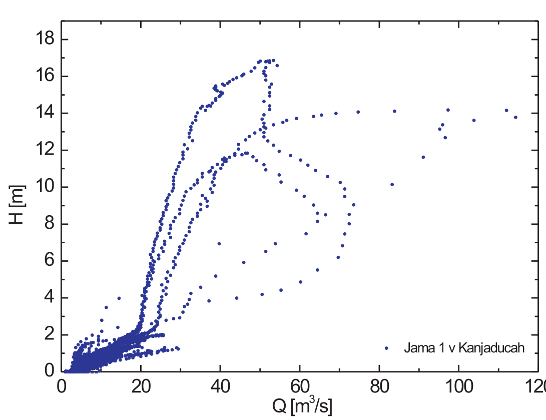


Fig. 6: Levels in Škocjan caves and Kačna cave (a) and Jama 1 v Kanjaducah (b) in dependence on the flow rates at Cerkvenikov mlin.

Levels in Škocjan caves and Kačna cave show similar behavior below 10 m^3/s. The level rises as the recharge increases according to the relations valid for the open channel flow (Dingman, 2002). When the flow exceeds 15 m^3/s, the curve in Kačna cave deviates. We attribute this to the constrictions downstream from the P2 in Kačna cave, which becomes fully flooded when flow exceeds 15 m^3/s. Fig. 7 presents an extended elevation of the section of the Kačna cave which includes P2. Grey area gives the passage height which is 4-7 m. The passage is about 15 m wide. Vertical scale above P2 shows levels, each bar representing 2 m. Dotted line gives the level of P2.

To see what happens when part of the channel becomes completely flooded, we have employed a simple numerical model of sloping channel system with restrictions as shown on Fig. 8. A system of four rectangular channels, each 400 m long, 5 m wide is subjected to the water input from the left. Channel 1 and 3 are more than 50 m high, while channel 2 and 4 representing restrictions are 3 and 1.5 m high.

We used Storm Water Management Model (V.5) obtained from the US Environmental Protection Agency (http://www.epa.gov/ednnrmrl/models/swmm/index.htm). The model allows calculations of flow and transport through the system of opened and closed channels as a response to a direct input or an input from the prescribed catchments area. One can apply static, kinematic or dynamic routing method and thus simulate many scenarios which are relevant for karst, when matrix flow could be neglected. The model has good potential for further in-depth exploration of flood wave passage through a well developed karst system (Campbell & Sullivan, 2002).

To a system presented on Fig 8. we introduced linear increasing flow rates. The Q-H graphs at points p_1 and p_2 are presented on Fig. 9.

Initially an open channel flow exists along the whole domain (Fig. 8a). The relation between flow and level for a uniform flow in an open channel can be obtained from the Chezy equation (Dingman, 2002). Flow and level are related by the power law $\Delta h \propto Q^n$, where $n = 6/10$ for a uniform rectangular channel (see Fig. 9). As the channel 4 becomes fully flooded (Fig. 8b) the level at p_2 deviates. Now the mass balance at point p_2 in channel 3 requires

$$A(H)\frac{dH}{dt} = Q_{in}(t) - Q_{out}\,, \qquad (1)$$

where *H* is the level, *A(H)* is the area of water surface in the channel 3 and $Q_{in}(t)$ is the inflow into the channel

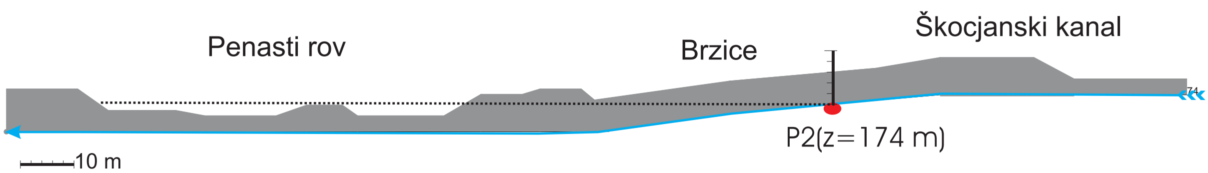


Fig. 7: Extended elevation of the section of Kačna cave that includes our measurement point. Grey area presents the channel height, dotted line the level of P2. Remapped from the original survey tables. (Source: Slovenian cave cadastre)

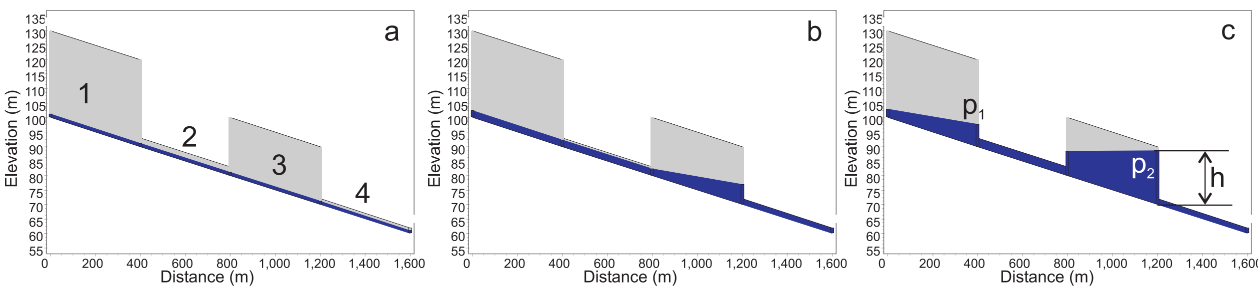


Fig. 8: System of sloping channels with restrictions. Restriction between points 4 and 5 is smaller than one between 2 and 3. A) Open channel flow is active along the whole domain. B) Restriction between points 4 and 5 is flooded. C) Both restrictions are flooded.

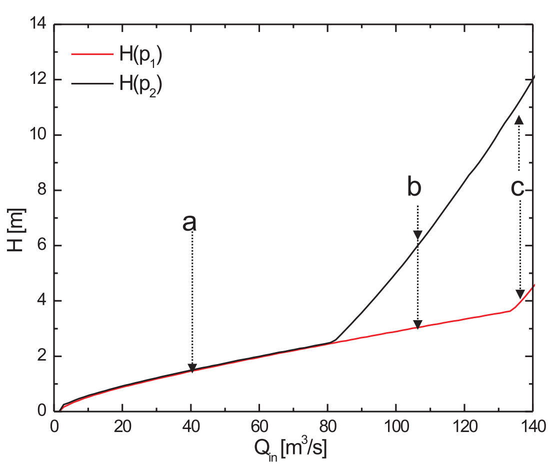


Fig. 9: Levels at points p_1 (red line) and p_2 (black line) in dependence on the input flow rates Q. Letters denote the situations a, b and c presented on Fig. 8.

3. Q_{out} is the outflow to the channel 4, given by Darcy-Weisbach (Beek *et al.*, 1999) equation

$$\Delta H + \Delta z = \frac{f \cdot L}{2gS^2 d} Q_{out}^{\ 2} = kQ_{out}^{\ 2} \qquad (2)$$

f is the friction factor, L the length of the conduit, S its cross-section, *d* its hydraulic diameter and *g* gravitational acceleration. ΔH is the difference between entrance and exit levels of channel 4 and Δz the elevation difference between the two sides. Combining Eqs. 1 and 2 we get

$$A\frac{dH(t)}{dt} + \frac{1}{\sqrt{k}}\sqrt{H(t) + \Delta z} = Q_{in}(t) \qquad (3)$$

Solution of Eq.3 gives the time dependence of the level, assuming that $Q_{in}(t)$, k and A are known. For arbitrary input we can find numerical solutions. We present model results when a flood wave recorded at Cerkvenikov mlin on May 25th (see Fig. 5) passes the system on the Fig. 8.

Fig. 10a presents the level hydrograph at p_2 and the input flow hydrograph Q_{in}, whilst Fig. 10b the flow-level curve. The dashed blue line on both figures denote the rising limb of the hydrograph.

The flow-level curve (Fig. 10b) exhibits a hysteresis which can be also observed on the flow-level curves of our real recorded hydrographs (Fig. 6), particularly for point P3, but also at P2. One reason is different location of flow and level hydrograph. Going downstream, the error we make by applying a constant time lag between the flow at Cerkvenikov mlin and the level at the station increases. We suspect that this is the main reason for the large areas of the hysteresis curves for Jama 1 v Kanjaducah.

Another reason for the hysteretic behavior is flooding caused by restrictions. For an in-depth study of this behavior we would have to analyse the solutions of Eq. 3, what we are not about to do. To demonstrate this we employ the even simpler model shown on Fig. 11. It comprise of a large 50 m high and 20 m wide channel ending with a 2 m high restriction of the same width. Input is at

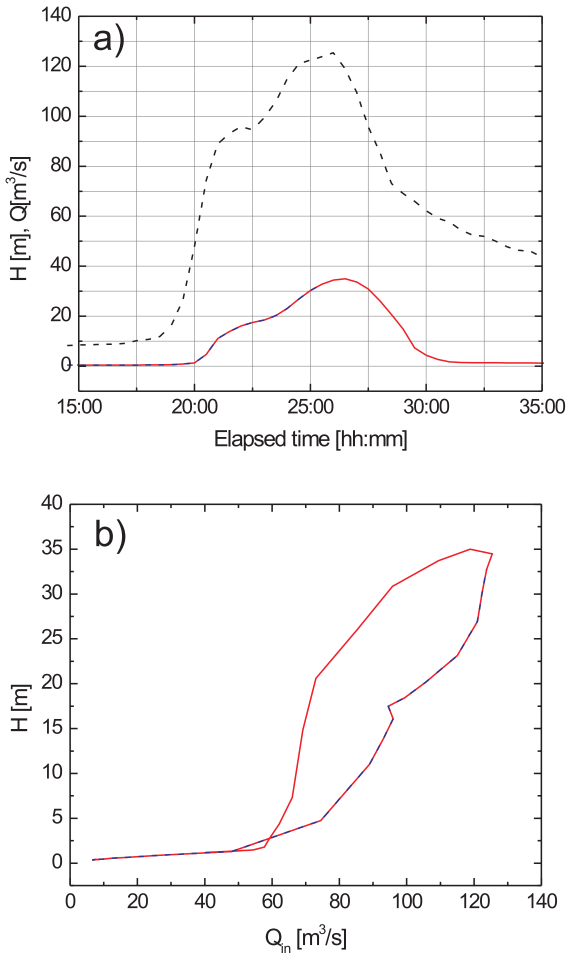


Fig. 10: Model results of the event (Fig. 5c) passing through the system on Fig. 8. ***a)*** *Dashed line presents the input flow rates, full lines give the level hydrogram h_2* ***b)*** *Flow-Level curve.*

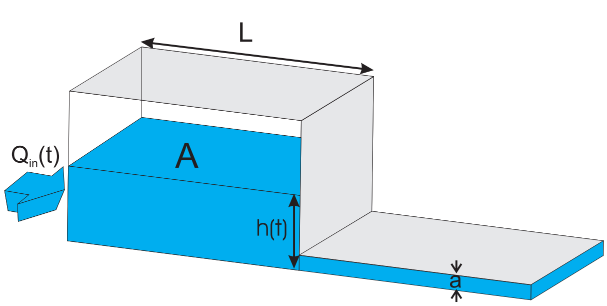


Fig. 11: Simple model of a large channel ending with restriction. The length of the entrance channel is L, a is the height of the restriction, A the surface area of the water prior to it and $Q_{in}(t)$ the input flow hydrograph.

the left-hand side and increases linearly from 0 to 150 m³/s between 0 – 24 hours and decreases linearly with the same slope during the second 24 hours.

The results are given in Figs. 12 and 13. Fig. 12a, presents the level response to a linear increase and drop of the flow rates (dashed line) for L = 1 km and different

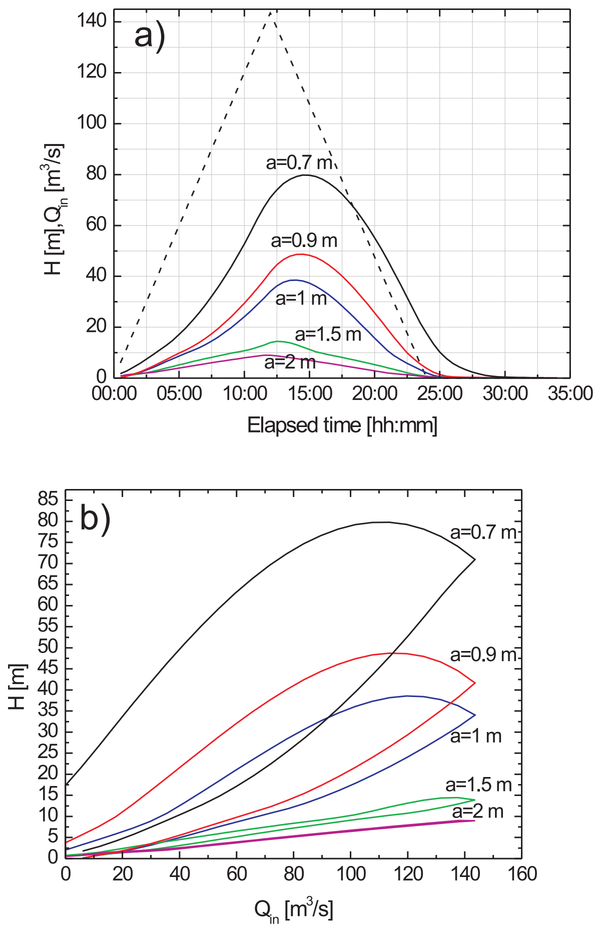


Fig. 12: a) Flow and level hydrographs for linearly increasing/ decreasing flood wave through the model given in Fig. 11. L=1 km. Different lines present results for various apertures of restriction as denoted on the figure. b) Q-H plots for different restriction apertures.

heights of the restriction as given on the graph. For *a* = 2 m we see that the shape of level curve resembles that of the flow. As the height of the restriction decreases the flow through it is more and more inhibited and the level curves become distorted. Fig. 12b shows Q-H plots for these cases. The areas of the curves increase as the height of the restriction decreases.

Fig. 13 presents case where the restriction height is constant, but the length of the input channel changes from 1 km to 20 km. The geometry of restriction is constant, with the height of 1 m. The level curves now de-

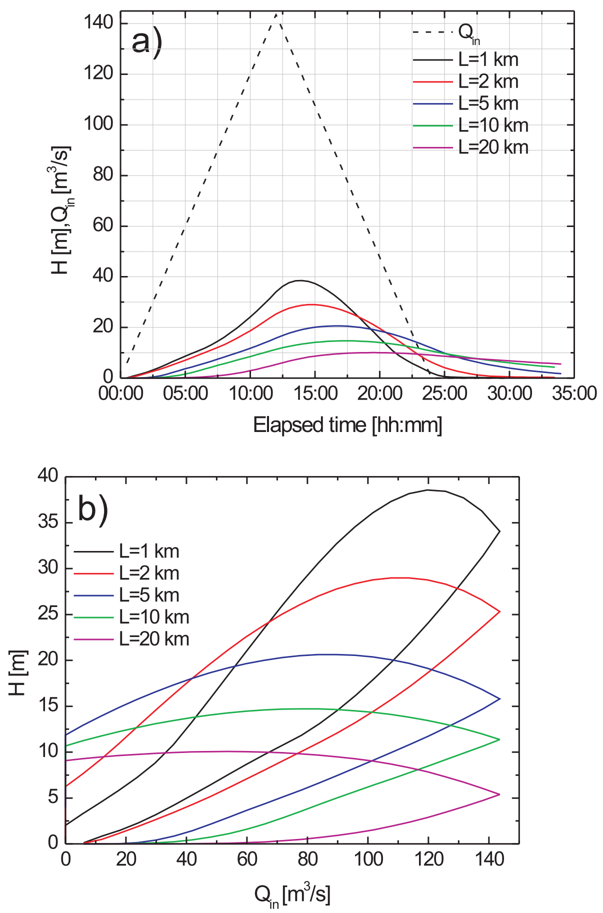


Fig. 13: a) Flow and level hydrographs for linearly increasing/decreasing flood wave through the model given in Fig. 11. a=1 m. Lines present results for different lengths of the input channel as denoted on the figure. b) Q-H plots for different lengths of the input channel.

pend on the flow-restriction relation given by Eq. 3, and also on the distortion of the input flood wave due to its propagation in the open channel.

Even though the models give at least qualitative explanation of what might happen in the real system, the latter is (un)fortunately not as simple as that. Explorers have been following flow directions and flood remains in Kačna cave since the discovery of Reka in the cave back in 1972. There are many bypass and overflow passages, two of them just a few meters above and few meters below the P2, both joining together and leading to a system of galleries at a higher elevation. Based on the flotsam occurrence. Mihevc (2001) found that extreme floods in Kačna cave reach 130 meters above P2.

As the monitoring of flood waves continues it will be very interesting to observe the dynamics of floods that may be of a larger scale than those in 2005. In 2002 an instrument was put into Škocjan caves that measures the water level. It recorded floods reaching 40 meters, much larger compared to a 5-meter flood in the present monitoring. The fastest rise recorded in Škocjan caves was 9 m/h. Unfortunately no such measurements were conducted in Kačna cave before 2005, where much steeper rises may be expected. Environment Agency data show that the Reka river discharge varied largely at individual floods.

We analyzed seven flood pulses to estimate the velocity of their propagation through the observed system by taking the peak to peak distance of the level derivative, i.e. the points of the highest rising rate. Not all floods could be easily analysed this way, as the input hydrograph was rather complex. Results are presented in Tab.1.

Date	**Q_{max}[m³/s]**	**Time C-P1 [h]**	**Time C-P2 [h]**	**Time C- P3 [h]**
27-Mar-05	15	2.5	3	6.3
25-Apr-05	120	2	3.5	10
1-Jul-05	19	2	2.5	5
5-Jul-05	10.1	2.5	3.5	8
7-Aug-05	10	3.5	4.5	9.5
11-Aug-05	26	2.5	4	7.5
29-Aug-05	19	2.5	3	5
Average travel time:		2.5	3.4	7.3

***Tab. 1:** Travel times of selected flood pulses from the hydrograph at Cerkvenikov mlin (**C**) to Martelova dvorana in Škocjan caves (**P1**), brzice (rapids) in Kačna cave (**P2**) and terminate lake in Jama 1 v Kanjeducah (**P3**).*

As can be seen from the table, about 2.5 hours is needed for the flood pulse to reach P1 in Škocjan caves, less than an hour more for P2 in Kačna cave and additional 4 hours for P3 in Jama 1 v Kanjaducah. An interesting point is that there are no big variations in the speed along the way. Kačna cave, which is approximately on the half way between Cerkvenikov mlin (C) and Jama 1 v Kanjaducah (P3) is also approximately at the half time of flood pulse travel between C and P3.

TEMPERATURES

Temperature is a parameter which carries much information on hydraulic and thermal conditions in the karst interior (Genthon *et al.*, 2005; Liedl *et al.*, 1998). Water exchanges its temperature with surrounding rocks on its underground course. The heat flux is proportional to the temperature gradient normal to the water-rock boundary. Assuming a good mixing of water, the water-rock temperature difference should decrease exponentially with the length of its underground flow. The exponential factor is a function of flow rate, geometry of the channel and the normal temperature gradient.

Fig. 14 presents the temperature evolution during recession after a large flood event (see Fig. 5b). Daily temperature oscillation at Kačna cave follows that of Škocjan cave, but its amplitude progressively decreases as the flow rates drop and the peak to peak distance increases. Oscillations at P3 are hardly observed and vanish when the flow is low enough (e.g. smaller than 0.5 m^3/s).

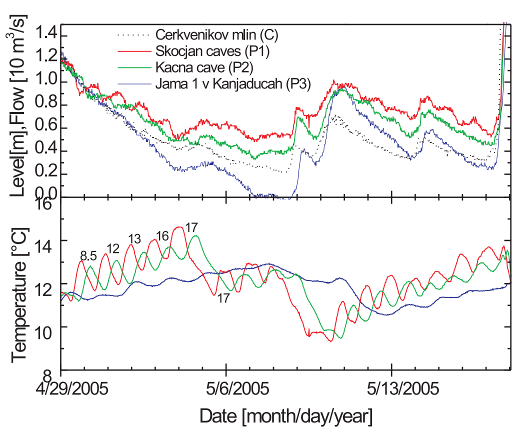


Fig 14: Flow, level and temperature following a flood event. Numbers at the temperature curves indicate peak to peak difference in hours between the temperatures at P1 and P2.

Further data and analysis are needed to understand the temperature dynamics upon arrival of the flood pulses. Nevertheless, we see from Fig. 15 that the levels and temperatures respond simultaneously to a small event on August 11th.

Along completely flooded parts the level signal is pressure transferred, and therefore faster than the temperature signal. Simultaneous arrivals of both signals show the absence of such segments, leading to a conclusion that an open surface flow of Reka along most of the way could be expected at least for event of comparable scales.

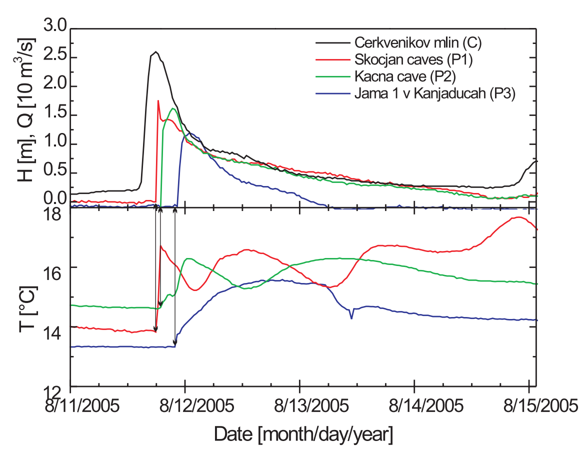


Fig. 15: Level and temperature responds to a small flood event following a period of dry conditions.

CONCLUSION AND FURTHER PERSPECTIVES

The intention of this paper was to present the first results; therefore conclusion will be rather short. There is a fast passage of a flood wave through the presented part of the system. To give the relation between the travel time of the water parcel and that of the flood pulse further data and analysis are required. Nevertheless some data indicate that the these times are similar at least for small flood events (see Fig. 15). During low flow, travel times become order of magnitude larger (Fig. 14). From the passage of flood waves through the system we anticipate a (continuous) system of large conduits also in the parts which are inaccessible at the moment.

Many assumptions are still to be proved. Data are being recorded at all measuring points. Valuable sets of data is expected from Brezno v Stršinkni dolini and caves on the Italian side of the plateau, which are located in the area where the gradient becomes practically flat.

Further actions include in-depth time series analysis, integration of precipitation data, dye tracing of main Reka flow with field fluorimeters positioned in caves and further numerical modelling of events passing through the conduit-restriction systems with open channel and pressure flow.

Flooding could be an important factor for the genesis of large voids in the studied caves (Mihevc, 2001). Large oscillations of water levels could be important if not crucial factor for the genesis of large voids like sub/vertical galleries in Jama 1 v Kanjaducah and Brezno v Stršinkni dolini and Lindner's hall in Grotta di Trebiciano.

ACKNOWLEDGMNETS

This research would not be possible without an invaluable work of generations of cavers in all investigated cave. Thanks to cavers from Divača and Sežana for the help with our work. The study has been supported by the Interreg project "Monitoring of the underground flow of reka Reka" (Vzpostavitev monitoringa podzemnega toka Reke).

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FIZIKALNO-KEMIČNE ZNAČILNOSTI IZLOČANJA TRAVERTINA – PRIMER PODSTENJŠKA (SLOVENIJA)

PHYSICO-CHEMICAL PROPERTIES OF TRAVERTINE DEPOSITION – THE CASE OF PODSTENJŠEK (SLOVENIA)

Janja KOGOVŠEK[1]

Izvleček UDK 556.3:553.556(497.4)

Janja Kogovšek: Fizikalno-kemične značilnosti izločanja travertina – primer Podstenjška (Slovenija)

Podane so osnovne fizikalno-kemične značilnosti kraškega izvira Podstenjšek, ki je v preteklosti izločal karbonate, o čemer pričajo bloki travertina ob strugi. Meritve in analize izvira ter njegovega vodnega toka niže na več zaporednih točkah so pokazale, da se iz vode prek celega leta izloča kalcijev karbonat. Intenzivnost izločanje je odvisna od pretoka in od segrevanja oz. ohlajanja vode. Iz enega litra vode se je na prek 1 km dolgi poti izločalo od nekaj do 36 mg $CaCO_3$/l, večina tega že na prvih 400 m.

Ključne besede: krasoslovje, kraški izvir, fizikalno-kemične značilnosti, izločanje kalcijevega karbonata, Slovenija.

Abstract UDC 556.3:553.556(497.4)

Janja Kogovšek: Physico-chemical properties of travertine deposition – the case of Podstenjšek (Slovenia)

The basic physico-chemical properties of the karst spring Podstenjšek, depositing carbonates in the past shown by travertine blocks in its riverbed are given. Measurements and analyses of the spring and its water flow downwards at several sampling points showed that during the whole year the water precipitates calcium carbonate. The intensity of deposition depends on discharge and warming or cooling of water. From one litre of water at the distance of one kilometre from some to 36 mg $CaCO_3$/l are deposited, the majority at the first 400 m.

Key words: karstology, karst spring, physico-chemical properties, calcium carbonate deposition, Slovenia.

UVOD

Podstenjšek je kraški izvir, ki je vezan na stik paleogenskega apnenca z neprepustnim flišem (Gospodarič *et al*. 1968). Po krajšem toku se izliva v Reko. Njegovo zaledje na severu sega do zaledja Pivke. Desna stran doline Zgornje Pivke je v povirnem delu od Knežaka do Pivke zelo ozka in omejena v glavnem na razmeroma malo razčlenjen kraški greben, Taborski hrbet. Na njegovi JZ strani je dolina Reke, tako da poteka po hrbtu razvodje med jadranskimi, med katerimi je tudi Podstenjšek, in črnomorskimi pritoki (Gospodarič et el. 1968). Jenko (1954) je ocenjeval, da se iz okolice Knežaka in Koritnic kar okoli 90% vode odteka v Bistrico, kar pa ni bilo potrjeno z barvanjem.

Vodozbirno območje Podstenjška sestavljajo kavernozno-razpoklinski apnenci in dolomiti kredne in paleogenske starosti s srednjo prepustnostjo (Kovačič 2001). Izvir se napaja z infiltracijo padavin. Leta 1992 so ga zajeli za oskrbo prebivalstva s pitno vodo. V neposrednem območju zaledja leži naselje Šembije. Konec devetdesetih let so zato v Šembijah uredili kanalizacijo, odpadne vode pa speljali na čistilno napravo. Vzdolž struge zgornjega dela Podstenjška so gmote travertina, ki pričajo o njegovem odlaganju v preteklosti.

V letih 1994, 1996, 1998 in 1999 smo zajeli deset serij vzorcev vode Podstenjška, v večini primerov pa tudi vodo Podstenjška na točkah dolvodno, da bi ugotovili osnovne značilnosti izvira in izločanje travertina iz njegove vode.

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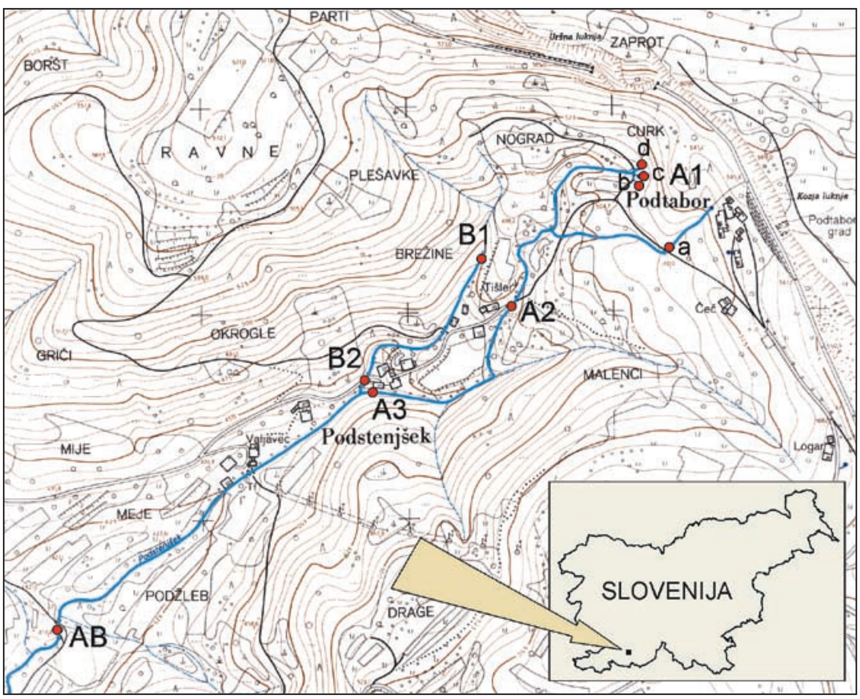
Opazovanja Podstenjška sem zastavila tako, da sem zajela različnejše hidrološke razmere, od nizkih do visokih voda. Spremljanje izločanja vzdolž njegove poti je tako potekalo ob različno velikih pretokih in v razmerah, ko se je voda na poti izločanja segrevala ali ohlajala oz., ko ni prihajalo do bistvenih sprememb temperature.

MESTA OPAZOVANJ IN METODE DELA

Izvir Podstenjšek (**A1**) je zajet za vodooskrbo. Večji del vode priteka iz Kozje jame, prelivna voda pa odteka mimo črpalnice (**a**). Drugi del vode Podstenjška prihaja na dan v treh izvirih desno od črpalnice (**b, c** in **d**), če gledamo dol-vodno (slika 1). V sušnih razmerah je bil serije pa s konduktometrom LF 196 (25°C). Te vrednosti smo na osnovi primerjalnih meritev z obema merilnikoma preračunali na vrednosti pri 20°C. Vsebnost raztopljenega kisika sem določala z oximetrom OXI 196, pH pa s pH 90, vse firme WTW.



Sl. 1: Zajemna mesta na izviru in vzdolž toka Podstenjška (Vir: Temeljni topografski načrt merila 1: 5000, © Geodetska uprava Republike Slovenije, 1978).

Fig. 1: Sampling points at spring and at downwards water flow (Source: Temeljni topografski načrt merila 1: 5000,© Geodetska uprava Republike Slovenije, 1978).

aktiven le izvir b. Vzorce smo zajemali na tem izviru, saj sem ugotovila, da je njegova sestava v okviru napak določitev enaka vodi, ki priteka iz Kozje jame (**a**). V času rednih opazovanj smo zajemali vzorce še pod mostom (**A2**), pred sotočjem (**A3**) z desnim manjšim pritokom ter niže v ravninskem toku pri hrastu (**AB**). Vzorčevali smo tudi omenjeni desni pritok na izviru (**B1**) in pred sotočjem z zgornjim tokom Podstenjška (**B2**).

Ob vzorčevanju smo na izbranih točkah merili temperaturo in specifično električno prevodnost (SEP) s konduktometrom LF 91 (20°C), firme WTW, zadnje tri

Vzorce vode sem zajemala v polietilenske plastenke brez zraka in so bili kasneje isti ali pa naslednji dan analizirani. Pri prenasičenih vzorcih namreč ob prezračevanju lahko prihaja do izločanja karbonatov. V laboratoriju smo določevali še vsebnost karbonatov, kalcija, magnezija, kloridov, nitratov, sulfatov in fosfatov po standardnih metodah (Standard Methods for Examination of Water and Wastewater 1992). Zajeli smo 10 serij vzorcev.

PADAVINSKE IN HIDROLOŠKE RAZMERE

V okviru 10 opazovanj, ko so bile opravljene meritve in vzorčenje, smo zajeli najrazličnejše razmere od nizkih do visokih voda. Ker nismo imeli meritev pretoka, so vsakokratne hidrološke razmere podane opisno.

Ob prvem vzorčenju 29.1.1994 so bili aktivni vsi izviri, skupni pretok b+c+d sem ocenila na nekaj litrov, medtem ko je bil pretok pod mostom, ko se mu pridruži še prelivna voda iz Kozje jame (a) okoli 20 l/s. Konec decembra 1993 je padel sneg, prva dva tedna v januarju pa je padlo kar nekaj dežja (v Postojni okoli 140 mm), nato pa ni bilo omembe vrednih padavin.

Ob drugem vzorčenju 25.3.1994 so bili pretoki po oceni nekoliko nižji, skupni pretok pod mostom pa sem ocenila na okoli 10 l/s. Februarja je padlo malo padavin, v Postojni le 90 mm. Desni pritok (B) je izviral podobno kot januarja 1994 pri drevesu.

Dne 1.12.1994, ko sem tretjič zajela vzorce, je bil skupni pretok Podstenjška pod mostom tolikšen, da je dobro prekrival dno, medtem ko je izvir B izviral više kot v času predhodnih vzorčenj. V začetku novembra je padlo v Postojni 100 mm dežja, nato pa je bilo sušno.

Ob vzorčenju 20.3.1996 je bil skupni pretok še nižji kot decembra 1994, saj mesec dni skoraj ni bilo padavin, vendar pa je bilo površje cel januar in februar pokrito s snežno odejo.

Dne 15.5.1996 sem ocenila vode od višje do visoke. V začetku aprila je intenzivno deževalo, kar nekaj dežja pa je padlo tudi maja pred vzorčenjem (v Postojni 90 mm).

Ob vzorčenju 6.8.1996 je bil najvišji izvir d suh, pretok izvira c pa je bil nižji kot izvira b, ki sem ga ocenila na 0,5 l/s. Pod mostom (A2) je bil pretok najnižji od vseh dotedanjih vzorčenj, okoli 5 l/s.

Dne 13.11.1996 sem pretoke ocenila kot srednje do višje in pretok izvira b na 1,5 l/s.

V času vzorčenja 10.8.1998, ko so prevladovale sušne razmere, smo ocenili pretok izvira B1 le na 0,25 l/s.

Ob vzorčenju 13.10.1998 so bili pretoki visoki, najvišji v okviru opazovanj, pod mostom je bila gladina vode nekako 30 cm nad dnom. Ves oktober je intenzivno deževalo in do dneva vzorčenja je v Postojni padlo že prek 180 mm dežja.

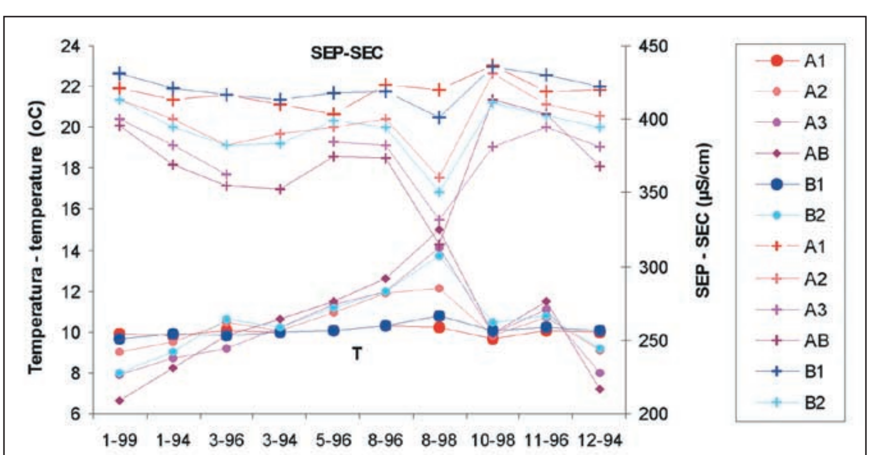
Dne 26.1.1999 je bil izvir d skoraj suh, izdatnejša sta bila c in b. Pod mostom je gladina vode dosegala 5-10 cm višine. Januarja je v Postojni do 26. dne padlo namreč le 55 mm snega in dežja skupaj.

REZULTATI

MERITVE TEMPERATURE, SEP IN pH

Meritve in vzorčenja so zajela razmere prek celega leta. Povprečna temperatura Podstenjška (izvir b) je bila 10,3°C, prek leta je nihala od 9,7 do 10,3°C. Povprečna temperatura izvira B1 je bila 10,1°C. Voda Podstenjška se je vzolž svojega toka poleti segrevala, najbolj avgusta; pozimi, decembra in januarja se je ohlajala; marca in oktobra pa se njena temperatura ni bistveno spreminjala (slika 2).

Povprečna SEP Podstenjška je znašala 417 µS/cm, najnižjo vrednost 404 µS/cm je dosegel maja 1996 ob najvišjem spomladanskem pretoku v okviru opazovanj. SEP je nihala v intervalu 20 µS/cm. Podobno smo izmer-



Sl. 2: Meritve temperature in SEP: na izviru Podstenjška (A1) ter na točkah A2 in A3, na izviru B1 in pred sotočjem na točki B2 ter na točki AB.

Fig. 2: Temperature and conductivity measurements: at Podstenjšek spring and at points A2 and A3, at B1 spring, at points B2 and AB.

ili na izviru B1, le da so vrednosti nihale v intervalu 30 µS/cm (slika 2).

Povprečna vrednost pH Postenjška je znašala 7,6 in je nihala med vrednostima 7,3 in 7,9. Podobno smo izmerili tudi za izvir B.

CELOKUPNA IN KARBONATNA TRDOTA TER Ca/Mg

Povprečna celokupna trdota Podstenjška (10 določitev) je bila 4,51 mekv/l in je nihala v sorazmerno ozkem intervalu od 4,26 do 4,74 mekv/l; povprečna karbonatna trdota je bila 4,19 mekv/l in je nihala v intervalu 3,98 – 4,47 mekv/l. Potek celokupne trdote je vzporeden s potekom karbonatne trdote in SEP prek leta. Opazne so nižje vrednosti spomladi ter višje konec poletja in v jesensko-zimskem obdobju. Nekarbonatna trdota je nihala v intervalu 0,26 – 0,38 mekv/l. Podobne vrednosti z manjšimi odstopanji je izkazoval tudi izvir B1.

Povprečna vrednost razmerja Ca/Mg Podstenjška je bila 11,1 in je nihala v intervalu 6,4-14,1. To nakazuje, da priteka voda v izvir pretežno iz apnenčastega, delno pa tudi iz dolomitnega sveta. Izstopajočo najnižjo vrednost (6,4) je Podstenjšek dosegal oktobra 1998 ob najvišjem pretoku v okviru opazovanj, ko je pritekala v izvir voda z najširšega zaledja, očitno intenzivneje tudi z območja, ki ga gradijo dolomiti. Tedaj smo v okviru opazovanj zabeležili tudi najvišjo karbonatno in celokupno trdoto. Ob nizkem, srednjem in višjem vodostaju so vrednosti Ca/Mg nihale okoli vrednosti 11,6. Podobno smo ugotavljali tudi za izvir B1, le da so njegove vrednosti nihale v nekoliko ožjem intervalu (Slika 3).

Popolnejšo sliko nihanj omenjenih parametrov bi podale zvezne meritve oz. meritve v primernem časovnem intervalu, posebno še v času vodnih valov po padavinah, ko običajno prihaja do največjih sprememb, kar so pokazale že podrobne meritve drugih kraških izvirov (Kogovšek 1999, 2001, Kogovšek *et al*. 2003).

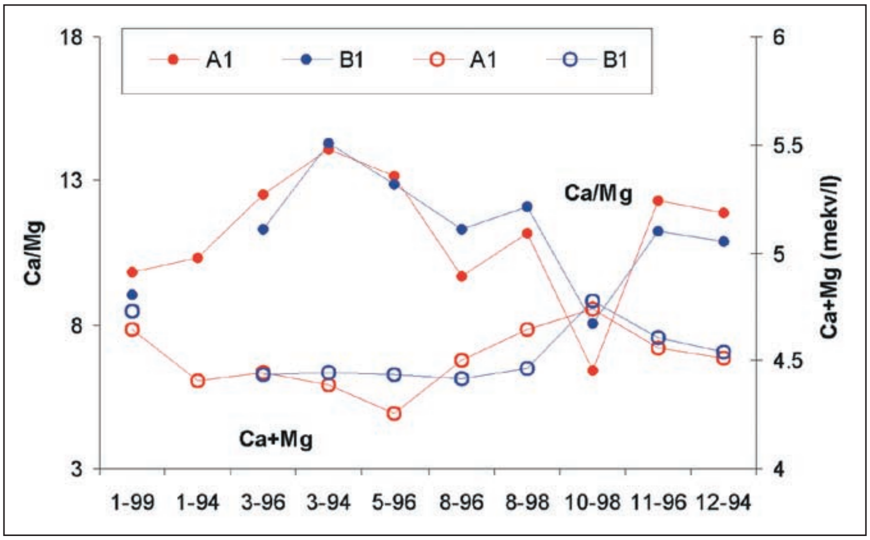
KAKOVOSTNI PARAMETRI: KLORIDI, NITRATI, FOSFATI, SULFATI

V okviru meritev in analiz smo leta 1996 začeli tudi z analizami za določitev vsebnosti nitratov, fosfatov, kloridov in sulfatov. Kljub sorazmerno majhnemu številu analiz (7 do 9) jih lahko privzamemo kot oceno tedanjega stanja, saj so analize zajele različne vodostaje in različne čase prek leta.

Povprečna vrednost kloridov je bila 3,8 mg Cl-/l, vrednosti pa so bile v intervalu 2,4 – 5 mg Cl^-/l. Povprečna vsebnost nitratov je bila 6,7 mg NO_3^-/l, analize pa so pokazale vrednosti v intervalu 5,5 – 7,9 mg NO_3^-/l. Povprečna vrednost o-fosfatov je bila 0,03 mg PO_4^{3-}/l, vrednosti pa so bile v intervalu 0,02 – 0,05 mg PO_4^{3-}/l. Vsebnost sulfatov je nihala od 7,8 do 10,5 mg SO_4^{2-}/l, povprečna vrednost pa je bila 8,9 mg SO_4^{2-}/l.

Kloridi, nitrati in o-fosfati izvira B1 se sorazmerno dobro ujemajo z vrednostmi za Podstenjšek, z občasnimi manjšimi odstopanji. Nekoliko izraziteje pa odstopajo sulfati.

Konec leta 1998 in januarja 1999, ko je bila postavljena čistilna naprava za naselje Šembije, nismo opazili opaznega izboljšanja kakovosti Podstenjška. Vendar pa ne vemo, ali je tedaj že obratovala. Iz dosedanjih raziskav spiranja kontaminantov skozi 100 m debelo vadozno cono vemo, da pride po odstranitvi vira onesnaženja do največjega izboljšanja kakovosti vode v prvih treh letih (Kogovšek 1997). Ker so izhodne vrednosti nitratov, fosfatov in kloridov sorazmerno nizke, bi lahko pričakovali kvečjemu zmanjšanje do polovičnih vrednosti.



Sl. 3: Potek celokupne trdote (Ca+Mg) ter razmerja Ca/Mg Podstenjška (A1) in izvira B1.

Fig. 3: Total hardness (Ca+Mg) in ratio Ca/MG of Podstenjšek spring and B1 spring.

IZLOČANJE KALCIJEVEGA KARBONATA

Izločanje karbonatov iz vode Podstenjška smo spremljali z meritvami SEP ter vzporednimi analizami karbonatov, kalcija ter celokupne trdote vzdolž toka Podstenjška na razdaljah A1-A2 in A2-A3 ter skupno na razdalji A1-AB (tabela 1), ko se mu je pridružil še stranski dotok B2. Vzporedno smo spremljali tudi izločanje iz vode pritoka na odseku B1 – B2 (tabela 1).

Tabela 1: Izločanje kalcijevega karbonata na opazovanih odsekih.
Table 1: *Calcium carbonate deposition at different sectors.*

Relacija	Razdalja (m)	Izločeni $CaCO_3$ – minimum		Izločeni $CaCO_3$ – maximum	
		(mekv/l)	mg $CaCO_3$/l	(mekv/l)	mg $CaCO_3$/l
A1 – A2	305	0	0	0,38	19
A2 – A3	260	0,06	3	0,28	14
A1 – A3	365	0,06	3	0,58	29
B1 – B2	215	0,16	8	0,38	19
A1 – AB	1050	0,15	8	0,72	36

Pokazalo se je, da se izloča predvsem kalcijev karbonat, saj so vrednosti karbonatov, kalcija in celokupne trdote vzdolž poti sočasno in enako upadale. Odstopanja so bila v okviru predvidenih napak določitev (do 0,04 mekv/l). Medtem je ostajala vsebnost magnezija skoraj nespremenjena, kar je skladno z dejstvom, da je topnostni produkt $MgCO_3$ v primerjavi s $CaCO_3$ večji. Podobno sem ugotavljala za izločanje sige v Planinski jami (Kogovšek & Habič 1981).

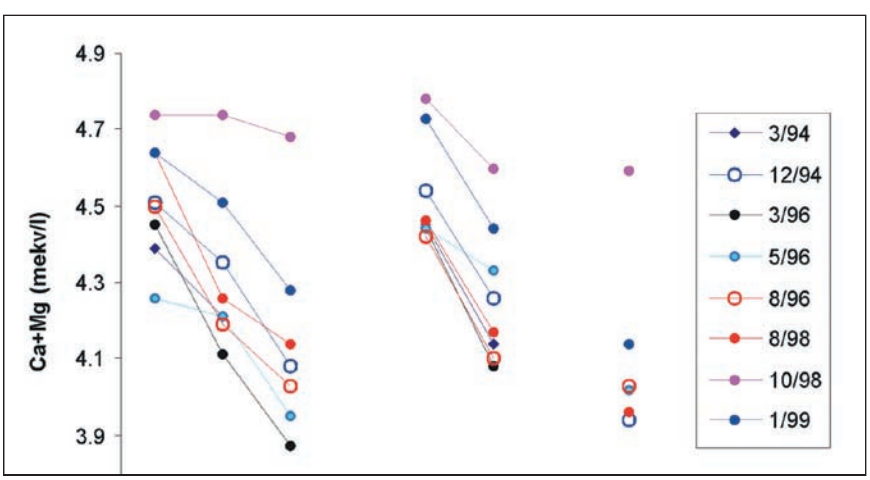
Meritve so pokazale, da se iz vode Podstenjška in njegovega pritoka (B1) izloča kalcijev karbonat prek celega leta, vendar različno intenzivno. Velik strmec začetnega toka omogoča intenzivno prezračevanje vode.

Na izločanje oz. na stopnjo izločanja najbolj vpliva pretok, saj smo ob najvišjem ocenjenem pretoku 13.10.1998 ugotovili najmanjšo stopnjo izločanja. Na odseku A1-A3 se je izločalo le 0,06 mekv $CaCO_3$ iz litra vode, kar je 3 mg $CaCO_3$ /l (slika 4). Vendar pa ima ob visokih pretokih nasproten učinek erozija.

Ob najnižjih pretokih marca 1996 ter avgusta 1996 in avgusta 1998 je prišlo ob segrevanju vode do najintenzivnejšega izločanja že na prvem 305 m dolgem odseku A1-A2. Na prezračevanje vode, uhajanje CO_2 in posledično izločanje kalcijevega karbonata, je poleg strmca ugodno vplivalo še segrevanje vode. Izločila se je več kot polovica (0,5 – 0,7) kalcijevega karbonata glede na izločeni kalcijev karbonat na celotni poti A1-AB. Ob najvišjem pretoku oktobra 1998 na tem odseku nismo določili izločanja in sklepam, da je bilo tako majhno, da ga je prekril razredčevalni efekt.

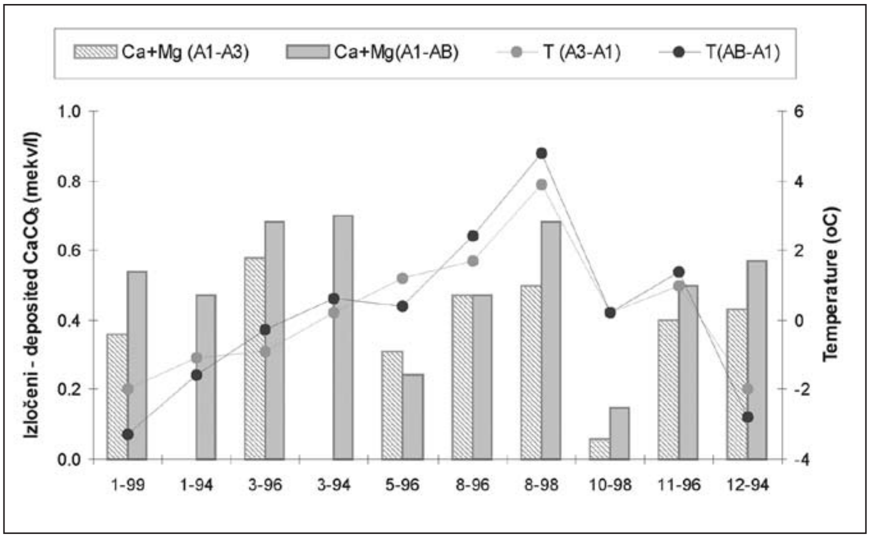
Ob nizkih in srednjih pretokih ob ohlajanju vode v zimskih mesecih, je prihajalo do največjega izločanja na drugem odseku A2-A3. Ohlajanje vode je v tem primeru zaviralo uhajanje CO_2, tako da je prišlo do najizdatnejšega izločanja nekoliko kasneje.

Avgusta 1996 se je ob nizkem vodostaju in ob segrevanju vode izločil ves razpoložljivi kalcijev karbonat že do točke A3. Običajno se je izločanje nadaljevalo do točke AB, vendar pa je bilo izločanje na odseku A3-AB znatno manjše v primerjavi z izločanjem na začetnem delu toka od A1 do A3 (slika 5).



Sl. 4: Celokupna trdota (Ca+Mg) na opazovanih točkah vzdolž toka Podstenjška (A1, A2, A3 in AB) ter na desnem pritoku (B1, B2).

Fig. 4: Total hardness (Ca+Mg) at observed points (A1, A2, A3, AB and B1 and B2).



Sl. 5: Izločeni kalcijev karbonat ob različnih razmerah prek leta na odseku A1-A3 in odseku A1-AB, ter vsakokratna sprememba temperature na točkah A3 oz. AB glede na temperaturo izvira.

Fig. 5: Travertine deposition during different hydrological conditions at section A1-A3 and A1-AB and temperature change at same sectors.

SKLEPI

Kamninska sestava zaledja kraških izvirov se odraža v kemijski sestavi njihove vode. Prek leta se lahko spreminja sestava vode v odvisnosti od padavinskih in hidroloških razmer. Sestava vode Podstenjška, ki se napaja z infiltracijo padavin, s povprečno vrednostjo Ca/Mg 11,1 (6,4 – 14,1) nakazuje, da dobiva vodo predvsem z apnenčastega sveta in le delno z dolomitnih območij. V času najvišjega vodostaja, oktobra 1998, ko se napaja z najširšega območja, je bil delež vode z dolomitnega sveta večji, kar se je odrazilo v nižji vrednosti Ca/Mg.

Občasne meritve izvira Podstenjška v času različnih hidroloških razmer prek leta so pokazale na majhna nihanja temperature, SEP in pH ter vsebnosti karbonatov, kalcija in magnezija. Povprečna temperatura je bila 10,1°C in je nihala v intervalu 0,6°C, povprečna vrednost SEP (20°C) pa 417 µS/cm in je nihala v intervalu 20 µS/cm. Povprečna celokupna trdota je bila 4,51 mekv/l, povprečna karbonatna trdota pa 4,19 mekv/l in sta nihali v intervalu 0,5 mekv/l. Vsebnost nitratov je nihala okoli vrednosti 6,7 mg NO_3^-/l, kloridov 3,8 mg Cl^-/l, o-fosfatov 0,03 mg PO_4^{3-}/l in sulfatov 8,9 mg SO_4^{2-}/l. Čeprav naselje Šembije leži in se širi v neposrednem zaledju Podstenjška, pa bi zaradi čiščenja odpadnih voda pričakovali zboljšanje oz. ohranitev kakovosti njegove vode, ki jo uporabljajo za vodooskrbo. Vendar pa lahko le sistematična opazovanja, ki vključujejo tudi podrobno dogajanje v vodnih valovih po padavinah, pokažejo učinkovitost čiščenja.

Voda Podstenjška je na izviru glede na zunanje pogoje prenasičena s karbonati in jih na svoji poti v dolino odlaga. Odlaga predvsem kalcijev karbonat. Največji del kalcijevega karbonata izloči že na začetni 365 m dolgi poti (A1-A3), manjši del pa še ob nadaljnji 700 m dolgi poti (A3-AB). Sorazmerno velik strmec na začetnem delu poti (A1-A3) omogoča dobro prezračevanje vode in izhajanje CO_2, ki je v poletnih mesecih, ko se voda na poti izločanja segreva, še hitrejše. Tako se poleti ob nizkih pretokih izloči ves razpoložljivi kalcijev karbonat že na prvi 365 m dolgi poti, najintenzivneje pa se je izločal že na prvem 305 m dolgem odseku. V zimskih mesecih ob ohlajanju je prišlo do najintenzivnejšega izločanja nekoliko kasneje. Ob visokih pretokih je stopnja izločanja minimalna in na celotnem več kot 1 km dolgem toku se je iz 1 l vode izločilo le nekaj mg $CaCO_3$. Največjo stopnjo izločanja pa smo izmerili ob nizkem pretoku, ko se je iz enega litra vode izločalo do 36 mg $CaCO_3$/l.

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PHYSICO-CHEMICAL PROPERTIES OF TRAVERTINE DEPOSITION – THE CASE OF PODSTENJŠEK (SLOVENIA)

SUMMARY

Podstenjšek is a karst spring at the contact of paleogene limestone and impermeable flysch (Gospodarič *et al.*, 1968) draining after a short stream into the Reka river. Recharge area of the Podstenjšek consists of cavernous-fissure limestone and dolomite of Cretaceous and Paleogene age with medium permeability (Kovačič 2001). The spring is fed by rainfall infiltration. Since 1992 it is captured for drinking water supply. In 1994, 1996, 1998 and 1999 we sampled ten series of water samples during different weather conditions and also samples of the Podstenjšek in a downgradient portion to find out the basic properties of the spring and its travertine deposition capacity.

Lithology of the karst springs is reflected in chemical composition of water. Over one year the water composition may change due to rainfall and hydrological circumstances. The Podstenjšek water, fed by rainfall infiltration, is characterized by average value of Ca/Mg 11.1 (6,4 – 14.1) indicating that water comes mostly from limestone region and only partly from dolomite. During the highest water level in October 1998 when water flowed from the widest area the rate of dolomite water was higher and the Ca/Mg ratio was consecutively lower.

Periodical measurements of the Podstenjšek spring in a time of different hydrologic conditions showed little temperature variations as well as SEC and pH and carbonate, calcium and magnesium levels over the whole year. Average temperature was 10.10°C oscillating in an interval of 0.60°C, average SEC value (200°C) was 417 μS/cm in an interval of 20 μS/cm. The average total hardness was 4.51 mekv/l, and average carbonate hardness 4.19 mekv/l oscillating in an interval of 0.5 mekv/l.

The nitrate level varied around 6.7 mg NO_3^-/l, chloride level 3.8 mg Cl^-/l, o-phosphates 0.03 mg PO_4^{3-}/l and sulphate levels 8.9 mg SO_4^{2-}/l. Although Šembije village lies and grows in the immediate recharge area of Podstenjšek one would expect the ammelioration of the water quality due to purifying of waste waters. But the analyses at the end of 1998 and 1999 did not show any effect of purifying. We know that washing and improvement of water quality demands a certain time and only systematic observations including a detailed study during water pulses after heavy rainfall can show the efficiency of purifying.

The Podstenjšek water at the spring is supersaturated by carbonates and they are deposited on the flow towards the valley. Mainly calcium carbonate is deposited.The largest part of calcium carbonate is deposited at the beginning of 365 m long flow and only smaller part in further 700 m. Relatively high gradient at the initial part allows a considerable aeration of water and release of CO_2; this augments in summer months when water warms up during its flow. Thus in summer at low discharge all the available calcium carbonate is deposited at the first 365 m long flow and the most intensively at the first 305 m. In winter when water cools down the most intensive deposition occurred a little later. During high discharge the rate of deposition is minimal and on the entire flow, more than 1 km long, only few mg of $CaCO_3$ were deposited from 1 l. The highest deposition occurred at low discharge when up to 36 mg of $CaCO_3$/l was deposited from 1 l.

COBISS: 1.01

GLACIAL KARST, WHY IT IMPORTANT TO RESEARCH
LEDENIŠKI PSEVDOKRAS

Bulat R. MAVLYUDOV

Abstract UDC 551.332:551.44
Bulat R. Mavlyudov: Glacial karst
Glacial karst (GK) is combination of phenomenon and processes as a result of which specific surface forms and cavities inside ice are formed. Hummocky relief with abundance of lakes, channels and reservoirs inside ice and on ice-rock contact are typical for GK. GK development occurs under acting of physical process of ice melting instead of limestone dissolution in classical karst. However processes directivities and arising forms in both cases are similar at system level. As karst processes in ice origin very fast it is give possibility to use them as physical models for limestone karst. Vice-versa, we can understand GK better if we use results of limestone karst investigations. However in both cases only general regularity can be used because some specific features are typical for each kind of karst. GK shows in development of such forms in ice: internal drainage systems (moulins, shafts, cascades, vadose galleries and phreatic channels, siphons, griphons) and under ice (vadose and phreatic channels), dry and water fill dolines on clean ice and on ice covered by moraine (debris-covered glaciers), glacier caves. Stages of GK development completely correspond to stages of limestone karst development. But because of glaciers motion it is possible to observe all stages of GK development on the surface of the same glacier from decrepit (at glacier tongue) up to early (in upper part of ablation zone). GK has large significance in glaciers evolution. GK is widely spread in all temperate and polythermal glaciers of the world. The accelerated glaciers degradation in present time gives a task of mandatory analysis of GK because of many glaciers can disappear very soon.
Keywords: glacial hydrology, debris-covered glacier, karst of glaciers, internal drainage systems, glacial karst evolution, similarity of glacial and calcareous karst.

Izvleček UDK 551.332:551.44
Bulat R. Mavlyudov: Ledeniški psevdokras
Ledeniški psevdokras je skupek procesov, katerih rezultat so značilne površinske oblike in jame v ledenikih. Za ledeniški psevdokras je značilen grbinasti relief z jezeri in kanali v notranjosti ledenika in ob stiku led-kamnina. Procesi, ki ustvarjajo ledeniški psevdokras in kras v karbonatih in evaporitih se razlikujejo, vendar so oblike, ki nastajajo v obeh sistemih, podobne. Procesi v ledu so hitri, zato je ledeniški psevdokras lahko primeren fizični model krasa v apnencu. Po drugi strani lahko s poznavanjem krasa v apnencih bolje razumemo ledeniški psevdokras. Seveda govorimo le o splošni podobnosti med fenomeni, medtem ko se oba tipa "krasa" v podrobnostih razlikujeta. Stopnje razvoja ledeniškega psevdokrasa se ujemajo s stopnjami rasvoja v apnenčastem krasu. Zaradi gibanja ledenika lahko razvojne stopnje ledeniškega psevdokrasa spremljamo vzdolž ledenika, od jezika do ablacijske cone. Ledeniški psevdokras je razširjen v ledenikih zmerne klime (temperate glaciers) in v politermalnih ledenikih.
Ključne besede: ledeniška hidrologija, pokriti ledenik, ledeniški psevdokras, notranji drenažni sistem, podobnost glacialnega in apniškega krasa.

*Author uses the term Glacial karst, which denotes features on the glacier surface and inside the glacier that result from the melting of ice. Other terms are used for his phenomena, like *Glacier pseudokarst* (see John Gunn (ed.), Encyclopedia of Caves and Karst, Fitzroy Dearborn, 2004)

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INTRODUCTION

In XIX century there was no karst division into separate kinds by rocks structure. Limestone on continents is the most widespread rock, which have direct or indirect influence on people life. Superficial and underground karst forms have begun to study mainly in limestone areas. Other kinds of karst rocks occupy smaller areas on the earth, therefore karst phenomena in them were studied less often. Glaciers are situated only in mountains and in Polar Regions, because features of their superficial relief and cavities have investigated later. We considered history of glacial caves research earlier (Mavlyudov, 2004a).

HISTORY OF GLACIAL KARST STUDY

Researchers were interested with perennial ice in calcareous cavities. But as caves in glaciers were considered as caves with ice in limestone these absolutely various cavities by genesis have received the uniform name «ice caves» and quite often studied by the same researchers (Balch, 1900). But nevertheless many scientists quite understood difference between these caves and specially accented attention on it (Browne, 1865, Listov, 1885). But about similarity of karst phenomena in glaciers and in limestone scientists began to speak only at the end of XIX century (Sieger, 1895). He said that porosity, solubility and weakened planes to the same degree characterized both for ice and limestone. Similar forms for glaciers and limestone are: karrens, natural shafts, moulins, caves, galleries, dolines, depressions without runoff etc. He found conditions necessary for relief formation on glaciers that similar to karst relief: flat glacier surface with small quantity of crevasses and slow ice movement. Moraine cover on ice surface protects it from melting but ice ablation occurs with large intensity only on walls of crevasses and moulins. At the end of XIX century this phenomenon was known for glaciers of Europe, America, New Zealand and Polar areas. Sieger considered that it is necessary to collect additional information for explanation of this karst analogy in limestone and ice.

Famous Russian geographer A. A. Kruber (1915) wrote that «karst phenomena origin in gypsum, in salt, in ice, but, firstly, these rocks in comparison with limestone occupy considerably smaller areas, and, second, the phenomena in named rocks represent some specific features in comparison with phenomena in limestone». Thus, Kruber did not distinguish karst phenomena in limestone, gypsum, salt and ice.

The first who in Russia has used for glaciers term GK was geographer S.V. Kalesnik (1935, 1939). He comes to conclusion about GK existence after study glaciers in headstream of Naryn River (Tien Shan) during 2nd International Polar Year. Describing dolines and moulins at tongues of some Central Asian glaciers (on Zerafshan Glacier, on Petrov's Glacier, on Pamir glaciers etc.), Kalesnik wrote that «apparently, here before us is *glacial karst* that is especially probable on glacier tongues, in areas of maximal ice melting and maximal concentration of subglacial water. Because GK originate in plastic material this is a reason why all crevasses origin after collapse of ice above subglacial tunnels are masked, soldered and alloyed».

Term GK with reference to geomorphology is present in monumental work devoted to quaternary glaciation (Charlesworth, 1957) in which it is spoken about GK wide spreading on glaciers in different parts of the world, which differ by small surfaces inclination and slow movement. For ice with moraine cover cryoconite holes, dolines and depressions with moulins and without them, karrens, caves and under surface rivers, blind and dry river valleys are typical. All of these forms have the duplicates in limestone. He distinguishes GK and karst only by ice plasticity and by presence of moraine cover on ice.

In the other book Kalesnik (1963) give other name for this phenomenon – *ice karst.*

Repeatedly GK concept in glaciology is entered a little bit later (Clayton, 1964). In opinion of the author for GK a plenty of dolines and depressions (frequently filled by small lakes), tunnels and caves, disappearing waterstreams, blind valleys, large springs, natural ice bridges and arches, karrens, separate ice blocks and residual sediments (ablation tillites) are typical. He saw full analogy of forms in ice and limestone. Therefore he has automatically transferred development laws of limestone karst to GK. There are 4 same conditions necessary for GK and limestones karst origin, which were precisely formulated in the middle of XX century (Thornbury, 1954), but were known earlier (Kruber, 1915).

It was supposed that GK was widely distributed on dead edges of North American glacial sheet in time of its degradation (Clayton, 1964). In our opinion fast destruction of glacial sheets, which edges at last glaciation were terminated on land, depends on wide GK development (Mavlyudov, 2005, 2006).

During many years after Clayton's publication term GK in glaciology was almost not mentioned. Usually considering relief on glaciers tongues recently began to use term «debris-covered glaciers» (Nakawo, Young, 1981). Cross relief and huge lakes quantity are typical for such glaciers. Generalization of publications about GK was made in one of glaciology reports (Benn, Evans, 1998). But it begins since Clayton only.

In work (Benn, Evans, 1998) it is marked that moraine sediments on ice restrict ice melting and it concentrates mainly in places where moraine cover is broken: on moulins walls and on slopes of dolines and lake depressions. Depressions slopes become too abrupt to keep of rock debris so clean ice here is usually exposed; intensity of ice melting here is maximal. Ice melting on walls (backwasting) – one of the most important components of ablation in lower glaciers parts covered by moraine such as Khumbu (Nepal) or Tasman (New Zealand) (Iwata, *et al.,* 1980, Kikbridge, 1993 and others). Importance of ablation localization in vicinities of depressions and crevasses on retreating debris-covered glaciers tongues just also had result, in opinion of authors, occurrence of term GK. Certainly, GK and limestone karst are not identical processes. Fissures in calcareous areas extend by calcium carbonate dissolution, and on glaciers crevasses extend preferably by ice melting. In the first case it is chemical process, in the second – physical.

Very detailed description of sedimentary and erosive processes and relief forms connected with each stage of GK development was given for edges of outlet Kötlu Glacier, Myrdalsjökull in Iceland (Krüger, 1994).

In work (Benn, Evans, 1998) it is shown that GK may occur at tongues of surging glaciers when after fast motion glacier tongue remains motionless for a long time.

TERMINOLOGY OF GLACIAL KARST

Recently GK study have progress as a result of creation of the international commission «Glacial Caves and Karst in Polar Regions» (GLACKIPR) in structure of IUS (Actes, 1995, Eraso, Pulina, 1992, 2001, Proceedings, 1991, 1992, 1998, 2002, 2003, 2005). Big part of symposiums materials connected with GK study. In 1994 question of commission renaming was discussed. Term «cryokarst» in the name of commission has received biggest (but not common) recognition in comparison with term «karst». It has resulted that 3-5 commission symposiums occurred under the name «Glacial Caves and Cryokarst in Polar and High-Mountains Regions». However ambiguity of term «cryokarst» has resulted that since 6th symposium in 2003 the commission has returned to the former name. It is not necessary to forget that the term «cryokarst» is the European analogue of the term «thermokarst» (Monroe, 1976), i.e. it is more applicable to frozen rocks than to glaciers.

In Russian glaciology term GK of Kalesnik is not used any more. In glaciological dictionary (Kotlyakov, 1984) this term is absent. In karstology for description of glacier caves firstly was used the term «thermokarst» (Maksimovich, 1963), but subsequently this term began to name areas with thaw dolines in frozen rocks. In karstological literature the term «pseudokarst» more frequently used (Andrejchuk, 1992). However this term ignore similarity of the processes in ice and in soluble rocks and also full coincidence of their karst forms. Some attempts of introduction of new term for description of processes in ice were undertaken. For example term «glaciokarst» was offered (Andrejchuk, 1992). But this attempt cannot be named successful as this term for a long time is used for designation of karst in limestone, originated under glaciers or activated by glacial meltwater (Monroe, 1976).

As now study of glaciers relief that similar to karst began increase, it is quite obvious, that has ripened necessity for term describing formation of this specific relief. For our opinion it would be reasonable to use term Glacial Karst (GK). This term shows that phenomena in glaciers are very similar to phenomena in karst rocks. The word «glacial» (but not ice) means features of this type of karst is formed not simply in ice but namely in glaciers. On analogies, calcareous karst it will be necessary to name «karst of limestone massifs» or «limestone karst».

CYCLE OF GLACIAL KARST DEVELOPMENT

On available representations (Clayton, 1964) by analogy to karst in limestone (Kruber, 1915) cycle of GK development consists of three stages: young, mature and decrepit. Basing on works (Cvijich, 1909, 1918, Kruber, 1915), we have added in cyclic evolution of GK delopment one more stage – early stage (Tab. 1) (Mavlyudov, 2004b). On the same glacier it is possible to find all stages of GK development from the earliest up to decrepit stage (Fig. 1). This is one of essential distinctions of GK from calcareous karst. Especially well it can be seen in tongues of retreating glaciers (from the ice edge) where it is possible to see gradual transitions from decrepit stage of GK through mature to stages of youth and early. On active glaciers the set of these stages will be incomplete. Frequently on such glaciers it is easy to find only early or less often – young stages of GK development.

Briefly we shall consider each stage of GK development.

EARLY STAGE.

For this stage of GK development is typical almost full absence of superficial forms and weak channels development inside glaciers. Glacier surface here is completely free from moraine. Besides, this area is situated closely to snowline (ELA) and may completely or not completely be clear out from snow in separate years. At presence firn there may be channels as in it thickness (originate at vertical infiltration of meltwater jets), and on firn/ice contact. However these channels are insignificant. As catch areas of superficial water streams are still insufficiently extensive, large internal channels here may not form yet. Dye tracing of water carried out closely to ELA have shown that water moves from here up to glacier tongue with very small velocity. Time of water movement was about some weeks (Bingham *et al.,* 2005 and others). It says about small channels opening in the upper part of glacier ablation zone. Nevertheless these channels exist, that allows allocating this stage of GK development. This stage may develops in the lower part of accumulation and in the upper part of ablation areas not only there, where there are water streams on glacier surface and crevasses in ice, but also where water inflows from areas adjoining to glacier or drain from lakes situated on rock/ice contact.

Tab. 1 – GK development cycle (Clayton, 1964) with author changes

	Stages GK development			
	Early	Young	Mature	Decrepit
Karst forms	Channels in snow, firn, on contact ice/firn, small moulins, widen crevasses, englacial channels	Moulins, shafts, englacial and subglacial channels	Dolins, caves, tunnels, water channels	Karst windows, depressions, котловины, uvalas, residual ice blocks
Drainage	Mainly surficial	Partly surficial, partly internal	Mainly internal	Internal, surficial (after ice disappear)
Ice thickness, m	150-400 and more	50-150	10-50	0-10
Surficial moraine deposits, thickness, m	Absent	Absent, except median moraines, some centimeters	Some centimeters, later > 1 m, unstable	From 1.5 to > 3 m, stable
Vegetation on moraine deposits	No	No	First weakened grass; subsequently bushes	Grassy and wood vegetation
Lakes, cleanliness of water, density of population	Rare lakes, in cracks, cold, transparent, without life	Enough rare, cold, transparent, without life	In dolins, cold, silty, without life	In dolines, depressions, uvalas and poljes; isolated from ice by moraine sediments; warm and clean; fresh-water plants and animals
Glacier movement	Active	Inactive	From small activity to motionless	Immobile

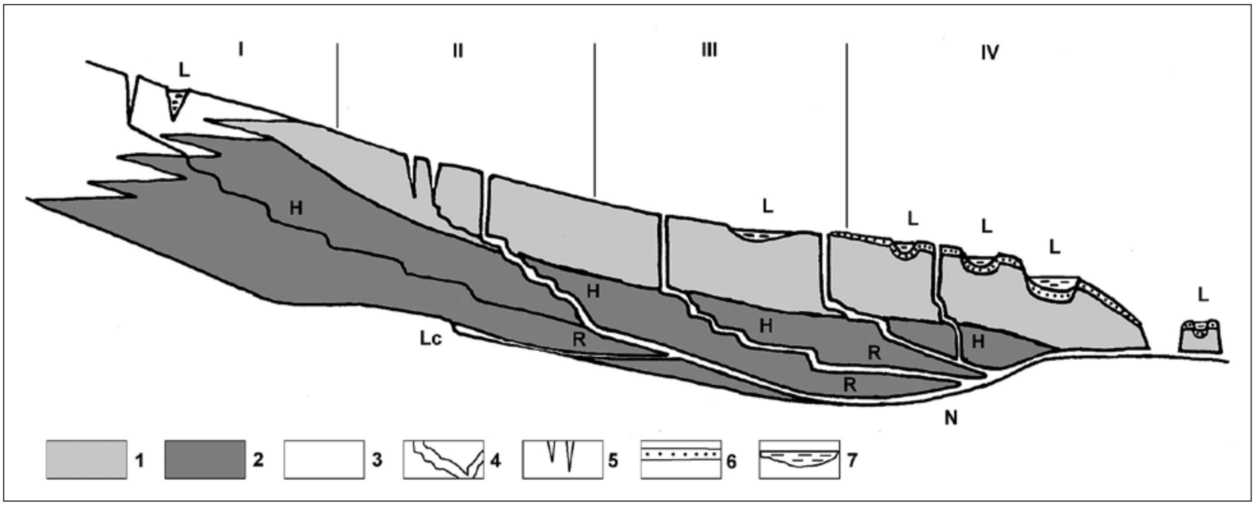

Fig. 1. Scheme of glacier with internal drainage system; on the right – massif of dead ice. 1 – cold ice layer; 2 – temperate ice layer; 3 – snow and firn; 4 – englacial and subglacial channels; 5 – glacial crevasses; 6 – moraine cover; 7 – lake water. H – vadose englacial channels (Hooke channels); R – freatic englacial channels (Röthlisberger channels); N – subglacial channels (Nye channels); Lc – linked-cavities channels behind bed ledges; L – lakes. I-IV – GK stages: I – early, II – young, III – mature, IV – decrepit.

YOUNG STAGE.

Boundaries of this stage distribution on glaciers are upper part of ablation zone above and a zone of occurrence of median moraines on ice surface – below. On active glaciers this stage may occupy almost all ablation area. On less active glaciers area of young stage may occupy half of ablation area. On almost motionless glaciers young stage can be found out only in the uppermost parts of ablation area (Fig. 2). As catch areas here are extensive enough, large superficial water streams may be formed. It promotes development of large channels in internal drainage. Occurrence of median moraines often promotes stream localization along moraines and formation of large water-streams. It leads to formation of developed systems of an internal drainage. Dye tracing of water streams has shown, that water velocity through channels beginning in this zone, are comparable to velocity in superficial water-streams and may reach 1 m/s (Stenborg, 1969 and others). Our speleological researches have shown that channels sizes inside ice are great enough: pits have depth up to 100 m and more, pits diameter may be up to 10 m and more, galleries width may be 0.3-4 m, height of galleries – from 2 up to 20 m. The channels sizes directly depend on volume of water-streams absorbed in ice. Superficial

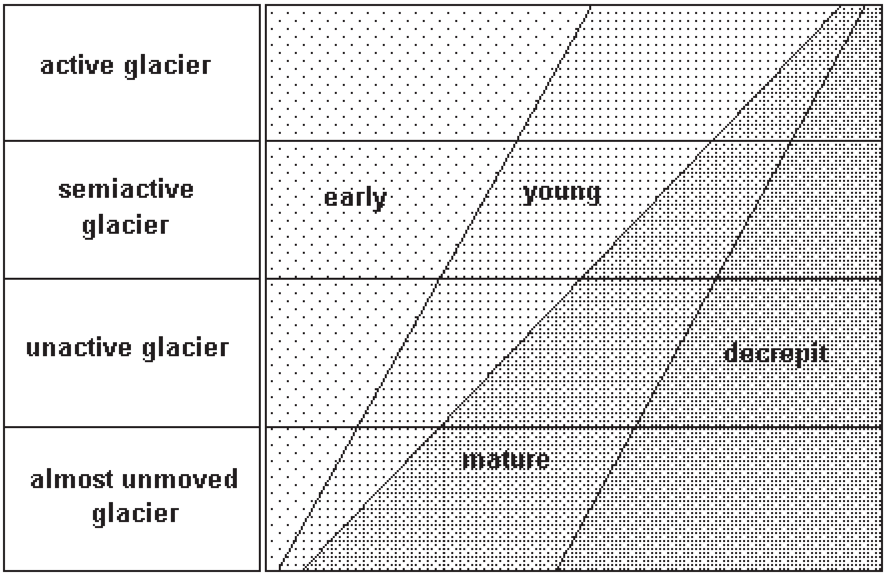

Fig. 2. Relationship of sizes of various zones appropriate to different stages of GK development on glaciers with different activity degree.

forms are submitted basically by closed lake depressions on ice, which are not numerous. Their number may grow in places of crevasses formation.

MATURE STAGE.

This stage is typical for parts of glaciers covered by moraine (Fig. 3). In the upper part of this stage zone moraine cover does not exceed 1/3 of glacier surface but in the middle part moraine covers ice completely. Thus in direction to glacier tongue thickness of moraine cover grows up to meter and more. At moraine cover thickness lower then 10 sm there is ice-melting activization due to stones heating (Nakawo, 2000). This is expressed in growth of quantity of meltwater on glacier surface. When moraine thickness exceeds 10 sm reduction of ice melting begins. At moraine thickness more than 0.5-0.7 m ice melting practically completely stops. For upper part of mature zone wide development of superficial water-streams and internal channels are typical. For lower part of mature zone superficial water-streams are not usual and for glacier surface smoothed hummocky relief is typical with plenty of dolines and depressions, many of which are occupied by lakes. Ice melting occurs here basically on lakes slopes. Lakes water is heated up much more strongly than ice covered by moraine (Sakai *et al.,* 2000). For this reason lakes quickly grow.

Quite often this stage, which is well expressed in relief on glacier surfaces, is named as GK (Krüger, 1986, Benn, Evans, 1998). In dependence of dammed degree of glacier tongues GK development may realized both by lake or dry scenario (Mavlyudov, 2005). Lake scenario of GK mature stage develops where glacier tongue is dammed by rock bar or end moraine. It conducts to formation of extensive lakes connected by numerous englacial and subglacial channels. Subsequently small lakes merge into one large lake. After that development of karst process departs on second plan and as the first acts calving.

Absence of glacier tongue damming leads to GK development under dry scenario when lakes exist at different levels. Expansion of lakes depressions occurs on ring crevasses by ice collapse (Fig. 4). As a result of GK activity glacier will disintegrate completely (at lake scenario) or will broken into separate blocks of dead ice (at dry scenario).

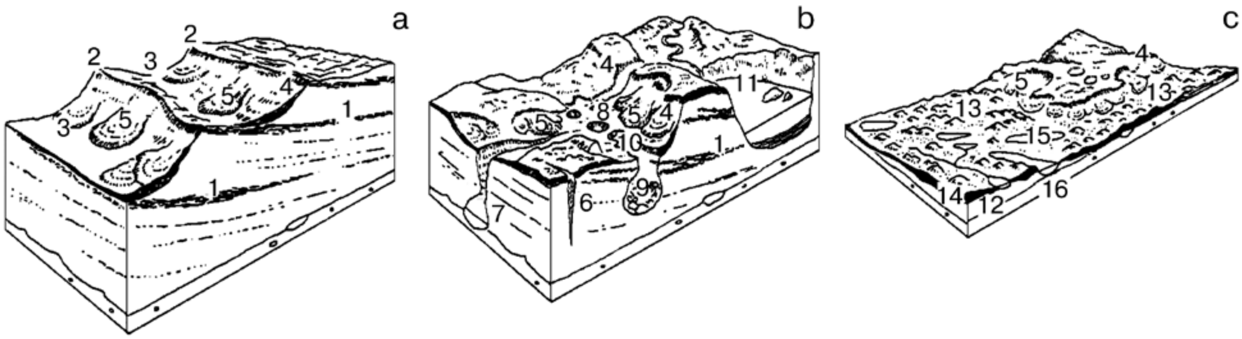

Fig. 3. Block-diagram showing development of mature and decrepit GK stages (Krüger, 1994). a-b) mature stage; c) decrepit stage. 1 – strips of rock fragments in glacial ice; 2 – ridges with ice core; 3 – through-shape valley; 4 – melting escapes of clean ice; 5 – rock fragments flow (colifluction); 6 – crevasses expanded by melting; 7 – subglacial channels; 8 – dolines; 9 – collapsed arch of tunnel; 10 – doline expanded by melting and collapse; 11 – lake extending due by melting on slopes; 12 – dead ice; 13 – hummocky plain, free from ice; 14 – superficial glacial sediments; 15 – lakes; 16 – subglacial sediments.

Fig. 4. View on collapse of dry scenario of mature stage of GK. Bashkara Glacier, Central Caucasus, 2005.

DECREPIT STAGE.

This stage develops on tongues of motionless glaciers or within the limits of isolated dead ice massifs (Fig. 3). Thickness of moraine cover changes from 1 to 3 m. Numerous windows are typical even at continuous ice cover. Except dolines and small depressions larger depressions – uvalas and poljes here are typical also. Water streams wandering under ice provide fast ice destruction. Wide directions range for water streams provides formation of big quantity of caves with small water streams. Galleries expansion in caves includes also action of airflows. Because of small ice thickness caves galleries are not compressed by plastic deformation. But for galleries are typical vaults collapses. In process of GK development area of glacier ice decrease. It continues until complete ice disappearance.

There are some variants of transition from one GK stage to another: 1) in active glaciers, 2) in motionless glaciers. In first case at stable position of ELA there is evolutionary displacement of GK stages boundaries in direction of glacier tongue. That is why area of young stage of GK development is displaced on glacier downwards turning into mature stage. By similar way changing of other GK stages occurs. All stages of GK development are formed approximately in one place of glacier surface during the long period. In this case boundaries of stage zones of GK development remain approximately on the same places. At ELA lowering there will be replacement of all zones boundaries in direction to glacier tongue.

Progressive movement of all GK zones boundaries in direction to upper glacier part will occur at glacier edges retreating and ELA increasing. When processes of GK formation will include all glacier surface, the further decreasing of glacier dimensions will result in size reduction or full lost of upper zone (early stage). So quantity of zones may be reduced gradual. After some time there will be only one zone (decrepit stage). Then the glacier will completely disappear.

In surging glaciers all events occurs by other way. In period before surge all GK stages will develop in glacier ablation area. During surge all GK structures will be completely destroyed. As ice melting during surge does not stop but existing ways of water throughflow will be destroyed during glacier motion, it may stimulate local water accumulation in englacial and subglacial reservoirs. It can lead to sudden water outbursts from under glaciers during surge. After surge GK structure begins to restore on all extent of ablation area. Firstly all ablation area will be in early and young GK stages. Intensity of GK development will increase in area of dead ice. It connects with features of local climate (warmest on glacier), moraine cover thickness on glacier surface, big quantity of crevasses, the crossed glacier surface that provides fast development of numerous lake depressions and their intensive growth. Therefore in the lower glacier part GK develops more intensively than in other glacier parts. It will result appearance firstly of two, then of three and, at last, of all 4 GK zones in ablation area. Increasing GK development in area of dead ice promotes accelerated ice degradation that prepares possibility for new glacier surge. It seems that calculated and real ice melting intensity under moraine cover differs very significant. Full destruction time of the Glacier Kolka tongue in the Caucasus after surge in 1969 was estimated as 25-30 years (Khodakov, 1978). But really glacier tongue has disappeared after 11 years. It means that GK increase ablation of debris-covered glaciers in some times.

Now we will outline channels evolution inside glaciers. Some authors (for example, Mikhajlev, 1989) tried directly apply schemes of karst cavities evolution to GK cavities. He considered that glacier caves as well as limestone caves evolve through following stages: crevasse-slot-hole, crevasse-channel, gallery, channel and collapse. In his opinion, the crevasse-slot-hole stage is characterized by occurrence of open fissures on glacier/bed contact and in glacier body in accumulation zone. Crevasse-channel stage is characterized by occurrence of narrow horizontal subglacial crevasses on contact with bed in accumulation area. Gallery stage is typical for ablation area with development of subglacial and englacial channels. Channel stage is usual for ablation zone with active development englacial and subglacial caves. Separate grottoes may reach 30-40 m length and 20 m height. Vaults collapses in subglacial caves conduct to formation of large dolines and depressions on glacier surface. Collapse-ablation stage is typical for moraine-covered part of glacier. Caves roof collapses and depression sizes growth are typical for this stage.

However we automatically may not transfer character of limestone caves development on ice. Against limestone caves, which mainly change in agreement with all these stages, in ice only channels at glaciers tongues can evolve through all this stages. Other channels may develop only up to gallery stage but then channels can completely disappeared because of secondary ice filling or under action of ice plastic deformation (creep). We know that later type channels on glaciers consist overwhelming majority.

GLACIAL KARST SPREADING

GK is enough widespread phenomenon. It was found on a plenty of glaciers all over the world: in Alaska (Clayton, 1964; Russel, 1893; Tarr, Martin, 1914), in Iceland (Krüger, 1994; Badino, 2002; Eraso *et al.,* 2002), in Spitsbergen (Gallo, 1977; Griselin, 1991; Shroeder, 1991, Krawczyk, Pulina, Rehak, 1997; Pulina, 1982, 1984, 1997; Mavlyudov, 2002; Mavlyudov, Solovyanova, 2003), in the north of Canada (Iken, 1972, Bingham *et al.,* 2005), in Sweden (Stenborg, 1968, 1969; Holmlund, 1988), in Caucasus (Mavlyudov, Solovyanova, 2005), in Alpes (Maroue, 1995, Piccini *et al.,* 2002), in Altai, in Central Asia (Kalesnik, 1935; Mavlyudov, 1994, 1995; Popov, 1936; Spengler, 1936; Badino, 2002), in Himalayan (Iwata *et al.,* 1980, Mavlyudov, 1992), in Andes (Aniya, 2001), in New Zealand (Kikbridge, 1993), Greenland and Antarctica (Eraso *et al.,* 1991) and in other places. Absence of any regions in the previous list simply means insufficient quantity of researches in this area. GK play important and possibly also an integral role during destruction of the majority of temperate and polythermal glaciers, especially if they are in retreating stage.

SIMILARITY AND DIFFERENCE OF GLACIAL KARST AND LIMESTONE KARST

Similarity GK and karst in soluble rocks is shown in convergence of cavities forms. Similarity of GK and karst is determined by identical conditions of cavities formation in soluble rocks and in ice. For cavities formation is need: 1) soluble rocks, 2) fissures and crevasses in rocks, 3) solvent of rock, 4) solvent movements and aggressiveness. Similarity of features of karst and GK also is shown in similarity of characteristics of both drainage systems. They have similar structure (arborescent channels form), an evolutionary cycles, seasonal prevalence of development, dependence on climate and rock conditions; they are singenetic to relief, divided into superficial and internal components.

Despite of processes difference of chemical rocks dissolution and physical ice melting both these process lead to identical results – loss of rock or ice layer on channels walls on contact with water-streams. Not consider kinetic of process of rock chemical dissolution by action of water streams and process of ice melting under action of water streams at molecular level we may speak about general similarity of this processes. This processes similarity is determined by similarity of curves of limestone dissolution and ice melting, which have linear character (Gabrovchek, 2000; Shumskij, 1955).

Formulas of carbonate concentration changes in water and of ice melting under action of water streams in time are almost similar (Eraso, Pulina, 1992, page 14-16). This similarity also defines forms of convergence in limestone and in ice. And as solvent in both processes is one substance – water, it defines similarity in hydraulic processes in both cases. This similarity underlies of possible data exchange between GK and karst in soluble rocks in the field of cavities origin and evolution.

Distinctions of processes occurred in limestone and in ice are determined, first of all, by various physical properties of ice and rocks. Density of ice is 917 kg/m^3, density of limestone – 2500 kg/m^3, heat conductivity of ice is 2.22 Wt/(m°K), heat conductivity of limestone – 0.9 Wt/(m°K), specific thermal capacity of ice is equal 2,12 KJ/(kg°K), specific thermal capacity of limestone – 2.5 KJ/(kg°K) (Shumskij, 1955, Dzidziguri *et al.,* 1966). As we see, the basic distinctions between limestone and ice are shown in rocks density, which approximately in 2.5 times is higher for limestone, and in heat conductivity which approximately in 2.5 times is more for ice. The last means that at identical heat arrival to both rocks, ice will heat up less than limestone. But it also means, that for cooling of ice and limestone on equal quantity of degrees, from the first it is necessary to remove approximately in 2.5 times heat more than from the second.

But the basic distinctions of processes occurring in limestone and ice are determined not by distinction in rocks thermophysical properties but by speed of their destruction. Therefore distinctions of processes in soluble rocks and in ice are determined by: speed of processes or speed of superficial and internal forms development; duration of evolution cycle; abort of development in winter time; presence of ice movement; presence of ice plastic deformations; ability for ice to heal of crevasses and cavities; influence of thermal conditions of ice; monolithness of ice, absence of some types of fissures in ice; difference of chemical process of rock dissolution from physical process of ice melting; channels displacement downwards on glacier during evolution.

Essential difference in physical properties of limestone and ice is shown in significant distinctions in behavior of drainage systems inside these rocks. But common structure of internal drainage systems in both rocks allows to speak about similarity of evolution of internal drainage in both rocks at a level of system.

The ideological affinity of glacial hydrology with karst hydrology and speleology means not only affinity in research methods of drainage systems in glaciers and limestone, but also affinity of theories describing drainage systems and their separate elements origin and evolution. For this reason many conclusions about GK structure and evolution are received by analogy to structure of drainage systems in limestone (Mavlyudov, 2006).

IMPORTANCE OF GLACIAL KARST STUDY

Internal glaciers drainage study is necessary part of nival-glacial systems researches (Krenke, 1982). GK has complex influence on glaciers. Investigations has shown that GK presence in glaciers cardinally changes physical ice properties, ice permeability for water, structure and chemistry of glacial runoff, character of sediments removing by water streams, separate characteristics of glaciers: water level position in different parts of glaciers, changes of cold ice layer thickness by ice warming around drainage channels. All these changes can be incentive reasons of numerous phenomena in glaciers: water outbursts, winter runoff, changes in speed of ice movement, glaciers surges, accelerated deglaciation. At some stages of glaciers evolution (in particular in deglaciation period) GK begins to control practically all processes in ice thickness and many processes on glaciers surface, becomes determining factor of glacier development.

Without taking into account GK influence on glaciers mistakes are possible in: 1) hydrological calculations; 2) hydrological processes modeling in glaciers; 3) results interpretation of majority of indirect methods of GK study (dye tracing of waters, runoff studying, definition of throughflow time, runoff chemistry, suspense sediments transport, cold ice layer thickness measurements etc.). If we do not know GK structure, it becomes not clear as water moves in ice thickness. If we shall not study GK: 1) an glaciers interior remain for us as «black boxes», 2) we shall irrevocably lose valuable scientific information based on character of internal glaciers destruction; 3) we shall not understand many processes in glaciers.

Only expensive ice drilling or study of glaciers water runoff regime usually give information about glacier internal structure. GK drainage channels researches allow us: a) to receive direct information about glacier structure, to make large crevasses survey, to establish presence and amplitudes of ice replacement on them after time of cavities formation; b) to take ice samples of any size from necessary depths for different purposes (definition of permeability, durability, water-saturation etc.); c) to determine morphometric characteristics of cavities. Analysis and mathematical processing of morphometric parameters of GK drainage channels allow to receive statistically steady parameters of channels sizes and content of cavities in ice of separate glaciers and their parts.

Analysis of plans and vertical cuts sections of separate cavities allows to determine main directions of crevasses and their connections with orientation of tension ellipsoid in separate parts of concrete glaciers. By statistical analysis of the data about length of rectilinear sites of drainage channels it is possible to determine sizes and a configuration of ice blocks, to establish density of hydrologically active crevasses inside these blocks.

Usually hydrological research is possible only in catch and outflow areas of glacial waters. Application of karstological (speleological) methods allow to carry out hydrological research also in internal water transit zone – directly inside drainage systems. Researches of them allow:

A) to establish position of water level (uniform hydrostatic water level, isolated conduits, «double porosity» with various filtration properties for crevasse zones and internal parts of ice blocks with small quantity of fissures and crevasses).

B) to establish structural and filtration anisotropy of glacier by realization of indicator experiments.

C) to establish character of water movement (free, pressure head, laminar, turbulent) in various parts of drainage systems to receive settlement characteristics of water streams inside drainage systems (stream velocity, water level, discharge, Reynolds and Fraud numbers and so on) and glacier in whole (filtration index etc.), to dismember hydrographers of springs (upwellings) at glaciers tongues (with allocation of dead volume in underground dammed and accumulative lakes) and curve of exhaustions (with allocation of various components of glacial runoff).

D) to coordinate seasonal changes of hydrodynamical parameters and temperatures of glacial water with data of meleorological and hydrological investigations on surface, with changes of springs discharges and with fluctuations of water levels in moulins and boreholes.

E) to receive differential values of GK activity for different seasons and hydrodynamical zones of glaciers.

GK study in future will allow to receive quantitative indicators of growth and dynamics of drainage channels in different glaciers and in different regions. With the help of these indicators in future, probably, it will be possible to make quantitative estimations not only for speed of origin and destruction of internal drainage systems, but also its role at different stages of glaciers evolution.

Further study of internal drainage will enable to explain mechanisms of such catastrophic glacial phenomena as outbreaks of glacial lakes and fast ice motion (surges). Detail study of an internal drainage will allow to understand GK evolution. It will enable to approach us to explanation of ancient glacial sheets destruction from quantitative positions.

Research of GK together with others glaciological researches will allow to look in a new fashion at a role of water in glaciers. It will enable to explain both properties of ice and feature of glaciers (movement, metamorphism, degradation features etc.).

Investigations of glaciers drainage systems, laws of their origin and evolution during ablation season and long periods of time, and also in connection with conditions and structure of glaciers enables to coordinate among themselves combinations of superficial and internal glaciers drainage systems. But also it is possible to solve inverse task: on basis of drainage systems study to understand conditions of separate parts and of whole glaciers. It will allow in the future on the basis of GK study including remote sensing methods together with the control of glaciers tongues positions to receive more full, wide and trustworthy information not only about a structure and a condition of many glaciers of a planet, but also character and tendencies of regional climate change.

Isomorphism of GK and karst allow to use achievements in research of one of karst type for finding out of development laws for other karst type. Calcareous karst is now enough well investigated. It means that laws of limestone karst development may be used for finding out corresponding laws in GK. And this «laws conversion» is possible without entering serious corrections (in view of time difference of drainage systems formation, and also in view of special properties of ice: fluidity and plasticity). It results now and will result in future progress in GK study including glaciers internal drainage. But it means also that many laws received at GK study may be used without very serious changes at researches of calcareous karst. It is especially tempting because of different speed of karst forms origin in limestone and ice (many hundreds thousands years for limestone karst and from several months to several years for GK). It means possibility not only directly observe origin of karst forms in glaciers of different regions with various climate, to carry out their exact measurements or even to put some types of experiments. It means GK may serve as natural model of calcareous karst. Certainly, not now, not in the future it will be impossible automatically to transfer laws of origin of separate forms from one karst type to another. But it does not mean that in general it will be impossible to take advantage from it. Hope therefore is quite competent that big interest, which has originate recently to GK study, in future will result in progress of calcareous karst study.

CONCLUSIONS

Thus forms and processes, which result in formation of karst relief (superficial and underground) on glaciers can named GK. Despite of some distinctions determined basically by ice properties, full similarity of superficial and internal karst forms in ice and limestone is observed. It means, that GK may serve as model for calcareous karst and on contrary. It is especially important as speeds of formation and evolution GK in millions times is higher than at calcareous karst. But we need take into account difference between ice and rocks and processes of chemical rocks dissolution and physical ice melting. GK also defines a lot of processes on glaciers: change in thermal ice conditions, maintenance of fast water delivery in ice thickness, water-contents changes in ice, ice properties changes, maintenance of glacier surges, outbursts of glacier-dammed lakes etc. Therefore GK study has the big prospects in future.

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LAKES IN GYPSUM KARST: SOME EXAMPLES IN ALPINE AND MEDITERRANEAN COUNTRIES

JEZERA V KRASU V SADRI: NEKAJ PRIMEROV IZ ALPSKIH IN SREDOZEMSKIH DEŽEL

Jean NICOD[1]

Abstract: UDC 556.55(467.1) 551.444(467.1)
Jean NICOD: Lakes in Gypsum Karst: some examples in Alpine and Mediterranean countries.
Numerous lakes of varying types have been studied in these areas. Their origin proceeds from the geomorphological processes in the gypsum karst: land subsidence or collapses in relation with the active dissolution of the gypsum and other evaporites, particularly in depth, at the groundwater level.
Most are small lakes, often ephemeral ponds in the alpine gypsum karsts, or flooded sinkholes in alluvial plains, in keeping with the fluctuations of the water-table. However, in the Mediterranean lands and Central Europa, some lacustrine basins are more important expanse; they arise from a complex evolution, and put various environmental problems. So are particularly studied the case of the lake of Besse in Provence, and in comparison the problems of the lakes of Pergusa (Sicily) and Banyoles (Catalonia).
Key words: Evaporite karst, gypsum, lake, Alps, Mediterranean.

Izvleček UDK 556.55(467.1) 551.444(467.1)
Jean Nicod: Jezera v krasu v sadri: nekaj primerov iz alpskih in sredozemskih dežel
V teh predelih so bila preučevana številna jezera različnih tipov. Nastala so zaradi geomorfoloških procesov v krasu v sadri, kot so: ugrezi ali udori v zvezi z raztapljanjem sadre in ostalih evaporitov, predvsem v globinah, v višini talne vode. Večina teh jezer je majhnih, često so to občasna jezerca v krasu v sadri v Alpah, ali pa zalite vrtače v aluvialnih ravninah, ki odražajo nihanje gladine talne vode. V sredozemskih deželah in v Srednji Evropi pa so nekatera povodja teh jezer precej večja; njihovemu nastanku so botrovali različni dejavniki in v zvezi z njimi se pojavljajo različne ekološke težave. Kot primer je posebej predstavljeno jezero Besse v Provansi, za primerjavo pa še jezeri Pergusa (Sicilija) in Banyoles (Katalonija).
Ključne besede: evaporitni kras, sadra, jezero, Alpe, Sredozemlje.

INTRODUCTION

Although the lakes in gypsum or evaporites karst are not generally studied, but only by local or punctual works, their processes of formation and evolution are very interesting. They present specific characteristics comparatively to karstic lakes in limestones and dolomites:

- the quick genesis of their basin, frequently by breakdown, collapse or suffosion processes consecutive to the accelerated solution of the gypsum or andhydrite (and more in the halite lens!) (NICOD 1993, KLIMCHOUK 1996, 2002);

- the possible extension by solution and land subsidence, recess of the borders by solution and collapse, or coalescence of contiguous sinkholes;

- their variable water level, depended not only on the hydrologic conditions (change of the groundwater level, input-output balance), but also on the subsidence or collapse of their basin bottom;

- the silting by the clay derived from the weathering of the argilaceous beds joined up the gypsum or other evaporites:

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- the high mineralization, poor ichtyologic fauna, locally anoxic water and possible sulfhydric gas irruption in relation with the bacterial action on dissolved sulphates.

As do all the phenomenons in gypsum karsts when they occur in the urban and suburban areas, the gypsum lakes give main impact problems: the changes of lake level and possible extension, or on the contrary silting and trend to marsh.

FORMS AND ORIGINS OF THE GYPSUM LAKES.

THE LAKES IN SMALL KARSTIC DEPRESSIONS

Most small lakes are located in karstic forms, funnel or sinkholes, produced by breakdown or collapse processes in relationship with active solution (fig. 1). In the alpine gypsum karst, as that of Col du Joly, Beaufortin (Savoie, France), a field of many funnels extend upon the outcrop of gypsum layers, in the mountain pasture, near 1900-2000 m (NICOD 1988). When the bottom of these depressions are blocked by residual clay or issued from morainic deposits, the lakes can be formed, but fast changed into marshs and bogs. (Photo 1)

Photo 1: Small transient ponds in gypsum funnels, in the alpine pasture near Col du Joly (1989 m), in the northern Beaufortin (Savoie).

On the contrary, the gypsum lakes in the lower altitudes, in plateau or plain, are connected with the aquifer, either in alluvial deposits, example of the lagunas (doline-lakes) in the Ebro terraces (W Zaragoza SORIANO, 1991), or with a multilayered aquifer, as in gypsum karst of the triassic plateaus of the inner Provence (example of the Louciens, La Roquebrussane, Var Department). The level of those lakes depends to the watertable, as the case they can be perennial or temporary; in the occurence of speed groundwater lowering, the bottom of the basin may be changed by subsidence or collapse processes. In the example of the Grand Loucien, the excessive level variation cause sometimes rockslides in limestone borders: so this crater-like landform tend to extend. (Photo 2)

Photo 2: The « Grand Loucien » near La Roquebrussanne (Central Var Department). Collapse basin in middle Trias limestones, variable level in connection to the groundwater.

THE POSSIBLE COMBINATION OF PROCESSES.

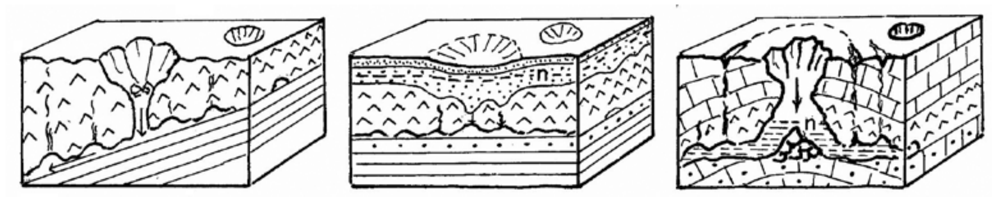
Some lacustrine basins proceed from a combination of two or several development processes. So in high altitude (near 2300 m) and alpine landscape, the lake of the Combe de la Nova in Beaufortin (Savoie), a submerged uvala in triassic gypsum band between shales, flows out in a sink-cave, active rockfall site (fig. 1, II). In the case of the lake of Mont-Cenis pass (1970 m, in Savoie, at the french-italian border) the glacial origin is clear, but a part of this basin is in a triassic gypsum band, where numerous funnels and sinkhole are opened; this structural arrangement has given a problem of losses, because of the raised level since the fitting out of the basin as reservoir for the hydroelectric power-plant (NICOD 1993). In the case of the Bonne Cougne pond, near Flassans in central Var Departement, it is spring-lake located in small polje in dolomites of middle Trias, now drained; its origin is in keeping with the dissolution of the underlying evaporitic lens, as in the lake of Besse (infra). In the « Causses » of the Middle Atlas (Morocco), several lacustrine basins in liassic limestones and dolomites proceed from the same processes: disssolution of underlying triassic gypsum lens, some in diapiric structures, and subsidence of the layers on top. Some are seasonal lakes (daias), as in the Ouiouane polje, and turn into salt crust in summer (MARTIN 1981). (Photo 3)

Modes of formation and evolution of the gypsum lakes

I – 3 sequences with respect to lithologic and geomorphologic conditions

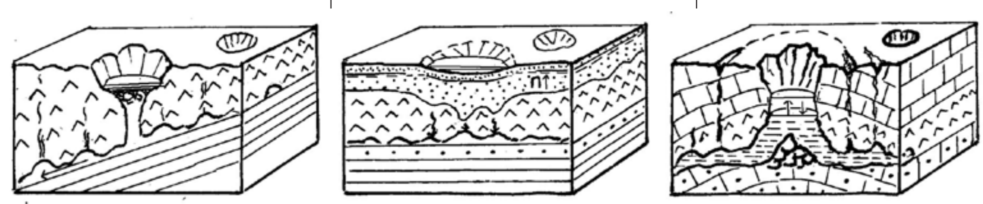
Geologic setting	**A**- Gypsum & anhydrite band : *Alpine Karsts*	**B**- Alluvial plain/ gypsum or evaporites	**C**- limestone plateau/ gypsum or evaporites

1-Mode of iformation of the basin



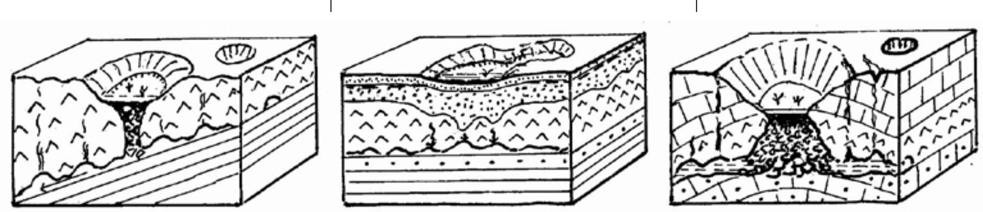
Type Processus Hydrology	Funnel Solution vadose circulation	Under-alluvial doline Solution + subsidence at alluvial water-table level **n**	Breakdown in deflooded cave (↓ of **n**)

2-Lakes in evolution



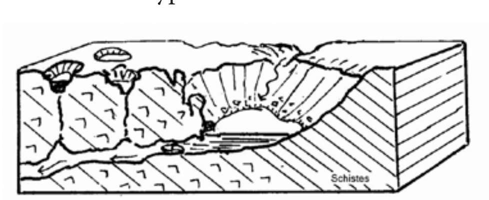
Type Hydrology	Funnel-lake over « plug », possible drain	Lake in doline permanent or temporary at alluvial water-table level **n**	« Crater » lake variable level **n** in keeping with the deep water-table
Examples	gypsum lakes Col du Joly, Beaufortin	Lagunas in Ebro terraces W Zaragoza	Grand Loucien La Roquebrussanne (Var)
References	NICOD (1988)	SORIANO (1991)	NICOD (1967, p.175)

3-Lakes at the end of evolution



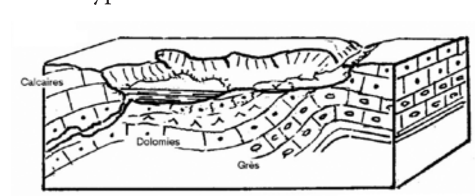
II – Compound cases

A*-Contact karst
Gypsum / shales



Lac de la Nova (Beaufortin , Savoie)
NICOD (1988)

C* Polje in compound structure
Gypsum lens in triassic dolomites



Lac de Bonne Cougne (SE Flassans, Var)

Fig. 1: Some basic types of formation and evolution of the lakes in gypsum karst.

Photo 3: The lake of the Combe de la Nova (2300 m, Beaufortin Savoie), submerged uvala in triassic gypsum band between shales. Loss in the gypsum rockfall (1994).

THE CASE OF AGUELMANE AZIGZA: RAIN-GAUGE LAKE !

Aguelmane Azigza (the Green Lake in Berber language) is situated in the southern part of the Causses of the Middle Atlas (Morocco). This main lake of the Causse of Ajdir, without outlet, gives spectacular inter-annual water-level changes: it is a record of the dry and humid periods at the regional scale. It is extended in the eastern end of an important polje, old landform expanded in the liassic dolomites, near 1490 m high, characterised by cupola hums and flat ground covered by residual deposits, dolomitic sands and terra rossa (MARTIN, 1981). The basin of the lake is a subsidence depression, following the fault system, in relationship with the dissolution of the evaporites in the underlying triassic formation. Active collapses and block-fallings in dominant scarps of liassic dolomitic limestones prove the permanence of this process. This play of dissolution at groundwater level, in the area of Causse of Ajdir is correlated with some sulphated and salt springs, north of this Causse, in the Oum-er-Rbia canyon (EL KHALKI & AKDIM 2001). (Photo 4 and Photo 5)

Photo 4: Small lake (daia), doline in diapiric structure (Causse d'Ajdir, Middle Atlas). Dry in summer, with salt crust (Photo Y. EL Khalki).

Photo 5: The lake Azigza, in the Causse d'Ajdir (Middle Atlas). Low level showed by the white scree, below the trail and cedar forest.

This part of the Middle-Atlas Causses is relatively good sprinkled and snow-covered in winter; the cedar forest subsists on the base of the scarps; but the inter-annual change of the rainfall and snow amount is very important. The rainfall and snow-melting in the polje supply the Aguelmane, however with high evaporation (~ 600 mm/y); but the lake-level is in connection with the aquifer in the dolomitic layers. Also this level can changed between 1490 m (in 1960) and 1471 m (1984), and even 1470 m in 1990. In high level, the lake may overflow in the polje; in lowest level, it covers only 37 ha, with 38 m of maximum deep.

The low level is in relationship with dry sequences, but a phase-lag of one or two years between the weak precipitations and the lowest water-level has be recognised (FLOWER & FOSTER, 1992): in my opinion that is caused by the slow response of the aquifer play in the liassic dolomites.

SOME MAIN LAKES.

In Central-Europe and Mediterranean countries, some largest lakes give variable forms, in relationship with diverse structures and hydrogeological settings, multiple evolution processes and various water supply. The table 1 shows the most important and knownest lakes, as representative examples of environmental problems.

Tab. 1: Main gypsum lakes in Central-Europe and Mediterranean countries, sorted according to their extension.

Lake Region, Land References	Surface *Altitude*	Depth. average max	Type Genesis Lithology	Working Hydrosystem Peculiarities
L. Invârtita (Nucşoara) Argeş Distr., Transilvania, Rom. BULGAREANU 1997	0.02 km^2 *877 m*	~5 m	Extended sinkhole from a ponor in the end of 19^{th} c. gypsum, aquitanian sandstone	Supplied by groundwater anoxic basin emit H_2S
L de Besse (Besse-sur-Issole) Var Dept., E Provence, F. NICOD 1991/99	0.04 km^2 *245 m*	3-4 m *9 m*	Collapse doline Middle-Trias limestones -id.- gypsum	In connection with aquifer + made-man supply by Issole partial drain-off in 1989
Nixsee (Nixei) Harzvorland (E Göttingen), D. PRIESNITZ, 1969	0.02-0.08 in flood → *250 m*	 6 m	Little polje dolomites gypsum of Zechstein	Flooded by spring (Springwiese) outflow → ponor
Laguna Grande (Archidona) Betic range, Andalucia, Spain PULIDO-BOSCH, 1989	0.06 km^2		Subsidence depression gypsum & halite of Trias	In relation with aquifer → Fuente Camacho Saline, dry in summer
Aguelmane Azigza Causse of Ajdir, Middle-Atlas, M. MARTIN 1981	0.34 km^2 *1490 à* *1471 m*	33 m (en 1989)	Collapse fault trough near polje in dolomites of Lias Trias clay + evaporites	Supplied by polje & aquifer very variable water-level Rain-gauge lake!
Lago di Pergusa (Enna) Central Sicily, Italy D'AMORE 1983	1.18 km^2 *667 m*	1,8 m	Large doline Pliocène marls Messinian gypsum + halite	Rain supply + groundwater without outlet trend to silting
Estany de Banyoles (Bañolas) Ampurdan, Catalonia, Spain JULIA BRUGUES 1980	1.83 km^2 *173 m*	10 m au N 20 m au S *130 m !*	Coalescence of sinkholes + travertine dam Eocene marls/gypsum	Supply by aquifer Anoxic bottom emit H_2S
Demiryurt gölü (Todürge gölü) Karst of Sivas, Anatolia, Turkey ALAGÖZ, 1967	3.3 km^2 *1295 m*	~4 m 28 m (funnel)	Submerged uvala Miocene gypsum	Supply by aquifer +affluent Outflow → Kizyl-Yrmak summer reduction →salt crusts

ENVIRONMENTAL PROBLEMS

The leak of the Lac de Besse (Central Provence), a «bottomless lake»!

This widest lake (4 ha) in the triassic plateaus of the Var Department is located near the old little town of Besse-sur-Issole. Its basin is a karstic depression in anticlinal structure of the middle Trias limestones (Muschelkalk); below the factured limestones (that make up the spur and cliff at the NW), the «Anhydritgruppe» formation is constituted by dolomites, dolomitic marls and gypsum (fig. 2). Mainly, the confined aquifer in these triassic formations and the outflow to the Issole river maintains the level of the lake, normanly nine metres deep; but in the dry years, the level can progressively subside, as in 1878; on account of this lowering, a small canal diverted from the Issole contributes to the supply of the basin. (Photo 6)

In december 1989, the level falls quickly, and the regional press print in enormous headlines: «*Après le gouffre glouton, le lac qui fuit!*», after the greedy pit, the leaky lake! A small cave opened on foot of the limestone cliff has absorbed in part the lake water (fig. 3), as previously in similar event in 1987 for one river near

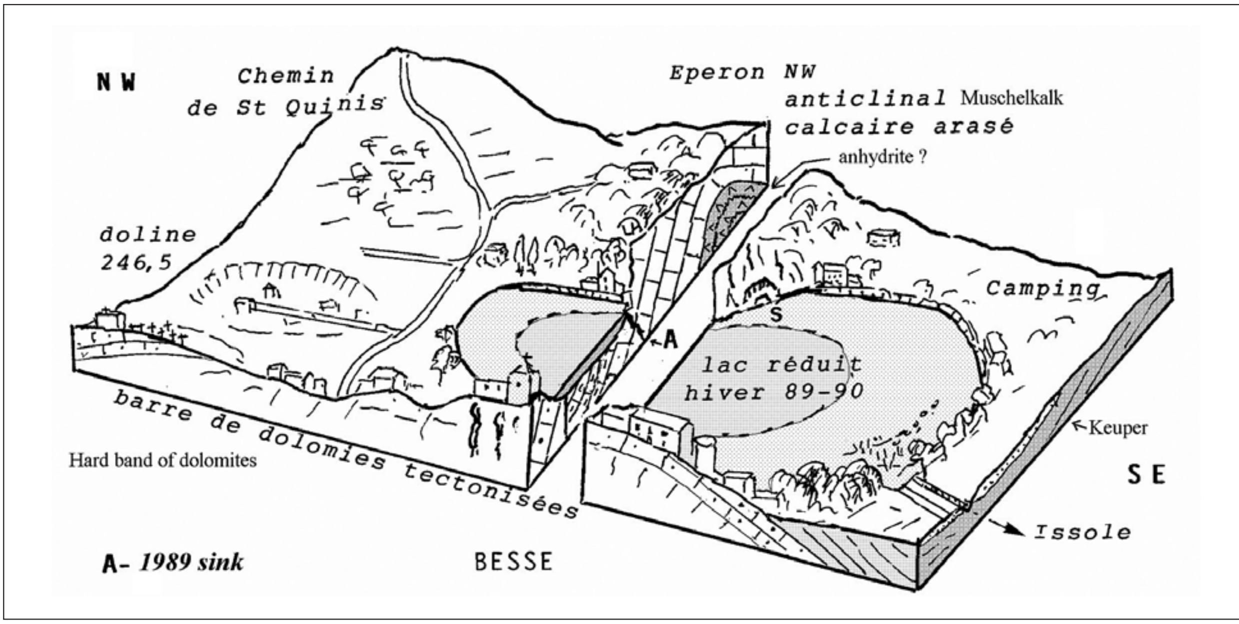


Fig. 2: Sketch of the lake of Besse, in its geological site.

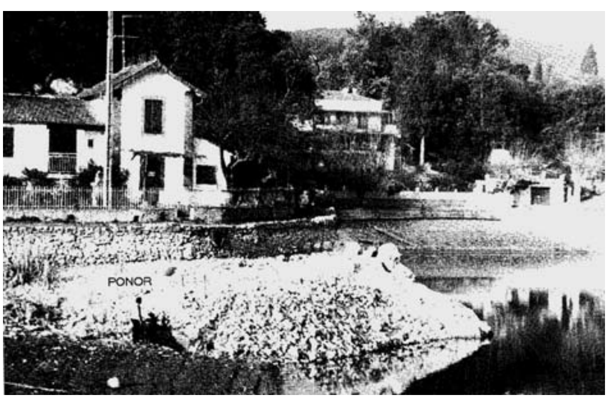


Fig. 3: Partly draining of the Lake of Besse in December 1989, by cleared pipe in the Muschelkalk spur. Lakes 1)

Photo 6: The lake of Besse-sur-Issole (Central Var Department) in 2005. View towards the Muschelkalk spur. Arrow marks the place of the 1989 sink.

Tourrettes in eastern Var Department. This phenomenon in lake of Besse is in relation with the drastic subsidence of the water-table, near 20 m. Two factors are added:

- the effect of several consecutive dry years;
- the effect of the over-working of the alluvial groundwater in the Issole valley by numerous well-borings, because the two aquifers are partly in connection.

Some improvment are worked in 1990, financed by Var Department:

- tightness of the critic area, by a cover of clay compacting;
- refitting of the canal from Issole river.

For this improvment, the lake level is restored; unfortunately a new falling occurs for some years, in relation with new dry climatic period.

Furthermore, in the decreased lake, the water become sligtly anoxic. These conditions cause some environmental problemes in the town of Besse, because the circumference of the water plan is shady recreation area, very important at the time of summer days for the citizens and tourists of next camping.

The decay of the Lago di Pergusa (near Enna, in Central Sicily).

That larger lake (1.83 km²), without outlet, is located in a wide oval karstic basin, from subsidence origin, in pliocene marls, upper gypsums of the gessoso-solfifera formation of Messinian (upper Miocene) (fig. 4). Numerous karstic phenomenons are recognized in this formation (FORTI & SAURO, 1996). The flowing on the surroundly sides (catchment area of 6 km²), and the ground-

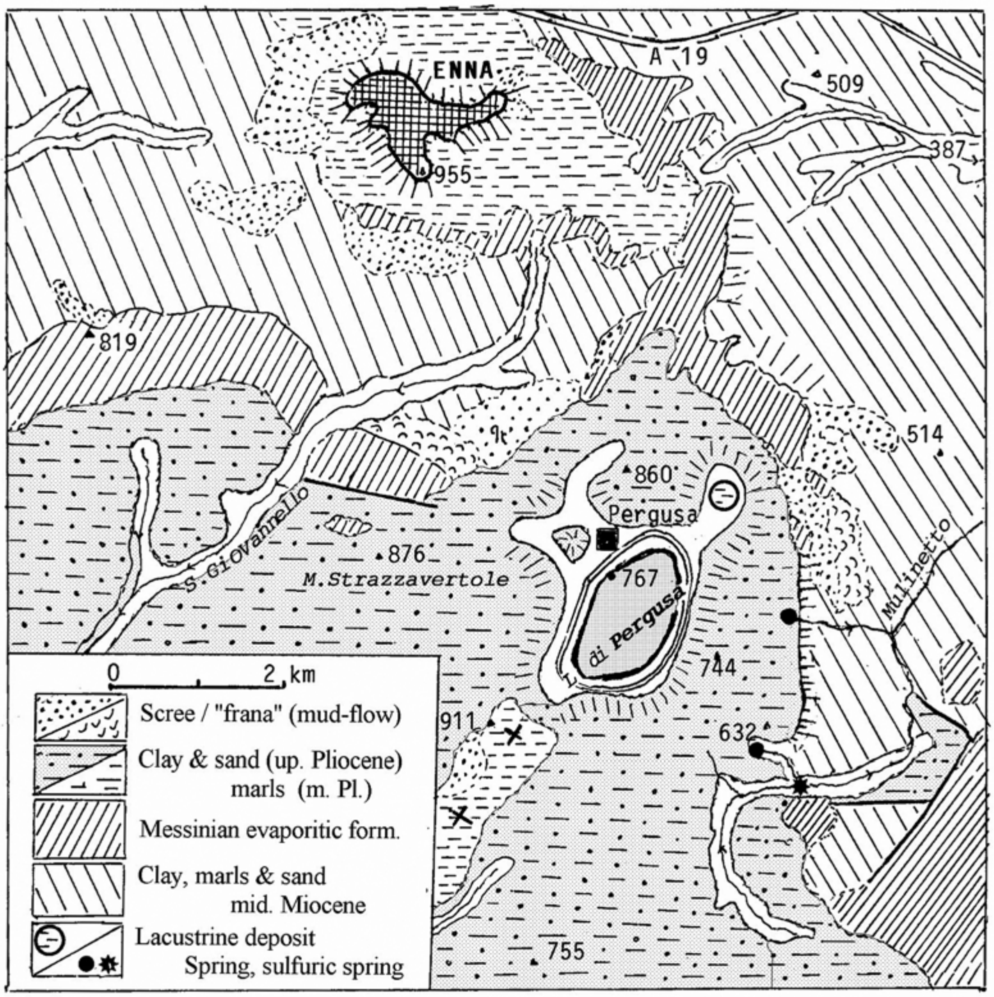


Fig. 4: The Lago di Pergusa, in its environment. Geology from the Carta Geologica d'Italia, 1/100 000, CALTANISSETTA, II Ediz., 1955

water of multilayered aquifer maintain the level. But its surface is reduced by the sedimentation, with silts from the weathering in Pliocene marls, and aquatic vegetation growth; moreover its level tend to subside (Tabl. 2).

Tab. 2: Decay of the Lago di Pergusa, from D'AMORE, 1983.

Dimensions	1896	1977
Perimeter	5.5 km	4.3 km
Surface	1.83 km²	1.35 km²
Maximum depth	4.6 m	2.4 m
Middle depth	2 m	1.8 m
Volume	5.8 x 10^6 m^3	2.6 x 10^6 m^3

Unfortunately, the site has been altered in the sixties at the time of the development programme of *Mezzogiorno*: an autodrom has encircled the lake! The growth of the Pergusa village, with hotels and campings, has increased the water polllution in summer, and the eutrophication with the proliferation of the green algae (Charophyceae). For to cure to the site deterioration, the *Consorzio di Bonifica di Borgo Cascino di Enna* supply the lake from the regional hydrosystem and the site has been classified as *«Green Zone»*.

The Estany de Banyoles (Bañolas), the large lake of Catalonia in urban area.

The large lake (~2 km²) of Banyoles is situated in the NE of Barcelona, at the active tectonic boundary between the hills of Garrotxa and the subsiding basin of the Ampurdan (fig. 5). The lacustrine complex depression is located in the blue marls over gypsum and limestone formations of the Eocene. The confined artesian aquifer of these limestones, supplied by a large catchment in the north-western hills, concurs to gypsum dissolution.

The lake has a double origin:

- the coalescence of some funnels and subsidence depressions;

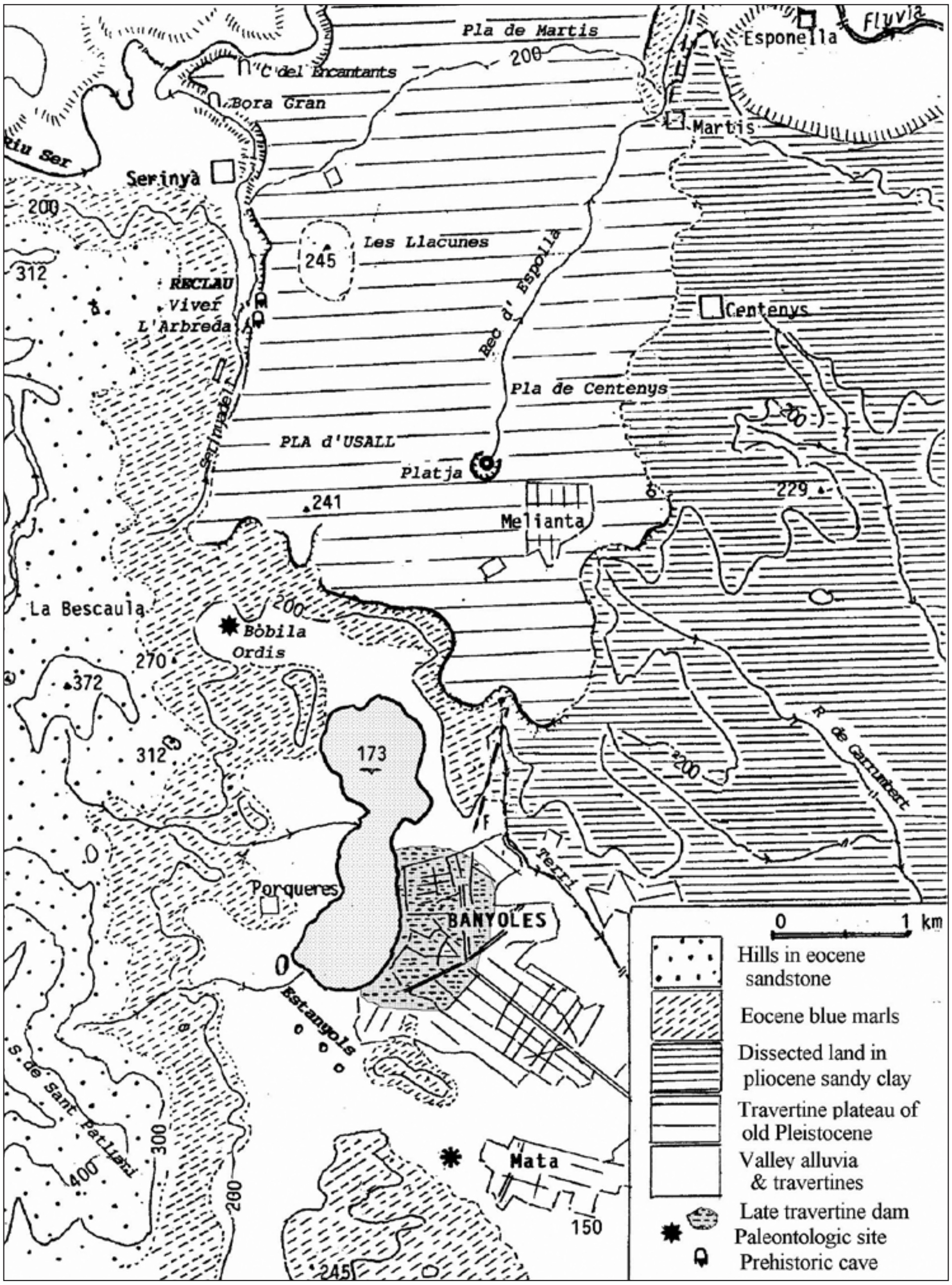


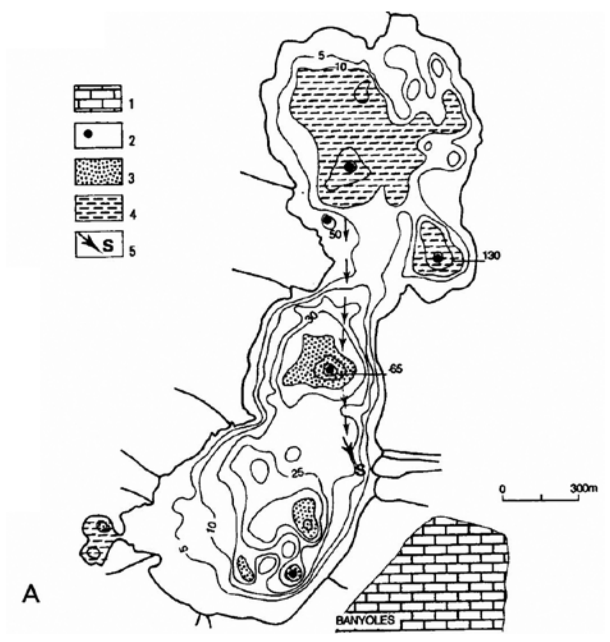
Fig. 5: The geomorphological situation of the lake of Banyoles.

- the water-level control by a travertine dam, builded on the Riu Terri outlet.

Round the lake, eight ponds (estanyols), of which one from a recent collapse in 1978 near Porqueres, show the enlargement by the solution and subsidence processes. In the lake bottom, several deep funnels (Cap de Bou – 130 m) play as artesian springs (fig. 6). In funnels, sulphate muds are in suspension (SANZ, 1985).

The travertine dam has been builded on the waterfalls at the outlet of the lake to Riu Terri, with waters of high carbonate-sulphate mineralization and by the action of the incrusting algae *(Cyanophyceae)* (JULIA BRUGUES, 1980). A part of the town of Banyoles is builded on the travertines and several levels of travertine formations are extended in the Terri valley, with paleontological and archeological sites; but the oldest and highest accumulation is the Pla d'Usall in the north. In this plateau, the *Platja* spring, more 40 m above the lake-level, proves again the power of the artesian hydrosystem.

The Estany of Banyoles constitutes an noteworthy ecological site with its ichtyologic fauna (abundance of carps), but also important recreation area for all water sports. Clearly that activity, and the urbanization of the area round the lake are pollutant sources.



← A – The bottom of the Lake of Banyoles
1 – travertine dam, 2 – deep funnel (m),
3 – suspension muds, 4 – H_2S concentration,
5 – H_2S migration

B – Funnel working ↓

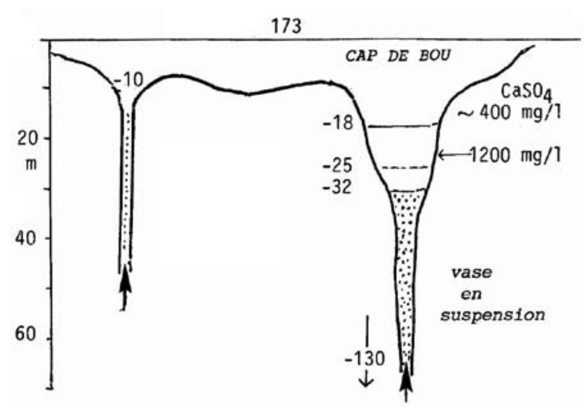


Fig. 6: The bottom of the Lake of Banyoles (from SANZ,1985).

CONCLUSION

The three lakes of Besse, Pergusa, and Banyoles show the most representative examples of environmental hazards and problems. As all phenomenons in gypsum karsts, their evolution depends on the active dissolution, and specific hydrogeological conditions. On account that produces high sensivity to anthropogenic changes, particularly with. the extent of urbanization atreas.

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PECULIAR MINEROGENETIC CAVE ENVIRONMENTS OF MEXICO: THE CUATRO CIÉNEGAS AREA

NENAVADNO MINERALOGENO JAMSKO OKOLJE V MEHIKI: PODROČJE CUATRO CIÉNEGAS

Paolo FORTI[1], Ermanno GALLI[2], Antonio ROSSI

Abstract UDC 552.54:551.44(72)
Paolo Forti & Ermanno Galli & Antonio Rossi: Peculiar minerogenetic cave environments of Mexico: the Cuatro Ciénegas area
The karst area of Quatro Ciénegas (Coahuila, Mexico) represents an ideal site to study cave mineralogy, because it hosts caves of different age and genesis (karst, thermal, mine caves). Among the speleothems studied is worth to mention a nest of aragonite cave pearls found deep inside the Reforma mine characterized by the total absence of growing layers inside them. Despite only few studied caves (8), some 32 different cave minerals have been detected, one of which is new for the cavern environment (kingsmountite) and another one, still under study, which probably will result new for science. Due to the scientific interest of their chemical deposits it should be very important to protect in the future the natural cavities of the karst systems of Cuatro Ciénegas in order to preserve a scientific patrimony, actually only partially known.
Keywords: cave minerals, guano minerals, minerogenetic mechanisms, climate, Cuatro Ciénegas desert, Mexico.

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Paolo Forti & Ermanno Galli & Antonio Rossi: Nenavadno mineralogeno jamsko okolje v Mehiki: področje Cuatro Ciénegas
Kraško ozemlje Quatro Ciénegas (Coahuila, Mehika) predstavlja idealno območje za preučevanje jamske mineralogije, saj so tam jame različne starosti in različnega nastanka (kraške, termalne, jamski rudniki). Med preučevanimi kapniki je vredno omeniti gnezdo aragonitnih jamskih biserov globoko v rudniku Reforma, za katere je značilna popolna odsotnost rastnih plasti (»letnic«). Kljub majhnemu številu preučevanih jam (8) je bilo odkritih 32 različnih jamskih mineralov, eden izmed njih nov za jamsko okolje (kingsmountite), drugi pa, ki je še v preučevanju, bo najbrž novo znanstveno odkritje. Zaradi znanstvenega pomena kemijskih odkladnin bi bilo zelo pomembno naravne jame kraškega sistema Quatro Ciénegas zaščititi, da bi s tem ohranili znanstveno dediščino, za zdaj šele deloma poznano.
Ključne besede: jamski minerali, minerali guana, mineralogeni mehanizmi, podnebje, puščava Quatro Ciénegas, Mehika.

INTRODUCTION

The natural caves are the seats of complex minerogenetic processes controlled by peculiar conditions existing in every single cave (Hill & Forti, 1997): hosting rock, cave sediments and circulating fluids are the most important factors controlling the development of the chemical deposits in caves. Forti (1996) stated that the hyperkarstic evolution occurs according to two chemical and physical contemporary processes: the corrosion/dissolution of pre-existing rocks and the deposition of speleothems with an extremely variable chemical composition.

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Recent researches, performed on internal cave deposits of European and extra-European locations, have brought to the identification of particular and extremely rare mineral phases, whose crystalline nature and chemical composition are strictly related to geological, climatological, lithological and hydrogeological continuously changing parametres (Frau *et al.,* 1998; Lattanzi *et al*., 1998).

Some very different minerogenetical mechanisms may induce the deposition of crystalline and/or amorphous phases, that are stable as long as the environmental conditions remain constant. These "products" can easily change or slightly modify if the genetical conditions change (Benedetto *et al*., 1998; Forti *et al*., 1999, 2000, 2001).

In this framework the thermal caves, which have been characterised at least once during their evolution by the presence of fluids with complex chemistry, are extremely interesting, permitting the evolution of polygenetic complex chemical deposits, mostly, although not always, correlated to the "Sulphur cycle" (Forti, 1989; Frau & Sabelli 2000).

Another peculiar class of natural cavities is represented by the "mine caves", cavities without any natural entrance, which have been intersected by mine galleries or other artificial tunnels: their minerogenetic interest comes from the possible interaction between karst fluids and ore bodies (Forti 2005, De Waele & Naseddu 2005).

The karst area of Quatro Ciénegas (Coahuila, Mexico) represents an ideal site to study cave mineralogy, because it hosts caves of different age and genesis (karst, thermal, mine caves) and therefore the chemical deposits developed inside them should result quite different from cave to cave, allowing the detection of many simultaneous and/or subsequent minerogenetic mechanisms.

In the present paper the observed speleothems are described and the related minerogenetic mechanisms are discussed in detail.

THE KARST OF CUATRO CIÉNEGAS

Cuatro Ciénegas plain is a Natural Protected Area since 1994; it is located in the state of Coahuila, Mexico, in the Sierra Madre Oriental at the eastern edge of the Chihuahua desert (Fig. 1).

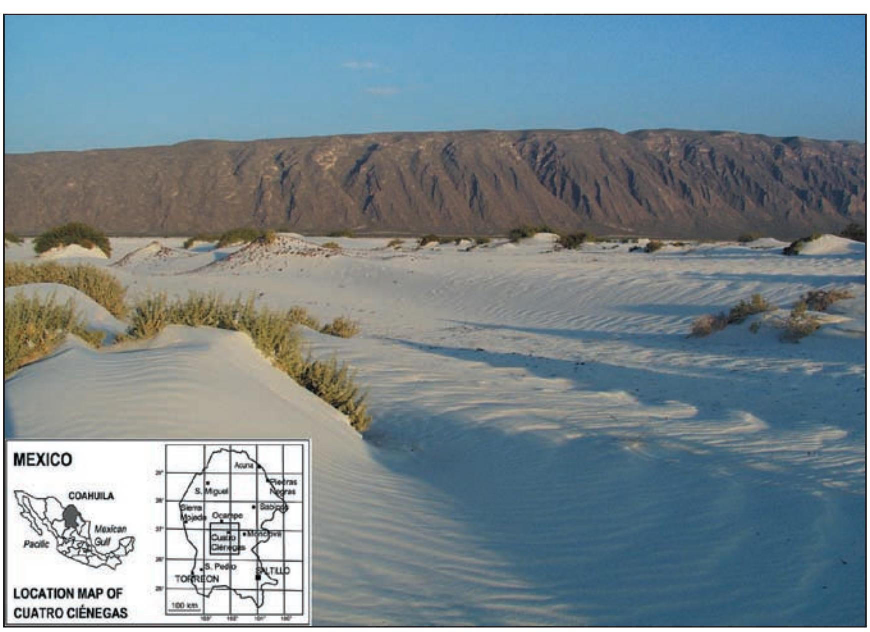

Fig. 1: Location map and a general view of the Cuatro Ciénegas desert.

This desert is characterized by a single period of rain, which normally consists of short but strong rainstorms in the summer period: they are caused by the moist air coming from the cyclones developing in the Mexican Gulf.

The rainiest period is September, with an average of 35 mm; anyway some years, particularly strong events may cause the fall of over 5 mm in a few hours, thus transforming the depressions in swallow ephemeral lakes.

Long rectilinear anticline ridges characterize the landscape of Cuatro Ciénegas whereas major valleys correspond to synclines. The most inclined slopes of major structures, mostly facing SW, often display vertical or overburden beds. Along them, deep transversal and longitudinal valleys form a typical trellis drainage pattern. In the pedemontane areas, several coalescent fluvial fans form a wide regular surface gently inclined, where streams display a disrupted and irregular pattern. Runoff is quite absent in these areas. The plains behave as endoreic basins where major storms form shallow lakes and ponds, the evaporation of which causes the formation of sulphates deposits. Eolian gypsum dunes occur in these areas.

Some of the major caves in the area of Cuatro Ciénegas are hypogenic in origin, created by rising thermal water. The best example is the Cueva Rancho Guadalupe, in the NE of Sierra la Fragua. This cave has a typical dendritic pattern and consists of maze conduits and spherical rooms (Bernabei *et al*., 2002).

Though it receives little rain, the Cuatro Ciénegas valley has abundant subterranean water, which creates hundreds of small pools, marshes, rivers, lakes (large, saline lakes locally called *lagunas or playas*), and canals with a unique biota of great interest to the international scientific community and at risk of extinction (Fig. 2).

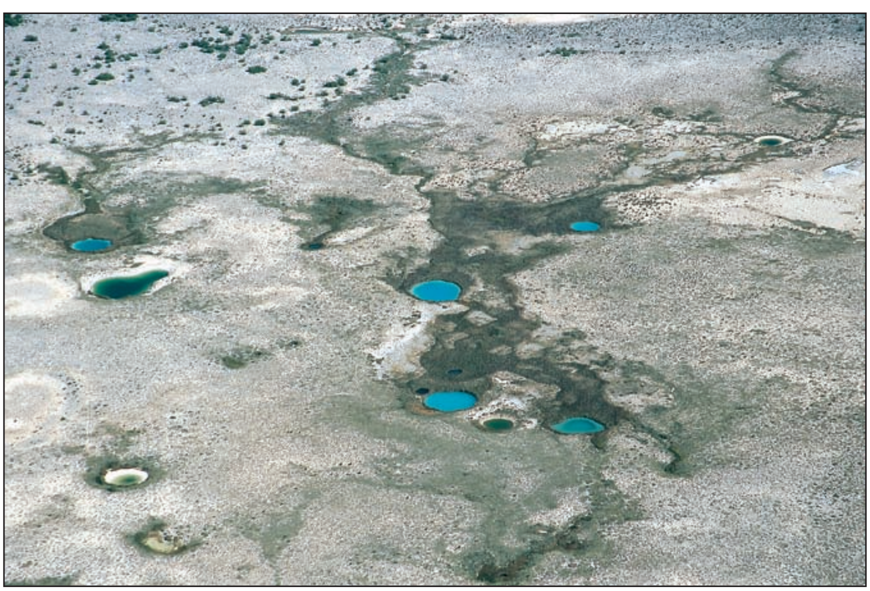

Fig. 2: Aerial view of the pools of the Cuatro Ciénegas desert.

A peculiar characteristics of the pools is the presence of living stromatolithes, which act as local primary agents of the food chain.

Despite the relevant ecological interest of the aquatic environment of Cuatro Ciénegas only in 2000 La Venta Exploring Team started a hydrogeological study of the pools and of high surrounding mountains proving that most of the pool recharge comes from karst structures; during this research over 60 caves were explored and mapped (Forti *et al.,* 2003).

The karst of Cuatro Ciénegas underwent a complex evolution over a very long span of time, which may be evaluated of several tens of millions years. Actually most of the karst systems show a rather inactive evolution, even if corrosion and/or depositional processes are still going on somewhere.

The speleogenetic mechanisms were very different among each other and therefore produced peculiar forms, which now allow reconstruction at least the mean steps of the complex evolution the caves of Quatro Ciénegas underwent.

This evolution may be subdivided into four principal types (Forti *et al*. 2003), which may be also regarded as subsequent stages being rather in chronological order even if some overlap occurred:

1. The genesis of mine caves (hyperkarst phenomenon)
2. The genesis of thermal caves (hyperkarst phenomenon)
3. The genesis of meteoric caves (karst phenomenon)
4. The development of biogenic forms inside previously formed caves (hyperkarst phenomenon)

The first two mechanisms are related to the uplifting of deep hot fluids, the third to the seepage of meteoric (rain) waters, the forth to the presence of huge bat communities, which colonized mainly the caves of the third type.

The study on the speleothems of the Cuatro Ciénegas caves, started in 2001, and it is far to be completed, but on the basis of the achieved results it is evident that this karst region can be considered as one of the most interesting in the world from the point of view of the hosted cave minerals.

This uncommon richness of mineralogical phases, most of which phosphates, is the direct consequence of the complex karst evolution this area underwent. Moreover, some of the "normal" karst caves became in the past (since several years ago) shelter for huge colonies of bats, thus allowing the accumulation of widespread guano deposits up to several metres thick: inside which microbiological reactions gave rise to an extraordinary variety of minerals.

Finally the karst springs are fed by mineralized waters uplifting from rather deep circuits and the peculiar climatic conditions of the desert of Cuatro Ciénegas inducing strong evaporations creating a "sabkha" type environment thus allowing the deposition of even very soluble minerals.

The scarcity of available time for the cave exploration and for mineral sampling obliged to restrict the mineralogical study to a rather small number of natural cavities. Anyway they have been selected to represent all the different environmental and minerogenetic conditions existing in Cuatro Ciénegas.

Among the analyzed caves there are mine caves (Reforma Mine), thermal caves (Cueva Rancho Guadalupe), karst cavities with bat colonies (Cueva Rossillo) and Cueva de los Murcielagos.

EXPERIMENTAL METHODS

A detailed analysis of all the samples by the stereoscopic microscope was performed to distinguish and to separate the different mineralogical phases present in each sample. Then the single phases were analysed by a powder diffractometre (Philips PW 1050/25), when the material was quantitatively enough and homogeneous, or by a Gandolfi camera (Ø: 114.6 mm, exposition: 24/48 hrs), when the material was scarce or inhomogeneous. Always the experimental conditions were: 40Kv e 20 mA tube, CuKα Ni filtered radiation (λ = 1.5418 Å). The analyses of the clay minerals were done not only over the natural samples but also after a glycerine treatment.

Almost all the samples analyzed by Gandolfi camera were later used to obtain images and chemical qualitative analyses through an electron scanning microscope (SEM Philips XL40) with an electronic microprobe (EDS-EDAX 9900) at the C.I.G.S. (Centro Interdipartimentale Grandi Strumenti) of the Modena and Reggio Emilia University.

THE MINE CAVES AND THEIR MINEROGENETIC MECHANISMS

The speleological interest of the mining areas around Cuatro Ciénegas is represented by the existence of "mine caves" (De Waele & Naseddu 2005, De Waele *et al.*, 1999, 2001; Forti *et al.*, 1999), karst cavities without any natural connection with the surface, which has been intersected by the mine galleries.

The oldest actually known karst (paleokarst) phenomena of the Cuatro Ciénegas area (Forti *et al.*, 2003) are those connected with the formation of the metallic sulphides ore bodies, mainly consisting of lead, zinc and, in a lesser extent, of silver, extensively mined in the past (De Vivo & Forti 2002).

The area of Cuatro Ciénegas was one of the very first Mexican regions in which mining activities started since the first half of the 14^{th} century. These activities lasted until 1958, when the most important mine (the Reforma mine) was definitively closed because the reached depth, far below the water table, made the production costs higher than the exploitation profits.

The ore bodies consist of sulphides with some supergenic minerals, most of which carbonates, dispersed within a carbonate breccia or filling karst cavities (Vargas *et al.*, 1993).

The fluids flowing inside the carbonate rocks developed caves along the bedding planes and the major discontinuities, mainly where the rock was highly fractured and therefore more permeable. These fluids simultaneously, or just after the development of the caves, filled them with lead and zinc sulphides as in the case of the Reforma Mine. Due to the progressive cooling down and loosing pressure of the thermal fluids, at the end of the mineral deposition, euhedral (middle thermality) quartz and finally low thermality calcite was formed.

In the first hypothesis (MVTOD) the caves filled by ore bodies should testify an old karst stage, partially connected to the seepage of meteoric waters, in a Cretaceous carbonate platform environment; in the second hypothesis the caves developed due to the uplifting of high temperature and pressure fluids, formed by the strong volcanic activity, which took place in the Upper Miocene (about 10-15 Myr BP).

This type of caves are practically never directly accessible and, even when intersected by mine galleries, they are hardly recognizable if completely deprived of the hosted ore bodies.

Their dimensions normally are of a few metres, but sometimes they are larger than ten metres. They exhibit an irregular shape without structural control; often they are rounded cavities elongated perpendicularly with respect to bedding. Good examples of such caves are visible inside the still accessible galleries of the Reforma Mine. These cavities are relatively rare worldwide and extremely important from the minerogenetic point of view: for example in Italy the mine caves of the Iglesiente (Sardinia) are the most known (De Waele *et al.* 1999, 2001).

Peculiar low-enthalpy reaction normally takes place inside such cavities, thus allowing the evolution of interesting and often rare speleothems and cave minerals.

In the area of Cuatro Ciénegas the mine caves are surely widespread even if they are actually very scarcely known.

This study took into consideration only a few cavities intersected by the main galleries inside the Reforma Mine: among them only the Cueva de los Cristales (Fig. 3) has a dimension of some tens of metres.

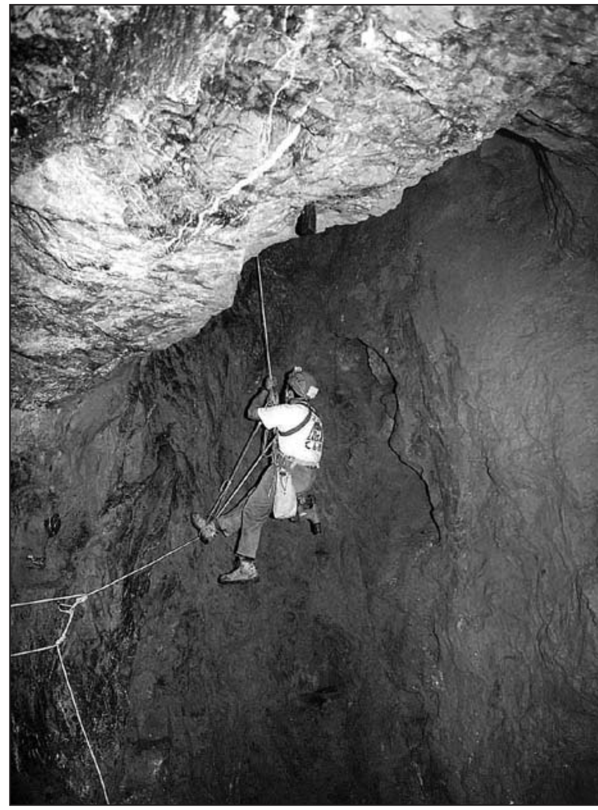

Fig. 3: The 30 metres high pit giving access to the Cueva de los Cristales inside the Reforma mine.

CUEVA DE LOS CRISTALES

It is a large cavity over 70 metres high and 100 long, developed along the big fault which controlled the deposition of the Pb/Zn sulphide ore bodies. Eight samples were taken from the wall of this cave where the primary minerals have been transformed to give rise to alteration compounds (Fig. 4).

The 6 detected minerals were:

Calcite: vitreous transparent euhedral rombohedral crystals up to 1 cm in size developed over iron hydroxides or as milky white to pale pink crusts;

Chlorite: it is an Mg, F fillosilicate; it consists of grains of different size with the same characteristics of the antigorite to which is always strictly associated;

Goethite: it is present as earthy from yellow to pale brown grains of different size;

Gypsum: it is present as thin dark grey layers covering the walls of small holes within the calcite crystals;

Hematite: it gave rise to a) small earthy reddish speleothems over sub-spherical hemi-transparent calcite grains or b) hard grains the powder of which has the typical bloody red colour.

Fig. 4: Cueva de los Cristales: transparent calcite crystals with hematite (A), illite (B) and goethite (C) within a broken speleothem.

LEVEL 12

A few more samples were collected in small karst cavities the "Level 12" gallery of the same mine, from 300 to 600 m from the entrance and at the end of this gallery. They consist of heterogeneous materials characterized by the presence of different mineral phases. The 6 detected minerals were:

Calcite: orange-yellow globular masses;

Goethite: it is present as earthy from yellow to pale brown grains of different size;

Gypsum: it is present as small lens-shaped aggregates of vitreous pale to dark grey crystals;

Hematite: it is strictly related to calcite and goethite;

Illite: this K fillosilicate is the major constituent of a clay and it consists of very small pale green-grey spheres over a black lithoid substratum;

Quartz: small euhedral transparent crystals.

The total number of the cave minerals found inside these mine caves (8) is by far lower than expected: in fact no lead or zinc compounds have been observed, while it is sure that such kind of minerals should be anyway present inside the karst cavities developed within the ore bodies.

In fact in a previous paper (Vargas *et al.*, 1993) cerussite, anglesite, smithsonite, hemimorphite, hydrozincite, hematite and limonite are reported as common supergene minerals of this mine. All of them have been well documented in the mine caves of Iglesiente (Hill & Forti, 1997), which are characterized by ore bodies and structural-lithological conditions very similar to those of Cuatro Ciénegas. Therefore it is logical to suppose that these minerals developed also inside the natural cavities of this mine.

But the principal ore body is actually completely flooded and therefore it is impossible to be reached; this fact is probably the main reason why these minerals have not been observed during the present study which has been focused only over the few mine caves existing in the upper part of the mine.

THE ARAGONITE CAVE PEARLS

One of the most important findings from the scientific point of view is a nest of aragonite cave pearls in which the internal growing layers were completely lacking (Forti, 2004).

Along the tunnel at the foot of the 170 m pit of the Reforma mine, several cave pearls nests were found lined with ultra-white pearls ranging from 1–2 mm to 2 cm in diameter (Fig. 5 left).

This tunnel was used by miners until just 50 years ago which would suggest that these speleothems only began to grow once the mine was abandoned, thus dating these formations at just half a century.

The largest pearls have a diameter of about 14 mm and the average size of their nuclei is 3 mm, therefore the average growth of those spleothems has been approximately 0.1 mm/year. Such a growth rate is considered average-average/fast for a carbonate speleothem in general and for a cave pearl in particular (Hill & Forti 1997).

Some of the pearls were found to have a cauliflower-shaped morphology, as a consequence of the coalescence of several single smaller pearls. This allows to state that the water supply to the nest should have been variable with periods of fast dripping followed by slow dripping or even completely dry periods, during which the originally insulated pearls cemented together. In fact cementation of different pearls may occur only if any kind of vibrations (induced by dripping) is completely avoided (Forti, 1983). Anyway, since composite pearls are quite rare, this would suggest that completely dry periods were far less frequent than the wet ones.

A mineral analysis by X-rays powder diffractions of the pearls has shown that the pearls consist of pure aragonite, the deposition of which is favoured when ions such as magnesium, lead and zinc, etc. are present in the feeding water (lead and zinc were originally extracted in the mine).

The cave pearls found in the Reforma Mine are extremely interesting because they completely lack growing layers (Fig 5, right), which would be of 0,1 mm/year if annual (Backer *et al.*, 1993). However, the Cuatro Ciénegas climate (dry/hot) would eventually have caused the development of many layers/year. In fact in such a climatic conditions, the relative long periods in between two subsequent rains surely avoid permanent dripping of infiltration water over the pearls nest, thus the development of the external layer would result stopped. If so, each rainfall or each series of close rainfalls would cause the development of one specific layer (Piancastelli & Forti, 1997).

Therefore the absence of concentric structure in the pearls of the Reforma mine is the result of very peculiar climatic conditions:

- Pearls must have a rather constant water supply during its growing.
- The chemical composition of the water supply must remain unchanged (irrespective of seasonal changes).

These seemingly simple conditions are in practice extremely difficult to be fitted in nature, which would explain why speleothems with no internal layers have been observed for the first time in the world here.

The Cuatro Ciénegas climate could hold the key to the evolution of these speleothems. Its aridity prevents most vegetal growth and soil covering, which in any case get quickly swept away by the regular strong winds. Therefore the infiltration water undergoes little or even none of the usual soil processes.

But this is not enough to explain the presence of the cave pearls in the Reforma Mine. The low rainfalls, high evaporation-transpiration, poor permeability around the mine could never guarantee a low but constant water supply in the tunnels. Therefore the water dripping into the pearl nests only occasionally may partially result from the rare rainfalls.

The constant presence of water in the depths of the mine is due to the daily temperature extremes typical of the Cuatro Ciénegas semi-arid climate and to the many man-made, interlinking tunnels on many different levels within the mountain, which in turn has a very stable temperature. These conditions allow for condensation, which would account for the constant presence of a few but continuously dripping water deep within the mountain.

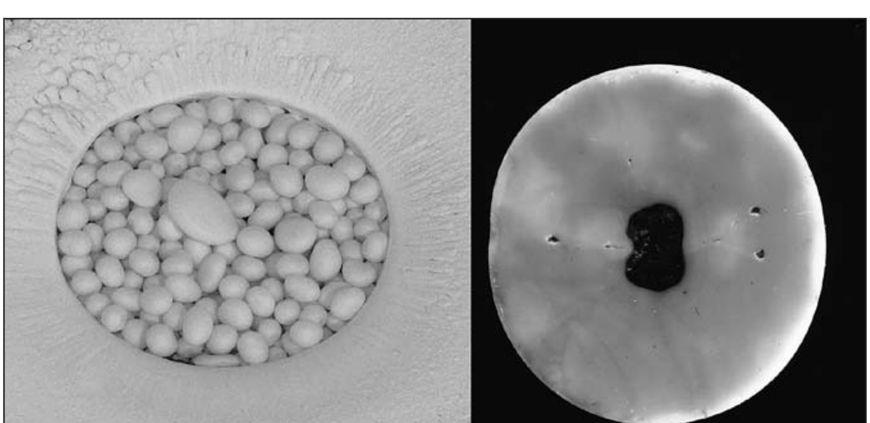

Fig. 5: The pearls nest of the Reforma mine (left) and a polished section of a cave pearl lacking of growing layers (right).

This condensation also explains the lack of any cyclicity in the depositional mechanism and, therefore, the absence of any (annual) growing layers. In fact the carbon dioxide content in condensation water is maintained stable due to CO_2 rather constant partial pressure within the mine over the year and the scarcity of meteoric water.

For these reasons the pearls found in the Reforma Mine has more far-reaching consequences. They have provided a method, based on the growth layers within a speleothem, for evaluating both qualitatively, as well as maybe quantitatively, the predominance of condensation over climatic-controlled water infiltration.

THE THERMAL CAVES AND THEIR MINEROGENETIC MECHANISMS

Some of the most interesting cavities of the Cuatro Ciènegas belong to this group; their genesis is linked to the uplifting of deep hot and chemically aggressive waters, which easily dissolve the rock during their slow movement toward the topographic surface. These waters were depleted of the heavy metals and of the other low solubility salts but represented the final stage of the processes, which gave rise to the mine caves.

The thermal caves, as well as the mine ones, are commonly called hypogenic, because they are generated by fluids coming from the depth (Forti, 1996). They normally lack of a natural entrance on the surface and when it is present, often it is the result of the demolition of the hosting outcrops by meteoric degradation.

The "pure" thermal caves are those whose development is exclusively controlled by the effect of thermal water uplifting, they are normally referred to as "monogenic": this kind of cavity is rare enough in the world and they have been described in details rather exclusively in the area of Budapest (Muller & Sarvary, 1977).

A "monogenic" cave is characterized by the presence of a reservoir of the thermal water (the equivalent of the magmatic chamber for a volcano), which consists of a huge "basal" chamber; several splitting and/or anastomized spherical cavities develop from the roof of such a chamber giving rise to a peculiar "branched tree" structure. The thermal caves of Cuatro Ciènegas belong to this category; therefore their importance exceeds the local interest (Fig. 6).

The Rancho Guadalupe cave, which is located just at the foot of the Sierra La Fragua, represents the best example of monogenic thermal cave.

It is a classical 3D maze cave with a net of conduits interconnecting large chambers all characterized by typical thermal corrosion forms. Due to the presence of some strange speleothems observed during the first visit, nine samples have been taken for an accurate mineralogical study, during the first exploration of this cave. Later, due to the peculiarity evidenced by the one sampled on top of an organic deposit rich in vegetal fibres up to 1 cm long, bird droppings and other animals excreta 4 more samples have been selected by the same deposit.

The study of the sampled speleothems confirmed the extraordinary importance of the secondary chemical deposits hosted in the Rancho Guadalupe cave (Forti *et al.*, 2004). Inside this cavity 18 different cave minerals have been observed (Tab. 1). Anyway the origin of only a few of them is directly related to the thermal processes which gave rise to the cave itself, others begun to grow after the thermal fluids definitively abandoned the cave and the meteoric waters entered the cave and finally some others were originated by the mineralization of some organic remains which were accumulated inside by small animals (mainly rodents) which use the cave as a shelter (Fig. 7).

Fig. 7: Cueva Rancho Guadalupe: a general view of a rodent shelter in a side passage close to the entrance of the cave where, beside whewellite, ardealite and sepiolite, a new still undefined mineralogical phase has been found.

The detected minerals are:

Aragonite: this polymorph of calcite is not common and it forms small milky-white to pale hazel-brown spheroidal grains;

Calcite: very common it is present as: a) radial aggregates of elongated (30x5 mm) vitreous, semitransparent,

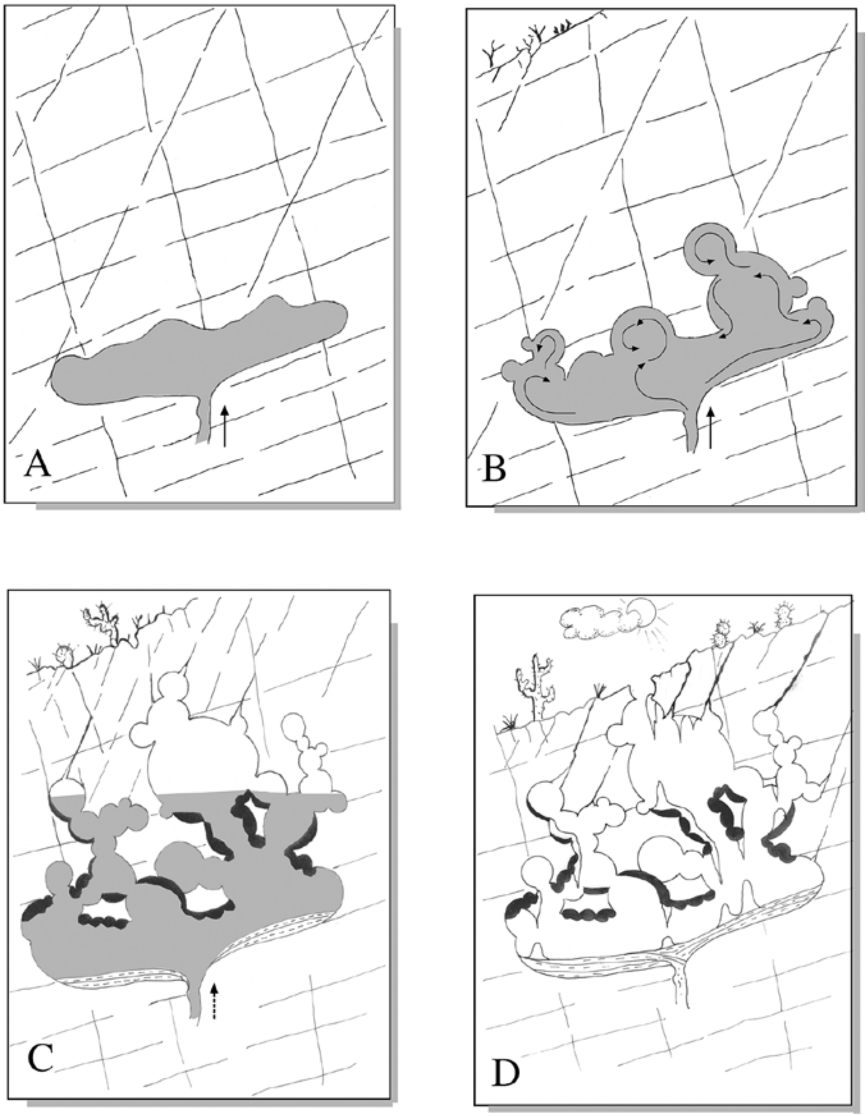

Fig. 6: Sketch for the evolution of the Rancho Guadalupe cave. A: due to the thickness and the low fracturation degree of the limestone, the uplifting of the thermal waters induces the development of a huge hydrothermal chamber in which they accumulates. B: The convective motions develop the upward evolution of a dendritic series of cohalescent subspherical voids. C: when part of the cave becomes partially unsaturated, the diffusion of CO_2 in the cave atmosphere allows for the development of some epiphreatic speleothems (cave cloud in black in the sketch) and the sedimentation over the cave floor of cave rafts, developed at the water-atmosphere interface; at the same time the meteoric seeping water starts the normal karst process in the unsaturated zone. D: the progressive erosion of the surface connects the cave to the exterior; the cave is then abandoned by the thermal waters. All the thermal forms and/or deposits are therefore fossilised, and meteoric seeping waters develop gravitational speleolothems (stalactites, stalagmites, flowstones…).

prismatic crystals which are often part of speleothems (flowstones); b) pale pink to brick-red hard material; or c) saccaroidal to powdery incoherent material;

Carnotite: this very rare uranil vanadate is present as small aggregates of canary-yellow small tabular crystals (SEM images in Fig. 8a,b);

Chlorapatite: it forms hard dark hazel-brown microcrystalline aggregates. The presence of Cl was confirmed by EDAX analyses;

Dolomite: it is present as aggregates of opaque, milky grains associated with sepiolite within the thick cave rafts deposit covering the whole floor of the thermal basal chamber;

Fluorite: it has been identified in a single sample: it consists of earthy and/or saccaroidal milky white grains within a speleothem (flowstone) on the wall of a small side bell shaped cavity;

Gypsum: it is present as: a) vitreous, milky crystals within a crust over a corrosion pocket of the wall; b) aggregates of small vitreous semitransparent dark-grey prismatic crystals;

Hydromagnesite: it gives rise very small spheroidal silky shining white aggregates of microcrystals. It is normally associated with monohydrocalcite (SEM image in Fig. 8c);

Monohydrocalcite: it normally consists of a earthy dust consisting of cream-white to pale hazel-brown micro spheres; sometimes it gives rise thin crusts and aggregates of small and fragile silky-lustre bladed crystals over the vegetable fibres (SEM images in Fig. 8d);

Niter: it presents: a) often as small effloresces of aggregates of thin transparent silky tabular crystals, often with a radial structure to simulate "an open book";

Tab. 1: Minerals identified in the karst systems of Cuatro Ciénegas: G – Cueva Rancho Guadalupe; L – Leona; M – Cueva de San Vicente (or de los Murciélagos); P – Cueva de Las Pinturas; R – Cueva Rosillo; Re – Reforma Mine; T – Tanche Nuevo; V – Vibora

Karst	Mineral	Chemical formula *	System	Figure no.	References
		HALIDES			
G	Fluorite	CaF_2	Cubic		Anthony et al. (1997), vol. III, 205
G	Sylvite	KCl	Cubic	9a	Anthony et al. (1997), vol. III, 545
		OXIDES			
R	Asbolane	$0.5[(Ni,Co)(OH)_2][MnO_2 \cdot nH_2O]$	Hexagonal		Anthony et al. (1997), vol. III, 26
R, Re	Goethite	α-FeOOH	Orthorhombic		Anthony et al. (1997), vol. III, 223
Re	Hematite	Fe_2O_3	Trigonal		Anthony et al. (1997), vol. III, 239
R	Lepidocrocite	γ-FeOOH	Orthorhombic	9f	Anthony et al. (1997), vol. III, 312
G	Opal-CT	$SiO_2 \cdot nH_2O$		8e	Smith (1998)
G, M, R, Re	Quartz	SiO_2	Trigonal		Anthony et al. (1995), vol. II, 672
		CARBONATES AND NITRATES			
G, Re	Aragonite	Ca[CO3]	Orthorhombic		Anthony et al. (2003), vol. V, 31
G,L,R,Re,T,V	Calcite	$Ca[CO_3]$	Trigonal		Anthony et al. (2003), vol. V, 101
G, Re	Dolomite	$CaMg[CO_3]_2$	Trigonal		Anthony et al. (2003), vol. V, 191
G	Hydromagnesite	$Mg_5[(OH)_2|CO_3)_4] \cdot 4H_2O$	Monoclinic	8c	Anthony et al. (2003), vol. V, 310
G	Monohydrocalcite	$Ca[CO_3] \cdot$ H2O	Hexagonal	8d	Anthony et al. (2003), vol. V, 465
G	Niter	$K[NO_3]$	Orthorhombic		Anthony et al. (2003), vol. V, 497
		SULFATES			
G, L, R, Re, T	Gypsum	$Ca[SO_4] \cdot 2H_2O$	Monoclinic		Anthony et al. (2003), vol. V, 271
		PHOSPHATES AND VANADATES			
M, P, R	Apatite group	$Ca_5[(F,OH,Cl,O)|(PO_4,CO_3)_3]$	Hexagonal	15d,e	Pau & Fleet (2002)
R	Ardealite	$Ca_2H[SO_4| PO_4] \cdot 4H_2O$	Monoclinic	12c	Anthony et al. (2000), vol. IV, 23
L, R, T	Brushite	$CaH[PO_4] \cdot 2H_2O$	Monoclinic	9c,d	Anthony et al. (2000), vol. IV, 83
G	Carnotite	$K_2[UO_2|VO_4]_2 \cdot 3H_2O$	Monoclinic	8a,b	Anthony et al. (2000), vol. IV, 96
G	Chlorapatite	$Ca_5[Cl|(PO_4)_3]$	Hexagonal		Anthony et al. (2000), vol. IV, 111
R	Crandallite	$CaAl_3[(OH)_6|PO_3OH|PO_4]$	Trigonal		Anthony et al. (2000), vol. IV, 130
R	Kingsmountite	Ca4FeAl4[(OH)2|(PO4)3]2. 12H2O	Monoclinic	15a,b	Anthony et al. (2000), vol. IV, 282
R	Montgomeryite	Ca4MgAl4[(OH)2|(PO4)3]2. 12H2O	Monoclinic		Anthony et al. (2000), vol. IV, 387
R	Taranakite	K3Al5[(PO3OH6)3|(PO4)2] · 18H2O	Trigonal	15c	Anthony et al. (2000), vol. IV, 581
M, R	Variscite	Al[PO4]. 2H2O	Orthorhombic		Anthony et al. (2000), vol. IV, 621
M, P, R	Whitlockite	$Ca_9(Mg,Fe)[PO_3OH|(PO_4)6]$	Trigonal	15d,e,f	Anthony et al. (2000), vol. IV, 653
		SILICATES			
Re	Illite	$(K,H_3O)Al_2[(H_2O,OH)_2|(Si,Al)_4 O_{10}]$	Monoclinic		Brigatti & Guggenheim (2002)
G	Sepiolite	$Mg_8 [(OH)_2|Si_6O_{15}] \cdot 12H_2O$	Orthorhombic	8e,f	Anthony et al. (1995), vol. II, 722
		ORGANIC COMPOUNDS			
R	Bitumen	nC_xH_y			
R	Guanine	$C_5H_3(NH_2)N_4O$	Monoclinic	9e	Anthony et al. (2003), vol. V, 265
G	Whewellite	$CaC_2O_4.H_2O$	Monoclinic	9b	Anthony et al. (2003), vol. V, 755
		NEW MINERAL(?)			
G	Unknown	Mg hydrated carbonate (?)			

*Classification and chemical formulae after Strunz & Nickel, 2001.

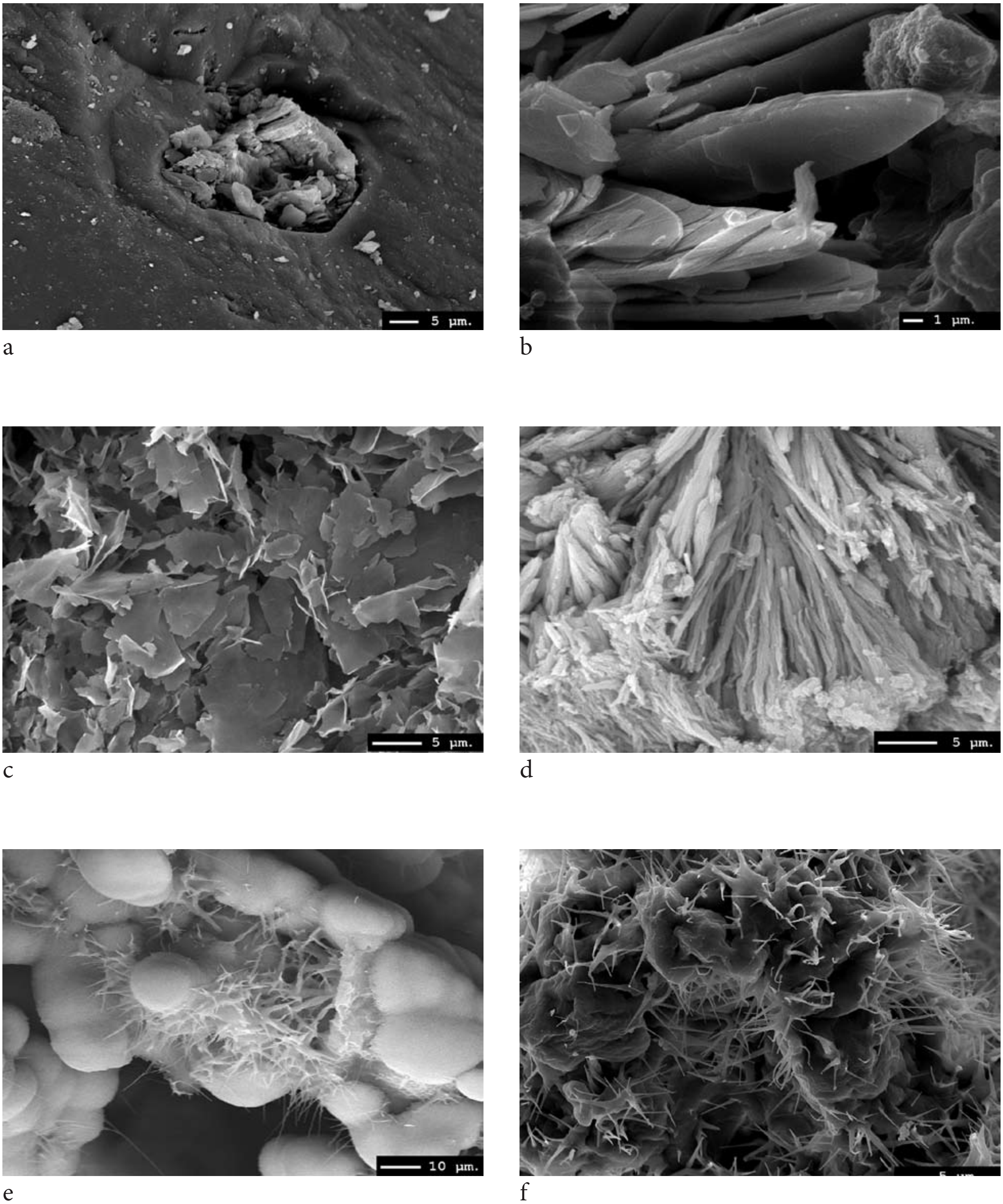

Fig. 8: SEM images of minerals from Cueva Rancho Guadalupe: a) inclusion of platy crystals of carnotite in tabular gypsum; b) magnification of a); c) aggregate of tabular crystal of hydromagnesite; d) fan like aggregate of platy crystals of monohydrocalcite; e) microspheres di opale-CT with fibrous sepiolite; f) fibrous sepiolite.

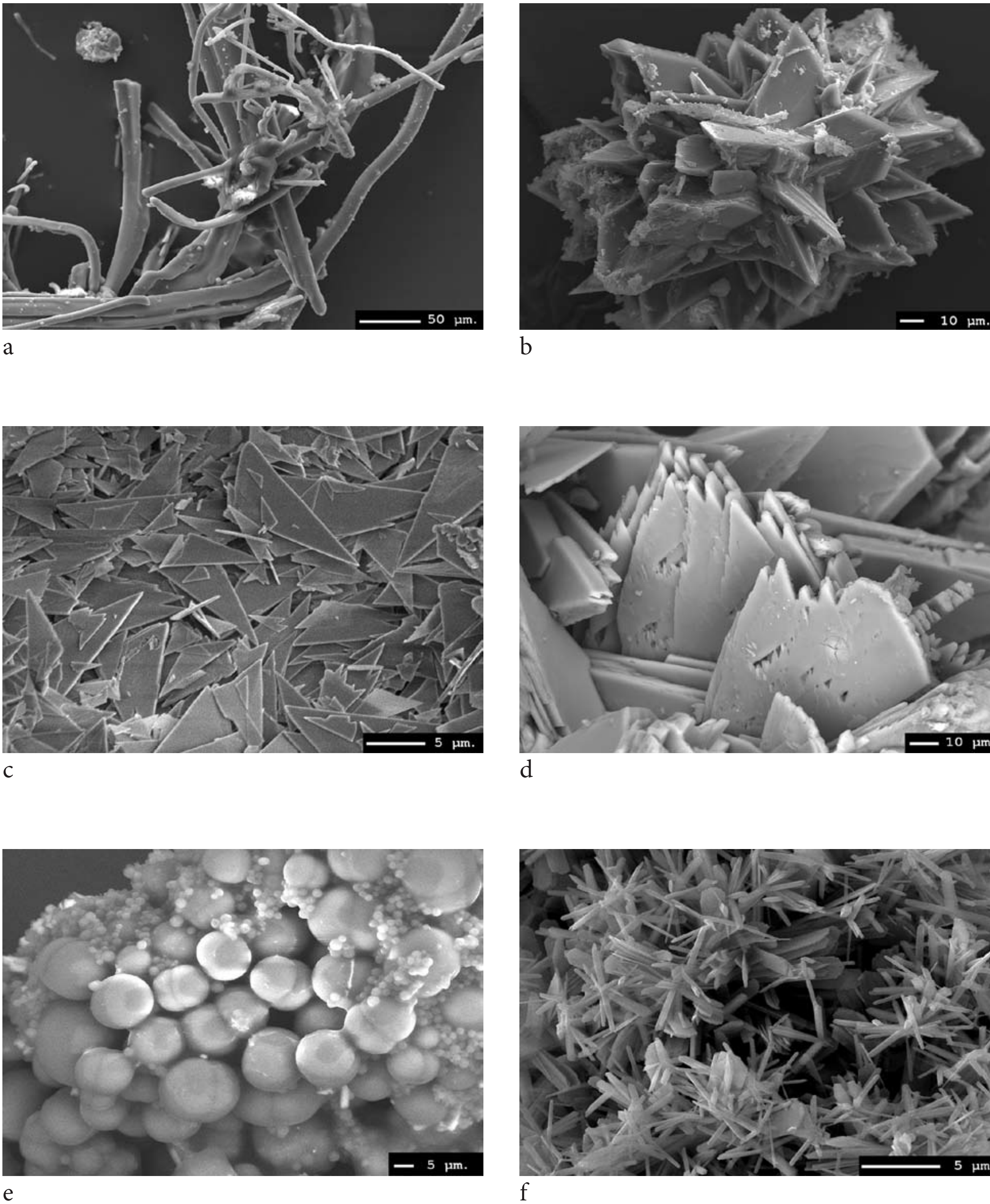

Fig. 9: SEM images of cave minerals from Cueva Rancho Guadalupe (a, b) and Cueva Rossillo (c, d, e, f): a) net of irregular fibres of sylvite; b) spheroidal aggregate of prismatic crystal of whewellite; c) aggregate of triangular plate crystals of brushite; d) close view of brushite crystals; e) aggregate of microspheres of guanine; f) star-like aggregates of lepidocrocite crystals.

b) sometimes as transparent crusts over the organic material;

Opal-CT: detected as incoherent milky white soft material like sawdust (SEM images in Fig. 8e);

Quartz: identified only by x-ray diffraction analyses within a thin gypsum-calcite speleothem;

Sepiolite: it gives rise to small hard milky white aggregates associated with dolomite within the cave rafts deposit covering the whole floor of the thermal basal chamber (SEM images in Fig. 8e,f);

Sylvite: observed as tuffs of vitreous, transparent bended filaments inside small pockets in the cave walls (SEM images in Fig. 9a);

Whewellite: this calcium oxalate monohydrate is present as small spherical aggregates of euhedral greasy, semitransparent prismatic crystals grown inside the coprolites (SEM images in Fig. 9b).

Anyway the uncommon richness and variety of the hosted cave minerals is not the principal reason of interest of this cave: in fact its importance from the mineralogical point of view depends on a mineral deposit, which has never been observed before in nature and which seems to be completely new for science. It is a highly crystalline magnesium compound, probably a hydrated carbonate, which is presently under examination to define univocally its structure and chemical formula. It occurs as extremely small (a few microns in diameter) milky white soft earthy spheroidal aggregates of tabular crystals inside organic materials (mainly vegetable fibres).

THE KARST CAVES AND THEIR MINEROGENETIC MECHANISMS

The most widespread karst phenomena are surely those connected with the seepage of meteoric water.

The karst forms induced by the diffuse and/or concentrated seepage are quite absent: in fact, even if the nature of the rock is carbonate and the fracturation degree is high, deep karst phenomena are normally scarcely developed and concentrated in very restricted areas. Most of the known cavities are sub-horizontal: they started as small interbedded conduits, which later have been widened by physical degradation starting from the entrance. Often they host plenty of speleothems even of huge dimension.

Sometimes the caves are fragment of old huge drainage tubes. Many of the cavities in the Sierra San Vincente and in the Cañon el Pedregoso are relict of old phreatic galleries developed in a period in which the rainfalls were by far higher than actually.

Often the karst caves do not host speleothems and/or cave minerals of interest: usually only calcite speleothems (stalactites, stalagmites, flowstones, etc…) are present, often with evident corrosion features induced by condensation processes. Among the cave minerals the crust and crystal aggregates of gypsum are fairly common: most of them are related to the dissolution of the discontinuous layers of this mineral present within the carbonate sequence, but some are generated by the oxidation of the sulphides associated to the ore bodies.

Normally the karst caves have scarce minerogenetic importance, but those, which have been and/or still are shelter for huge colonies of bats may exhibit a wide variety of secondary cave deposits. In fact actually the most active minerogenetic processes are related to the presence of guano deposits. Several thousand of years ago millions of bats colonized some caves, mostly of meteoric origin, after the active water flow stopped inside, thus allowing the development of widespread deposits of an incredible amount of guano (Fig. 10).

Fig. 10: Cueva Rossillo: one of the widespread large guano deposits.

The oxidation and mineralization processes of guano are strongly exothermic and release high quantity of H_2O and CO_2 thus inducing strong convective movements within the cave atmosphere, and producing a discrete amount of strong acids: mainly nitric (HNO_3), sulphuric (H_2SO_4) and phosphoric (H_3PO_4).

These processes may have strong morphologic consequences (Fig. 11), causing the development of peculiar condensation-corrosion forms like megascallops on the protruding walls and huge spherical domes in the cei-

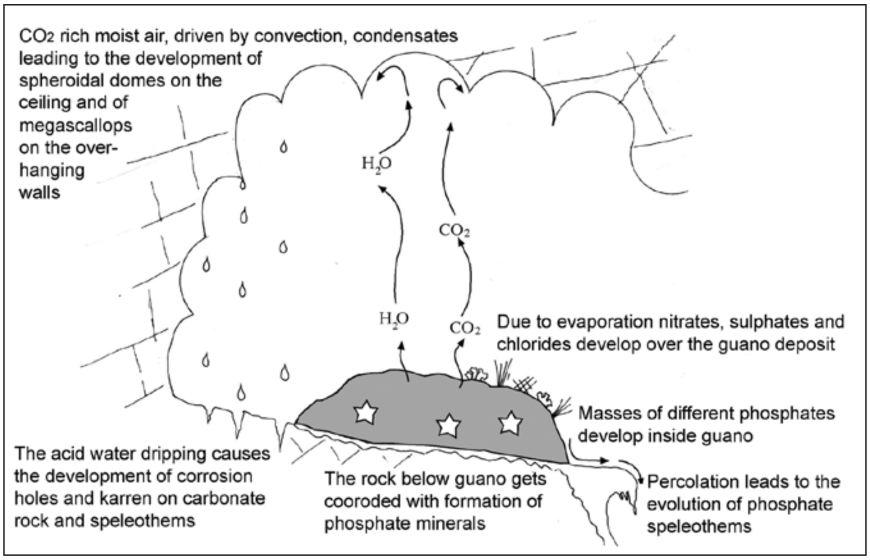

Fig. 11: Sketch of the morphological and mineralogical effect induced by guano deposits (Forti et al.*, 2004).*

lings or allowing for the evolution of corrosion furrows and/or holes in the cave floor.

The condensation water reacts with the carbonate rock, the other minerals eventually dispersed inside, the clay and sand deposits giving rise to many secondary minerals, among which the phosphates are the most widespread and may develop even as huge speleothems (Fig. 12).

Fig. 12: Cueva Rossillo: a) a thick phosphate flowstone developed in the final part of the cave; b) layers different in colour and/or texture are evident in a polished cross section; c) microsphere of pale yellow ardealite in a small void of the speleothem; d) the different layers observed with a polarizing microscope with crossed nicols.

CUEVA ROSILLO

It is a classical karst cave which has been deeply modified by the presence of an extremely large bat colony over a long time interval. The cave consists of a single huge gallery (average size 10 x 10 metres) some 1 km long. Its origin is related to important karst drainage below the groundwater level in a period in which the climate must be by far more humid than actually. The widespread presence of domes in the ceiling, megascallops in the walls and sponge-works on the floor is the direct consequence of the still occurring strong acid aggression due to the presence of huge fossil and/or actual guano deposits. The main cave gallery present on the floor a 5-7 m deep canyon developed when the lowering of the groundwater lever allowed for an epiphreatic to unsaturated evolution. Later the canyon was rather completely filled by sediments (mainly guano and its by-products): in the last century these sediments were intensely mined to produce fertilizers (Fig. 13).

Fig. 13: One of the many tunnels dug by guano miners in the floor of the main gallery of the Cueva Rossilo.

Where the guano leaking seeped along the limestone beds then gave rise to huge speleothems with inside layer of different thickness and colours, which often presented small cavities filled sometimes by pale vitreous crystals or dusty hazel-brown to pale pink grey material.

In one case, the seepage of organics leached by guano in the upper series of the cave developed small black stalactites, the colour of which was due to the presence of bitumen within the different growing layers of the speleothems (Fig. 14).

A total of 15 samples have been taken from sediments on the cave floor and from speleothems; the observed minerals are:

Apatite group: this generic name was given to hydroxylapatite, carbonate-hydroxylapatite, carbonate-fluorapatite and fluorapatite because it was rather impossible to discriminate among these phosphates. They are the most frequent phases in both the sampled sediments and speleothems. Their morphology resulted extremely variable: a) hard microcrystalline china-ware material,

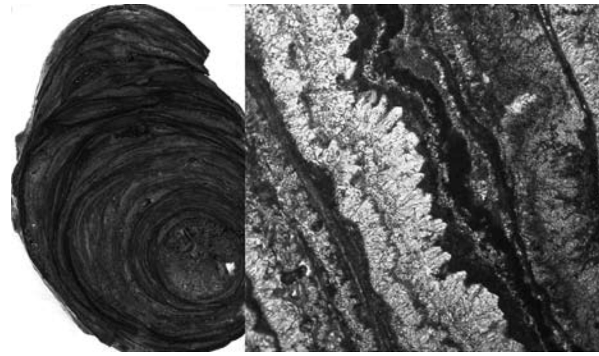

Fig. 14: Cueva Rossillo: polished section (left) of the black stalactite and a thin section (right) of it showing thin bitumen films adsorbed over calcite layers.

sometime layered with colours ranging from ivory to hazel brown, from pale brown to dark brown due to the dispersed presence of carbon rich phases; b) plastic light greasy pale pink powder, which sometime gives rise to small spheres, which in turn may be insulated or aggregated to form thin crusts; c) tuffs of radial aggregates of thin vitreous colourless to white acicular crystals; d) irregular grains of hard orange-red material (SEM images in Fig. 15d,e);

Ardealite: vary rare, it has been observed only in one sample where it was associated to gypsum within a small sphere of greasy pale lemon-yellow microcrystalline material (SEM image in Fig. 12c);

Bitumen: this organic compound is responsible for the pigmentation of the growing layers of a small dark brown calcite stalactite (5 x 2 cm) collected already broken close to the cave entrance. The concentration of this compound was high enough to allow a strong H2S smell while crushing the sample;

Asbolane: this Ni and Mn hydroxide is rare for the cave environment and in 4C was identified only in a couple of samples. It consists of small black earthy and spongy spheres within an earthy white material;

Brushite: common mineral which has been observed in several forms: a) thin crusts of vitreous, semitransparent milky white to pale greenish tabular crystals; b) aggregates of transparent lance shaped crystals; c) tuffs of thin elongated fairly bended crystals; d) aggregates of soft earthy grains, of small prismatic tabular crystals and of pale hazel-brown larger crystals; e) earthy milky white irregular grains; f) lens shaped aggregates of shining crystals within the earthy milky white material (SEM images in Fig. 9c,d);

Calcite: it is by far the most common mineral and consequently it is present in very different forms: a) in sub-spherical aggregates of radial elongated (30 x 5 mm) semitransparent vitreous prismatic crystals, similar to those observed inside some speleothems in a side cor-

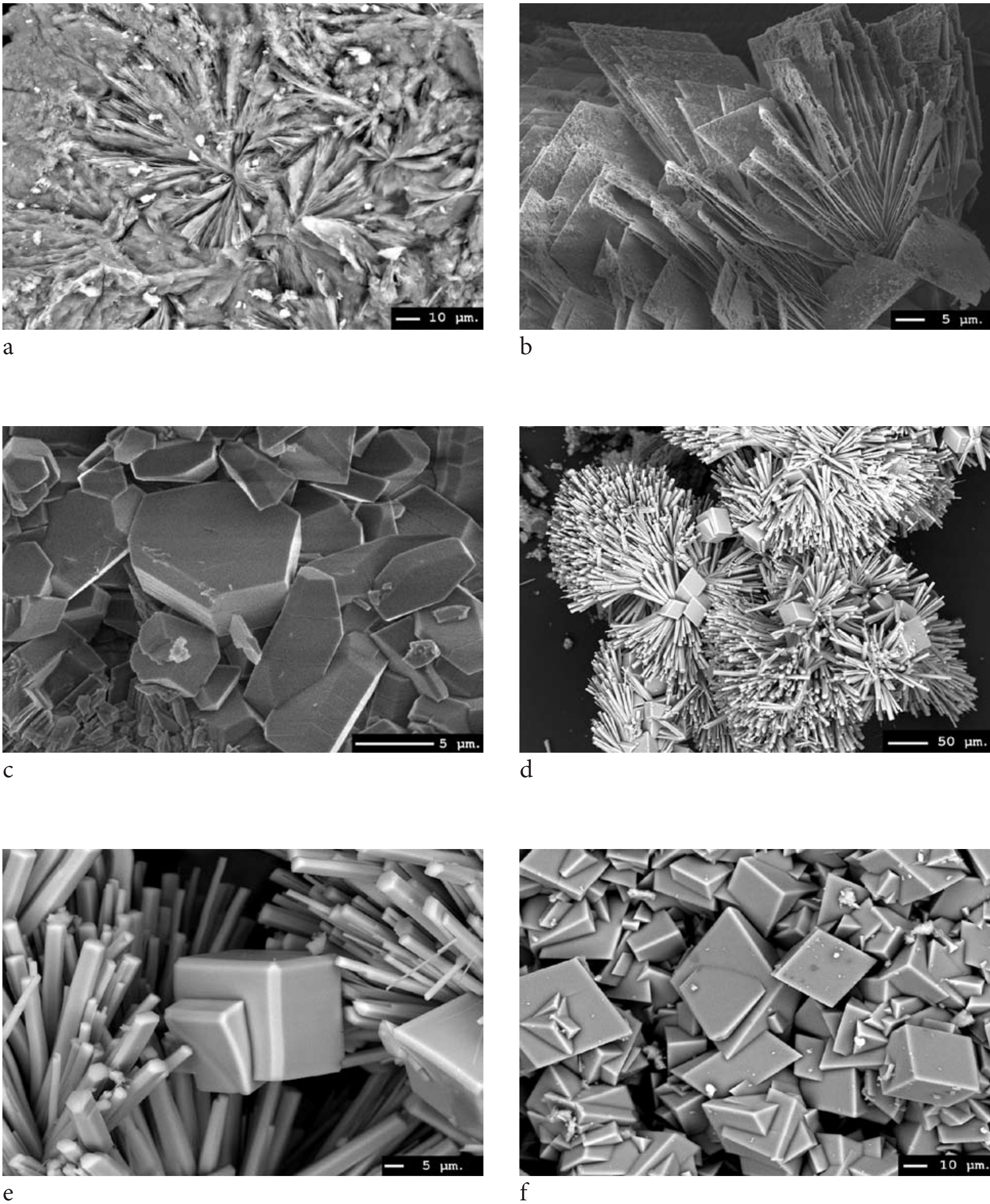

Fig. 15: SEM images of cave minerals from Cueva Rossillo (a, b, c) and Cueva de los Murcielagos (d, e, f): rose-like aggregates of tabular crystals of kingsmountite; b) tabular subparallel crystals of kingsmountite; c) prismatic ditrigonal crystals of taranakite; d) radial aggregates of fibrous crystals of apatite with rombohedral whitlockite; e) magnification of d) to put in evidence an overgrow of whitlockite; f) aggregate of euhedral rombohedral, sometime twinned, whitlockite crystals.

ridor; b) hard pale pink to brick-red microcrystalline material; c) as incoherent ochre-yellow sandy to dusty sediment;

Crandallite: extremely rare; it has been observed only in a single sample as thin irregular vitreous crust partially covering a yellow grain;

Goethite: it is present as earthy lemon-yellow to ochre-yellow grains;

Guanine: this rare organic compound gave rise to small black partially hard grains (SEM image in Fig. 9e);

Gypsum: rather common; it is present as: a) aggregates of fibrous silky-lustre micro crystals; b) vitreous lustre, transparent slightly grained, tabular prismatic crystal with a pseudo-square base;

Kingsmountite: it is always associated with montgomeryite and whitlockite; it is present as: a) thin small pale pink crusts or spheroidal aggregates of silky lustre, silver shining scaled crystals, which cover the walls of some cavities within the milky white material; b) aggregates of radial (open book) extremely thin silky blades over the surface of a single milky white grain (SEM images in Fig. 15a,b);

Lepidocrocite: this polymorph of goethite is fairly rare; it has been observed only in the alteration crust developed over an iron art craft (a small vessel or a cup) probably left by guano miners some tens of years ago and now found some 50 cm inside the fresh guano. The alteration crust consists of a millimetric layer of empty ochre-yellow to ruby red micro-spheres; at large magnification prismatic structures seem to be present over their surface. In this crust lepidocrocite is strictly associated with goethite, apatite and gypsum (SEM image in Fig. 9f);

Montgomeryite: it gave rise to small (Ø < 2.5 mm) pale yellow partially empty spheres, which consist of silky tabular radial crystals arranged in concentric layers;

Quartz: it has been found as cave mineral a single time over a sub-spherical grain of variscite. It consists of a hard thin transparent crust;

Taranachite: spherical soft aggregates of saccaroidal vitreous milky white micro-crystals (SEM image in Fig. 15c);

Variscite: very rare observed in a single sample where it is the nucleus of a rounded grain with the outer part made by quartz. It consists of lemon yellow micro-crystalline material;

Whitlockite: semitransparent thin hard crusts with the outer surface smooth or consisting of semi-spheres of colourless or pale yellow to pale brown, vitreous, sometimes silky shining crystals covering the walls of some small empty voids within a china-ware material (SEM images in Fig. 15d,e,f).

CUEVA DE LOS MURCIELAGOS (BATS CAVE)

This cave has been drastically modified by guano miners, who left inside most of their art crafts like wood ladders and leaching structures: for this reason the cave is know also with the name of San Vincente mine. Anyway it is a classical karst cave, partially modified by the hyperkarst reactions connected with guano digestion.

Seven samples have been collected in this cave: three consist of fragments of small calcite stalactites, three of which consist of fragments of broken calcite stalactites (soda straw) and/or stalagmites; some pieces of flowstones consisting of honey yellow calcite are also present. Most of these samples are covered by a thin whitish powder. The other four samples are globular yellowish speleothems (up to 15 mm in diameter) the structure of which consists partially of pale yellow fibrous radial crystals and of a hard layered material with plenty of small cavities, sometimes covered by a thin semi-transparent calcite layer.

Beside calcite, the other observed minerals are:

Apatite: the phosphates hydroxylapatite, carbonate-hydroxylapatite, carbonate-fluorapatite and fluorapatite are grouped under this generic name, due to the difficulty to discriminate among them. They occur as: 1) small aggregates of fibrous pale-yellow material; b) vitreous semi-transparent layers over the fibrous material; c) crusts consisting of small milky white to cream yellow spheres;

Kingsmountite: this Ca, Fe, Al phosphate is easily recognized even at naked eye; it consist of: a) bladed millimetric bladed crystals with easy cleavage b) small crusts made by perfectly rounded shining yellow grains dispersed inside in an earthy whitish material;

Quartz: hard thin transparent crust in association with variscite;

Variscite: semitransparent thin hard crusts with smooth outer surface.

A few other karst caves have been sampled during the study (Leona, Las Pinturas, Tanche Nuevo, and Vibora) but they resulted of scarce mineralogical interest hosting only very common cave minerals (calcite, gypsum, hydroxilapatite and whitlockite) and therefore they will not be described here. Anyway their hosted chemical deposits are summarized together with those of all the other caves in the Tab. 1.

FINAL REMARKS

The mineralogical study of the secondary chemical deposits developed within the karst systems of Cuatro Ciénegas put in evidence the great variety of minerogenetic processes which were and/or are still active in this area: this is the reason why the number of observed cave minerals (Tab. 1) is very high in comparison to that normally present in a single karst area.

Moreover, the study of some of the caves in the area, even if not exhaustive, confirmed their extraordinary mineralogical interest: in fact in two natural cavities (Cueva Rossillo and Cueva Rancho Guadalupe) over 15 different cave minerals have been found, number which puts them among the most interesting caves of the world as for variety and richness of hosted mineralogical species.

Some of the 32 identified minerals (ardealite, asbolan, carnotite, crandallite, monohydrocalcite, montgomeryite, niter, sepiolite, sylvite, variscite, whitlockite) must be considered "rare" in the cave environment (Hill & Forti, 1997), while one Al, Fe, Ca hydrated phosphate (kingsmountite) has been cited for the fist time as cave mineral from Rossillo cave.

Previously this mineral was described by Dunn *et al.* (1979) from the Mine Foote, near Kings Mountain town, North Caroline (USA): the kingsmountite of Rossillo cave has the same morphology of the olotype, occurring as bladed tiny crystals, usually in radial hemispherical aggregates up to 1 mm in diameter. Kingsmountite is isostructural and therefore with an X-ray powder pattern similar to that of montgomeryite, but it may only be discriminate on the basis of chemical analyses because kingsmountite lacks of significative amounts of Mg.

While phosphate largely prevails in Rossillo cave due to the large amount of guano deposits, oxides and carbonates are the main cave minerals in the Rancho Guadalupe cave. In this cave it is worth of mention the presence of carnotite as small aggregates of bright, greenish-yellow plate crystals < 50 μm in length, as inclusion in tabular gypsum (Fig. 8 alb); this occurrence seems to be very similar to that of the Horsethief Cave, Wyoming (USA) (Mosh & Polyak, 1996).

In the Rancho Guadalupe cave there are several different silicate minerals: quartz, sequences of aligned micro-spheres (up to 15 μm in diameter) of opal-CT (Fig. 8e), and sepiolite (Fig. 8f), the origin of which should be related to diagenetic processes involving opal in an Mg-rich environment (the simultaneous presence of dolomite supports this hypothesis).

Among the organic compounds the guanine of Cueva Rossillo and wewellite of Cueva Rancho Guadalupe are worth of mention. The first of these compounds (Fig. 9e) gave rise to micro-spheres up to 20 μm in size and it is extremely rare for the cavern environment and up to present it was reported only from a few caves where it derived directly from bat guano mineralization. Whewellite of Rancho Guadalupe forms sub spherical aggregates of prismatic crystals (Fig. 9b): its origin is related to animal excreta (Martini *et al.*, 1990).

Finally the magnesium carbonate from Cueva Rancho Guadalupe, still under study, is highly probably to become not only a new cave mineral but probably new for science.

Beside this ongoing research, the mineralogical studies in the karst systems of Cuatro Ciénegas cannot be considered concluded, mostly those related to the mine caves.

As already written in the relative paragraph, the cave minerals observed in these caves are far to represent if not the totality at least a significant portion of those which should have developed in this environment: future research shall be surely addressed toward this topic.

Anyway the mine environment has already proved to be of noticeable interest and scientific importance: in fact a completely new kind of cave pearls has been observed in the Reforma mine.

It is thank to these cave pearls to be possible to realize a new method to define the relative ratio between condensation and seeping waters feeding a speleothem.

Due to the peculiarity and noticeable scientific interest of the secondary cave minerals of the karst systems of Cuatro Ciénegas it should be important that the natural cavities of such an area would be protected in the near future, in order to preserve their very high scientific patrimony, which actually is only partially known.

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LITHOLOGICAL AND MORPHOLOGICAL CHARACTERISTICS AND ROCK RELIEF OF THE LAO HEI GIN SHILIN-STONE FOREST (LUNAN, SW CHINA)

LITOLOŠKE IN MORFOLOŠKE ZNAČILNOSTI TER SKALNI RELIEF LAO HEI GIN KAMNITEGA GOZDA (LUNAN, JZ KITAJSKA)

Martin KNEZ[1] & Tadej SLABE[1]

Abstract UDC 551.435.8(510)
Martin Knez & Tadej Slabe: Lithological and morphological characteristics and rock relief of the Lao Hei Gin shilin-stone forest (Lunan, SW China)
The Lao Hei Gin stone forest is yet one more of the diverse and famed Lunan stone forests created from subcutaneous karren. The initial morphogenesis of the stone pillars started along almost horizontal bedding planes and mostly sub-vertical faults and cracks already covered by thick layers of sediments and soil. The forest's stone pillars stand individually or in groups. The dominant and most characteristic shape of the pillars is mushroom-like, with alternating lithological characteristics of the carbonate beds expressed in a vertical direction.
Key words: Lunan shilin-stone forests, lithology, rock relief, morphogenesis, SW China.

Izvleček UDK 551.435.8(510)
Martin Knez & Tadej Slabe: Litološke in morfološke značilnosti ter skalni relief Lao Hei Gin kamnitega gozda (Lunan, JZ Kitajska)
Lao Hei Gin kamniti gozd je še eden izmed raznovrstnih in znamenitih lunanskih kamnitih gozdov, ki so nastali iz podtalnih škrapelj. Inicialna morfogeneza kamnitih stebrov je namreč začela potekati vzdolž skoraj vodoravnih lezik in večinoma subvertikalnih prelomov in razpok že pod debelimi plastmi naplavin in prsti. Kamniti stebri v gozdu so posamezni ali gručasti. Prevladujoča in najbolj značilna oblika stebrov je gobasta, saj se v njej v navpični smeri odražajo spreminjajoče se litološke lastnosti karbonatnih plasti.
Ključne besede: lunanski kamniti gozdovi, litologija, skalni relief, morfogeneza, JZ Kitajska.

INTRODUCTION

Shilin-stone forests (Knez & Slabe in print) developed from subcutaneous karst karren where thick layers of sediments and soil covered the carbonate rock. They are composed of stone pillars and stone teeth (Song 1986), formed on various horizontal and mildly inclined rock beds (5–150), cut by vertical faults and cracks (Ford & Salomon & Williams 1996).

The central part of the Lunan stone forest covers over 80 ha, while larger and smaller stone forests spread over 350 km^2. Unique among the stone forests is Lao Hei Gin. The forest is composed of pillars, standing in groups or individually, that can reach up to 20 m in height. Most are lower, however, up to about 10 m. The dominant and most characteristic form of the pillars is a mushroom-like shape. Watercourses run through caves that occur some 20 to 30 m deep below the forests.

We have presented our research of the Lunan stone forests in more detail in descriptions and collected notes published in the book "South China Karst 1" (Chen *et al.* 1998) and elsewhere (e.g. Knez & Slabe 2001a, 2001b,

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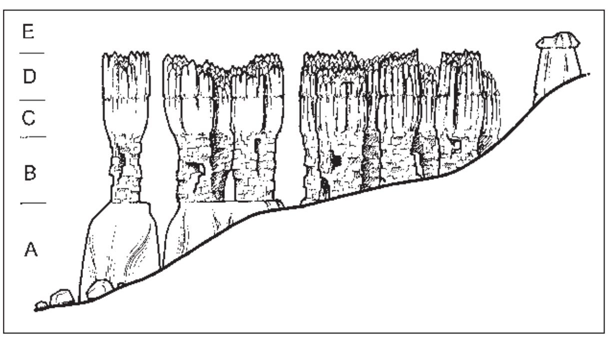
2002). In this article we are adding the results of our exploration of yet another stone forest, unique in its formation.

Figure 1: Lao Hei Gin stone forest.
Slika 1: Lao Hei Gin kamniti gozd.



The Lao Hei Gin stone forest (Figs. 1, 2, 3) lies 20 km north of Major Stone Forest. Individual stone pillars and larger rock blocks shaped by corrosion and erosion cover only about 2 km^2. Morphologically the stone pillars are similar to those in the Naigu stone forest.

Figure 2: Lao Hei Gin stone forest. Top view.
Slika 2: Lao Hei Gin kamniti gozd. Pogled z vrha.

Figure 3; Cross section of the Lao Hei Gin stone forest.
Slika 3: Prerez Lao Hei Gin kamnitega gozda.

LITHOLOGICAL CHARACTERISTICS OF THE STONE FOREST

The geological column is divided into 5 lithologically and morphologically diverse sequences: A, B, C, D and E (Figs. 3, 4, 5). Sequence A is built mostly of low-porous and grained late diagenetic dolomite, sequence B is of highly porous late diagenetic grained dolomite, sequence C is of slightly dolomitic limestone, sequence D is of low-porous grained late diagenetic dolomite and sequence E is of compact speckled dolomitic limestone. The total thickness of the researched geological profile (stone pillar) is 26 m.

SEQUENCE A

This sequence is 7 m thick. The lower part of the stone pillar is formed from highly re-crystalised dolosparite to dolomicrosparite of a grainstone type. The primary limestone had been highly diagenetically transformed – under a microscope we can observe subhedral to euhedral dolomite grains, which form a hipidiotopic to idiotopic structure. The dolomite grains are up to one-third of a millimetre in size. In diffused light they mostly have a slightly brown hue, whereas individual larger grains are exceptionally clean and almost totally translucent. Autogenous overgrowth is clearly visible in a small percentage of the dolomite crystals. The rock also contains a certain percentage of calcite. Secondary porosity is substantial.

SEQUENCE B

Sequence B is 8 m thick and does not mineralogically differ much from sequence A; on average, however, the rock does contain twice the amount of calcite as the rock from sequence A. The rock in this sequence is a grainstone-type dolosparite to dolomicrosparite. Grainstone-type dolomite (dolomicrosparite to dolosparite) consists of subhedral to euhedral dolomite grains that form a hipidiotopic to idiotopic structure. The essential difference of the rock from both sequences is that the rock in sequence B shows substantially more secondary porosity than the rock in sequence A. On average, the dolomite

Figure 4: Single mushroom-like stone pillars.
Slika 4: Posamezni kamniti stebri gobastih oblik.

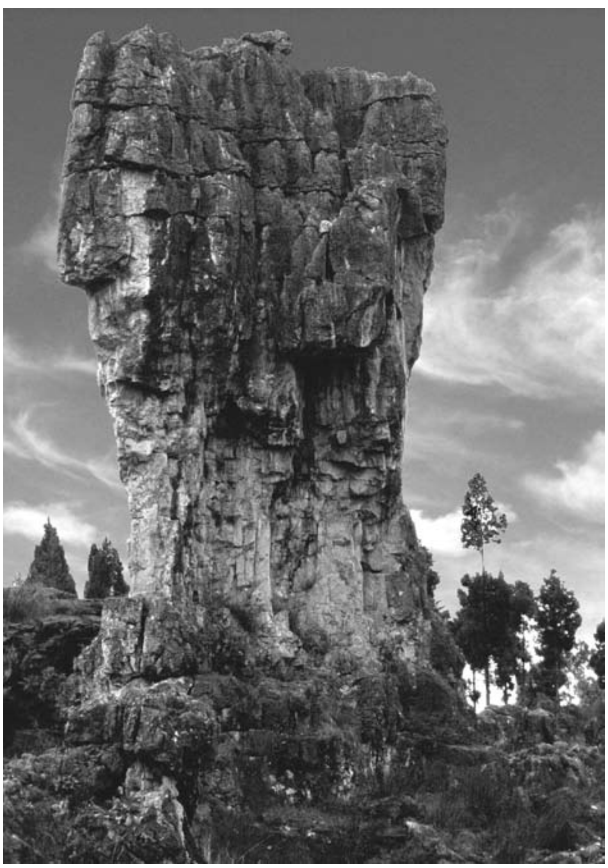


Figure 5: Stone pillar, which shape is dictated by rock.
Slika 5: Steber, katerega obliko narekuje kamnina.

crystals are smaller than the crystals in sequence A – in the upper part of the sequence even less than one tenth of a mm – and less pure.

SEQUENCE C

Sequence C is 4 m thick. Here the rock is mostly limestone with no more than 10% dolomite crystals. The boundary between sequences B and C is sharp and immediately

Figure 6: Subcutaneously shaped stone teeth.
Slika 6: Podtalno oblikovani kamniti zobje.

transforms into biopelintramicrite to biopelmicrosparite in the vertical direction. The fossil remains are generally less preserved; only occasionally did some foraminiferas and thick-shelled gastropods have better undergone the diagenetic processes. Secondary porosity is barely present.

SEQUENCE D

The thickness of sequence C is 5 m. The upper part of the pillars forms a highly re-crystalised and grained dolosparite to dolomicrosparite. The boundary between sequence C and sequence D is often blurred and difficult to determine visually and macroscopically. The primary limestone was highly diagenetically altered. Under a microscope we can observe subhedral to euhedral dolomite grains, which form a hipidiotopic to idiotopic structure of the rock. The dolomite grains in this sequence are also about one-third of a mm in size. In diffused light the dolomite grains mostly have a slightly brown hue.

SEQUENCE E

Sequence E is up to 2 m thick. Massive dolomitic limestone is characteristic for the upper part, which we found only on some pillars. On the outside it has a coarse and speckled appearance, characteristic of a large part of the Naigu stone forest (Knez & Slabe 2001a). Because of the bulginess on the rock surface, coarseness and subsequent algae overgrowth, the dolomite fields are dark grey. On the rock surface we can see them as dark grey to black spots, which gradate into lighter limestone fields in all directions. In most parts of the sequence, the percentages of the surface, as well as volume, of non-dolomitic limestone and dolomitic zones are equal.

SHAPE OF THE STONE FOREST

The larger groups of stone pillars consist of several tens of pillars (Figs. 1, 2, 3, 4). Between them are corroded fissures or narrow passages. The smaller groups of pillars, composed of ten or fewer pillars, are most often cut only by cracks and corroded fissures. Over a relatively large area of the stone forest we find only individual pillars and stone teeth. Individual pillars are relatively large, broad and high, or else they are low and wide.

The bedding is reflected in the form of pillars mainly because of the diverse composition of the rock. Below the soil, as well as on the surface, the B beds decay and decompose faster, and subsequently the individual thinner and tall pillars are unstable. The tall pillars are generally mushroom-shaped. The beds of sequences A, C and D are more resistant and extensive. In some areas the upper parts of the pillars have disappeared, and only low pillars formed in rock sequence A are preserved. Subcutaneous tubes transformed by rainfall dripping down the pillars frequently hollow the porous rock of the beds B. The rare pillar tops that form in such rock are often diversely shaped.

THE ROCK RELIEF OF THE STONE FOREST

We find three distinct types of rock forms on the pillars: subcutaneous forms, forms created by rainfall and combined rock forms. The creation of these rock forms and their uniqueness is defined mainly by the rock itself, especially where it is exposed. The subcutaneous forms are less explicitly defined by the rock.

SUBCUTANEOUS ROCK FORMS

These forms are divided into those that were formed below the deposits and the soil as the result of water flowing at the contact of the rock and the soil, and forms created by water percolation through the soil that only partially covers the rock, and the rock forms that formed at the level of the soil or deposits that surround the rock (Slabe 1999).

The first group of subcutaneous rock forms are subcutaneous channels of various sizes that were formed by continuous water-flow at the contact of the rock and the deposits that covered the rock and filled the fissures in the vertical cracks. The diameter of the larger channels can reach up to several metres (Fig. 6). They dissect all different rock sequences. At the tops of the higher pillars they were transformed by rainfall, while the B beds decompose too quickly for the channels to remain preserved on them for a longer period. They are therefore mainly a characteristic of the lower parts of the pillars and stone teeth. Subcutaneous scallops that form on the relatively permeable contact area of the rock and the deposits are preserved mostly in beds A, C and D or on the B beds that had been exposed for only a shorter period. Also the walls of the largest subcutaneous channels could be dissected by them.

The more extensive pillar tops and teeth are segmented by mid-sized and smaller subcutaneous channels and subcutaneous cups (Slabe 1999, 259) that were formed under the soil that partially covered the rock, therefore as the result of water percolation through the soil and its flow along the area where it touches the rock.

They have characteristic semi-circular cross sections or cross sections in the shape of the upturned letter omega. They are wider at the lower part of cross-section, their diameters can reach up to 1 m. They are usually linked into a branched network. The subcutaneous cups (Slabe 1999, 263) are of various sizes and diameters, from a few centimetres to a metre or more. They occur on the tops of large pillars and on the bottoms of funnelled notches in the walls below them. The most porous strata are fairly densely perforated by subcutaneous tubes of diameters ranging between a few centimetres and a metre or two.

The pillars in the B beds are generally distinctly undercut below the ground, which is visible from the overhanging lower parts of the pillars that have developed on these rock strata.

COMBINED ROCK FORMS

These are the larger channels in the upper parts of the pillar walls. They develop as the result of water flowing from subcutaneous channels, which appear on the larger pillar tops, or by water dripping from the funnelled notches. Subcutaneous cups occur at the bottom of the latter or else were once present there. They thus have larger or smaller funnel-shaped outlets at the edges of the tops, which have in most cases been transformed by rainfall. They are especially noticeable in the beds of the A, C and D groups, or, if the top is in the D beds they reach to the B beds. Their distribution and shapes, relatively narrow and deep, are defined by how crushed the rock is, how serrated the rims of the rock are, and also by the composition of the rock.

Rainfall transforms, mainly deepens, the former subcutaneous channels and cups that criss-cross the wider tops. Such rock formations therefore exhibit traces of subcutaneous dissolution of the rock and of the rainwater, which can gradually, with the denudation of the rock, completely take over. Below the soil the channels and cups are relatively evenly shaped with smooth walls, but as they become exposed their shapes become distinctively uneven with many branches and segmented rims.

Half-bells are formed on the more durable levels of soil and deposits that surround the pillars (Slabe 1999).

ROCK FORMATIONS CARVED BY RAINFALL

These types of rock formations, especially the smallest flutes and cups, do not occur on this type of rock. The exceptions are the more limited highest zones of the stone forest, where the tooth tops are created in the dolomitic limestone of the E beds. Segmentation of most of the tops is therefore defined by the composition and diversification of the rock (Fig. 7). Rock exposed to rainfall is coarse

Figure 7: The top of stone pillar carved by rainfall.
Slika 7: Vrh kamnitega stebra oblikovan z deževnico.

and contains only rock formations that do not exceed the size of the individual segmentation of the coarse surface. The solution pans with distinctly segmented and coarse surfaces are developing from subcutaneous cups; only the bottoms of solution pans that are covered by thin layer deposits and are overgrown remain even and relatively smooth.

On the steep walls the segments resemble channels, usually very narrow but relatively deep and angulated, with diameters that measure 1–10 cm and are 2–3 m long.

At the highest section of the stone forest we find dolomitic limestone on the pillar tops, with flutes carved in them (Fig. 8). Smaller channels of a diameter of 1–2 cm

Figure 8: Dolomitic-limestone stone teeth.
Slika 8: Dolomitno apnenčasti kamniti zobje.

appear on the limestone where there are fields of dolomite in the limestone, which generally protrude a centimetre or two from the wall and do not exhibit other rock formations.

CONCLUSION

The stone pillars in the forest are either solitary or in groups within which there are only cracks and fissures. They were formed at various levels on nearly horizontal rock beds and in corresponding shapes. The exposed lower part of the geological profile or stone pillar is composed of fully dolomitised limestone, the middle part (sequence B) is composed of porous dolomite and the upper parts of the stone pillars are composed of more durable limestone and dolomitic limestone, resistant to erosion. Sequence B rock beds decay and decompose faster, below, as well as above the ground, and since they are generally covered by more durable strata, the pillars form characteristic mushroom-like shapes. The pillars are wider below the narrower parts if the lower dolomite strata are exposed.

The rock relief consists of various groups of rock forms: subcutaneous, those carved by rainfall and combined forms – their characteristics are defined by the composition of the various rock beds. The tops are sharp and well segmented around the cracks. Such are all the forms carved by rainfall – these are channeled rock forms and solution pans. Their surface is notably coarse. On limestone beds that occur only in some of the highest lying parts of the stone forest, the flutes and small channels are evenly shaped. On porous and faster-disintegrating beds, there are no distinct rock formations carved by rainfall, except at the beginning on exposed rock covered by more rounded parts of the subcutaneous rock relief. These are distinctly formed on all different types of rock beds. Only their surface is mildly coarse.

In our research we have observed (Knez 1998; Slabe 1998; Knez & Slabe 2001a, 2001b) that the lithological composition and tectonic properties of the rock play a decisive role that corresponds to the morphological picture of the stone pillars and that are essentially important in selective corrosion and erosion.

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LITOLOŠKE IN MORFOLOŠKE ZNAČILNOSTI TER SKALNI RELIEF LAO HEI GIN KAMNITEGA GOZDA (LUNAN, JZ KITAJSKA)

POVZETEK

Lao Hei Gin kamniti gozd (Sl. 1, 2, 3, 4) je nastal iz podtalnih kraških škrapelj. Karbonatne kamnine so bile namreč pokrite z debelimi plastmi naplavin in s prstjo. Kamniti stebri in kamniti zobje so se razvili v raznovrstnih, skoraj vodoravnih ali položnih skladih kamnine, ki so jo razkosali navpični prelomi in razpoke. Gozd sestavljajo stebri, ki so gručasto strnjeni ali pa posamezni in dosežejo do 20 m višine, večina je nižjih, visokih do 10 m. Prevladujoča in najbolj značilna oblika stebrov je gobasta. 20 do 30 m globoko pod gozdom so jame, skozi katere se pretakajo vodni tokovi. Lao Hei Gin kamniti gozd leži okrog 20 km severno od Shilina. Posamezni kamniti stebri in večji korozijsko in erozijsko preoblikovani bloki kamnine zavzemajo le okrog 2 km^2. Morfološko so kamniti stebri podobni tistim iz Naigu kamnitega gozda.

Glede na litološke in morfološke značilnosti smo geološki stolpec razdelili v 5 sekvenc: A, B, C, D in E (Sl. 3, 5). Sekvenca A je zgrajena večinoma iz slabo poroznega zrnatega poznodiagenetskega dolomita, sekvenca B iz zelo poroznega poznodiagenetskega zrnatega dolomita, sekvenca C iz rahlo dolomitnega apnenca, sekvenca D iz slabo poroznega zrnatega poznodiagenetskega dolomita, sekvenca E iz kompaktnega marogasto dolomitiziranega apnenca. Skupna debelina raziskanega geološkega profila (kamnitega stebra) je 26 m.

Večje gruče kamnitih stebrov so sestavljene iz več deset stebrov. Med njimi so špranje ali pa ožji prehodi. Manjše gruče stebrov, ki jih sestavlja deset in manj stebrov, pa sekajo največkrat le razpoke in špranje. Na razmeroma veliki površini kamnitega gozda so le posamezni stebri in skalni zobje. Posamezni stebri so razmeroma veliki, široki in visoki ali pa so nizki (1-2 m) in široki.

Skladovitost kamnine se v obliki stebrov odslikava predvsem zaradi različne sestave kamnine v posameznih plasteh. Skladi B tako pod tlemi kot na površju preperevajo in razpadajo hitreje in posamezni tanjši ter visoki stebri so zato neobstojni. Visoki stebri pa so praviloma izrazite gobaste oblike. Skladi A, C in D so namreč obstojnejši in obsežnejši. Ponekod zgornjih delov stebrov ni več, ohranjeni so le nizki stebri, ki so oblikovani v kamnini A. Porozna kamnina skladov B je pogosto prevotljena s podtalnimi cevmi, ki jih preoblikuje deževnica, polzeča po stebrih navzdol. Redki vrhovi stebrov, ki se oblikujejo na takšni kamnini, so največkrat neenotnih oblik.

Skalni relief sestavljajo vse značilne skupine skalnih oblik, podtalne (Sl. 6), tiste, ki jih dolbe deževnica in sestavljene skalne oblike, jim pa značilnosti v precejšni meri določa sestava različnih skladov kamnine. Vrhovi so ostrih in ob razpokah drobno razčlenjenih oblik, takšne so vse skalne oblike, ki jih dolbe deževnica, to so žlebovom podobne skalne oblike in škavnice, njihova površina pa je izrazito hrapava (Sl. 7). Na apnenčastih skladih, ki se pojavijo le na posameznih najvišjih delih kamnitega gozda, so žlebiči in žlebovi pravilnih oblik. Na poroznih in hitreje razpadajočih skladih ni značilnih skalnih oblik, ki jih dolbe deževnica, le sprva, po razgaljenju kamnine, jih prekrivajo zaobljene oblike podtalnega skalnega reliefa. Te se namreč izrazito oblikujejo na vseh različnih skladih kamnine. Le njihova površina je drobno hrapava.

Pri naših raziskavah vse bolj ugotavljamo (Knez 1988; Slabe 1988; Knez & Slabe 2001a, 2001b), da se tudi najmanjše litološke razlike v kamnini zelo jasno odražajo v morfogenetskem razvoju kamnitih gozdov.

COBISS: 1.02

VULCANOSPELEOLOGY IN SAUDI ARABIA
VULKANOSPELEOLOGIJA V SAVDSKI ARABIJI

John J. PINT[1]

Abstract UDC 551.21:551.44(532)
John J. Pint:Vulcanospeleology in Saudi Arabia
Saudi Arabia has over 80,000 km^2 of lava fields, locally known as harrats. However, only a few studies of lava caves in Saudi Arabia have been published internationally. This article summarizes the published and unpublished findings of all known expeditions to lava caves in the kingdom. Prior to 2001, reports of such caves were mostly limited to sightings of collapse holes by vulcanologists surveying the lava fields. Few caves were entered and no cave maps were produced. In 2001 and 2002, expeditions were organized to Harrat Kishb, located northeast of Makkah (Mecca). Three lava caves measuring 22 m, 150 m and 320 m in length were surveyed and the collapse features of a fourth cave—possibly over 3 km long—were studied. Two throwing sticks, a plant-fiber rope and the remains of stone walls were found in some of these caves. In 2003, lava tubes measuring 530 m and 208 m were surveyed in Harrat Ithnayn and Harrat Khaybar, respectively. Animal bones and coprolites were found in both caves. In 2003 and 2004, studies were carried out in Hibashi Cave, located in Harrat Nawasif/Al Buqum, 245 km southeast of Makkah. The cave was surveyed (length: 689.5 m) and found to contain two layers of burnt bat guano overlying a bed of redeposited loess up to 1.5 meters deep and up to 5800 years old. At least 19 different minerals were found, three being extremely rare organic compounds related to the guano combustion. Bones, horns, coprolites, ruins of a wall and a human skull ca. 425 years old were also found. There is evidence of many more lava caves in Saudi Arabia, particularly in Harrat Khaybar. Formal archeological and biological studies have not yet been carried out in Saudi lava caves but may produce interesting results.
Key words: lava tubes, lava caves, Saudi Arabia, vulcanospeleology, speleology.

Izvleček UDK 551.21:551.44(532)
John J. Pint: Vulkanospeleologija v Savdski Arabiji
V Savdski Arabiji je preko 80.000 km^2 lavinih polj, lokalno poznanih pod imenom harrat. O njih je bilo do sedaj v mednarodni literaturi objavljenih le malo študij. Članek povzema objavljana in neobjavljena odkritja vseh znanih odprav v lavine cevi. Pred letom 2001 so vulkanologi poročali o udorih, ki so jih opažali med raziskovanji polj v lavi, obiskali pa so le malo jam, jamskih načrtov ni bilo. V letih 2001-2002 so organizirali več odprav na območje Harrat Hishb, nedaleč od Meke. Raziskali in izmerili so tri jame, dolge 22, 150 in 300 m. Poleg tega so raziskovali tudi podorne oblike četrte jame, verjetno dolge preko 3 km. V jamah so našli dve sulici, vrv iz rastlinskih vlaken in ostanke kamnitega zidu. Leta 2003 so na območju polj v lavi Harrat Ithnavn in Harrat Khaybar raziskali in izmerili 530 in 208 metrov dolgi jami. V njih so našli živalske kosti in koprolite. V letih 2003-2004 so raziskovali v jami Hibashi na območju polja Harrat Nawasif/Al Buqum, 246 km jugovzhodno od Meke. Jama je bila izmerjena v dolžini 690 m, v njej pa so našli dve plasti izgorelega netopirskega gvana, ki pokriva plast presedimentirane naplavine, debele 1.5 m in stare do 5800 let. V jami je bilo najdenih vsaj 19 različnih mineralov, od tega so trije izredno redke organske spojine, nastale kot posledica izgorevanja gvana. Našli so bile tudi kosti, rogove, koprolite, ostanke zidov in človeško lobanjo staro 425 let. V Savdski Arabiji je še veliko neraziskanih cevi v lavi, predvsem na območju Harrat Khaybar. Pravih arheoloških in bioloških raziskav še ni bilo, si pa lahko od njih veliko obetamo.
Klljučne beside: cevi v lavi, jame v lavi, Savdska Arabija, vulkanospeleologija, speleologija.

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INTRODUCTION

This article presents a brief history of Vulcanospeleology in the Kingdom of Saudi Arabia and summarizes the known studies carried out in Saudi lava caves. Some of these studies have been published internationally (Forti *et al*., 2004; Forti, 2005; Pint and Pint, 2005) or locally in Saudi Arabia (Roobol *et al*., 2002; Pint *et al*., 2005). Others are alluded to in non-scientific field trip reports on the Saudicaves web site (www.saudicaves.com). Many other details still remain in the field notes of the speleologists who visited the caves. It is hoped that this article will assist researchers and authorities in ascertaining what is presently known about lava caves in Saudi Arabia and in determining the nature and direction of future vulcanospeleological studies on the Arabian Peninsula.

Fig. 1 shows the location of most of the lava fields (Harrats) of Saudi Arabia, which cover an area of at least 80,000 km^2. Cave locations are given in the text below, but seconds of latitude and longitude have been omitted, in order to help protect these caves from accidental damage or deliberate vandalism. The exact locations of these caves can be found in Pint, 2002.

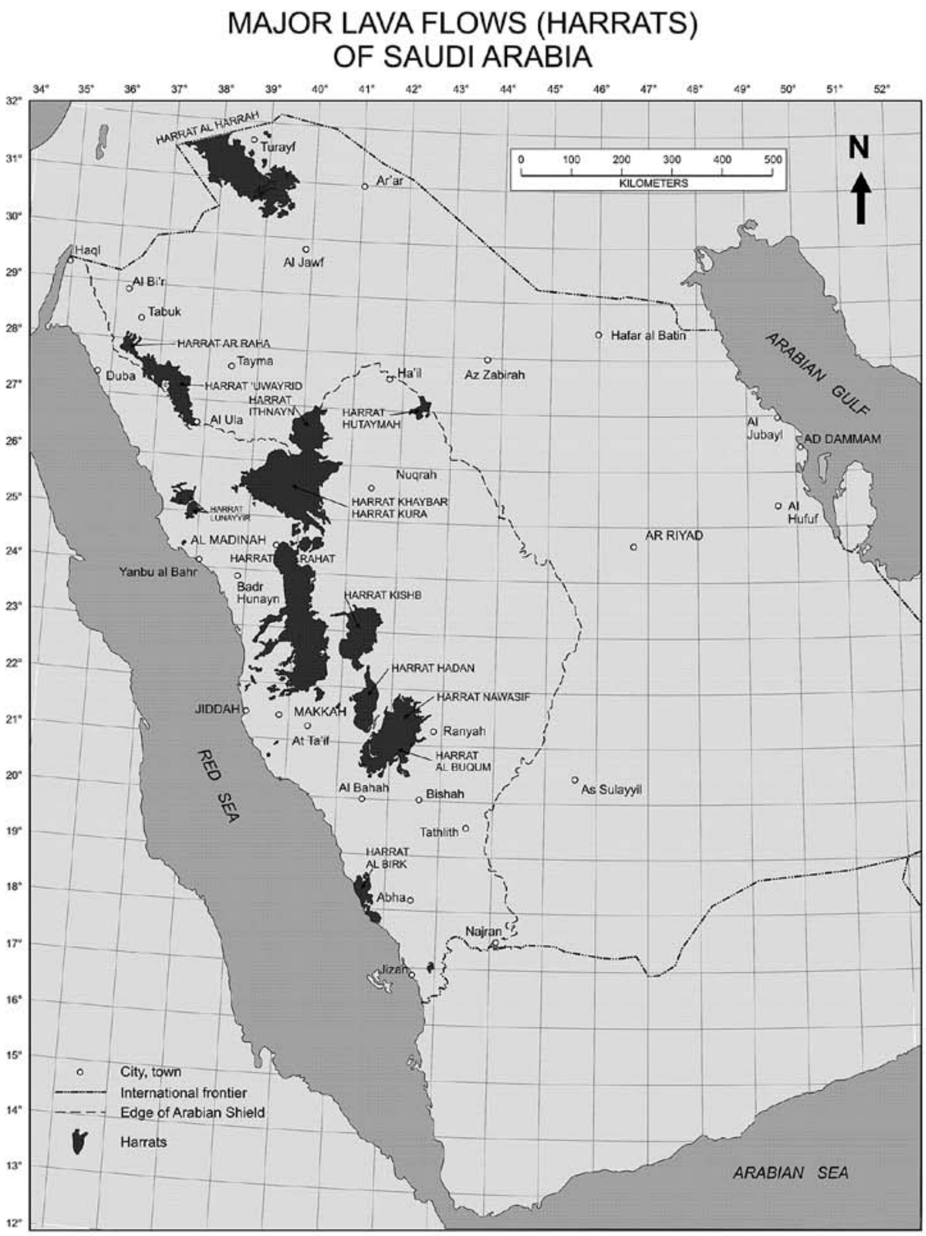

Fig.1: Map showing the major Cenozoic lava fields of Saudi Arabia.

EARLY STUDIES

Roobol and Camp (1991a) reported the existence of lava-tube caves up to 10 m high on Harrat Khaybar, a large lava field north of Medina. In one of these caves—located in a flow from Jebel Qidr Volcano—delicate lava stalactites were observed. A 100-meter-long lava tube in southern Harrat Khaybar was found to contain a fumarole at its deepest point. In another publication, Roobol and Camp (1991b) describe lava tubes on Harrat Kishb, which is located northeast of Mecca. In particular, they mention seeing the collapse holes of a lava tube which might be 3 km long.

REPORT ON THERMAL ACTIVITY IN A LAVA TUBE

Geologist Mahmoud Al-Shanti reports that his father, Dr. Ahmed Al-Shanti, one of Saudi Arabia's most eminent geologists, once investigated reports that an individual had suffered severe leg burns inside a cave probably located in Harrat Khaybar. Because the cave appeared to be inside a lava field and might indicate renewed thermal activity in the area, the government requested Dr. Al-Shanti to investigate. A visit to the cave in question proved that the source of heat was a smoldering fire beneath the surface of a large bed of dry guano (Al-Shanti, 2003). The only other cave in Saudi Arabia where guano fires have been documented is Ghar Al Hibashi (see below).

EARLY MEASUREMENT OF KAHF AL SHUWAYMIS

Perhaps the first attempt to accurately map a lava tube in Saudi Arabia was made by Mamdoah Al-Rashid, headmaster of the Shuwaymis school system, who used a 50 m-long tape to measure the length of Kahf Al Shuwaymis, located in Harrat Ithnayn and described below. The date of this event is not recorded, nor is there any reference to the use of a company, but Mr. Rashid's calculation of the cave's length (500 m) comes very close to the length of 530 m measured in a recent survey using a compass and a Disto laser measuring device (Fig. 7). If the length of side passages (30 m) is removed from the total, Mr. Rashid's results are exactly on the mark (Rashid, 2002).

While the above reports and incidents indicate that Saudi Arabia does indeed have lava caves, they did not result in the production of lava-cave maps or studies of the genesis, nature or content of such caves. This situation changed in November of 2001 when Dr. John Roobol led an expedition to the vicinity of Jebel Hil Volcano in Harrat Kishb. The explicit purpose of the expedition was to locate and survey lava caves, as well as to describe them accurately.

RECENT STUDIES

THE KISHB SURVEYS

The first expedition to Harrat Kishb took place November 10-14, 2001, led by Dr. J. Roobol, J. Pint and M. Al-Shanti. The project took place at the urging of Dr. William Halliday, member and founder of the Commission on Volcanic Caves of the International Union of Speleology (UIS). By coincidence, Dr. Roobol had received, from geologist Faisal Allam, several photographs of cave entrances found some 6 km east of Jebel Hil in Harrat Kishb. Accordingly, the goals of the expedition were to locate the caves shown in the photographs as well as to precisely locate the collapse holes west of Jebel Hil which were observed by Roobol and Camp (1991b) and thought to be entrances to a lava tube.

After much searching, the photographed caves were located and one of them, Mut'eb Cave, was surveyed. In addition, the GPS locations of twelve collapse entrances of the Jebel Hil Lava Tube were taken, a difficult undertaking since 12 km of mostly a'a lava had to be traversed on foot.

A second visit to Harrat Kishb was made from February 2-5, 2002, again led by J. Roobol, J. Pint and M. Al-Shanti. Ghostly Cave was surveyed and a new cave, Dahl Faisal, was located and surveyed. The results of the Kishb Surveys were published in Roobol *et al*., 2002.

GEOLOGY OF THE HIL BASALT

All the surveyed caves found in Harrat Kishb are located in the Hil Basalt, which is a basaltic lava field younger than one million years, with an area of 5,892 km², centered about 270 km northeast of Jeddah. These deposits comprise both scoria cones and lava flows which were probably formed during a moist climatic period or pluvial interval and which are distinguished from overlying subunits because they are significantly eroded (Roobol *et al*., 2002).

MUT'EB CAVE

Mut'eb Cave, or Kahf Al Mut'eb is registered as number 124 in Pint, 2002 and is located at 22°55'N, 41°24'E.

Geological setting
The cave is found in a sinuous ridge of smooth, hard pahoehoe lava curving around an older, obstructing scoria cone in the volcanic deposits of the Hil Basalt.

Description
The cave is 150 m long. The entrance to the cave measures 3 x 7 m and is found on the eastern side of a collapse 20 m in diameter. There are remains of an ancient, man-made wall across the front of the cave. A single passage trends east, sometimes reaching a width of 20 m. The passage height varies from 3 to 5 m. Sand or clay-rich sediment cover the floor to an undetermined depth. The cave contains abandoned wasps' nests, mounds of rock-dove guano, animal bones, and bat urine stains on the walls and ceiling. A 40-cm-long cord composed of long plant fibers, with one knot in it, was hidden beneath a flat rock at the eastern end of the cave (Roobol *et al.*, 2002; Pint and Pint, 2005).

Comments
To the author's knowledge, Mut'eb was the first lava cave in Saudi Arabia to be accurately surveyed (Grade 5D in the survey classification system used by the British Cave Research Association. This requires a magnetic survey with horizontal and vertical angles measured to ±1°; distances recorded to the nearest centimeter, station positions identified to less than 10 cm and measurement of significant changes in passage dimensions at survey stations and wherever needed.) See Fig. 2.

Because a man-made structure is found at the entrance to this cave and because an apparently ancient artifact was found deep inside, it is suggested that the cave be investigated by archeologists. Note that Mut'eb Cave, in Harrat Kishb, is located approximately 55 km east of the celebrated Darb Zubaydah, a well-marked trail complete with shelters, water wells and reservoirs one day's march apart (See Fig. 12). The trail led from Baghdad to Mecca and was built by Queen Zubaydah, the enterprising wife of Caliph Harun al-Rashid around the beginning of the ninth century A.D.

GHOSTLY CAVE

Ghostly Cave or Kahf Al Ashbaah is registered as number 123 in Pint, 2002 and is located at 22°55'N, 41°25'E.

Geological setting
The cave is found in a flat area of basaltic pahoehoe lava in the volcanic deposits of the Hil Basalt.

Description
The cave is 320 m long. The entrance is a collapse 10 m in diameter with a 7 m drop to a flat floor below. The passage leads off east and west. Up to 50 stalagmite-like mounds of rock-dove guano are found just inside the entrance to the western passage along with the remains of a stone wall partly buried beneath bird guano. The cave passages

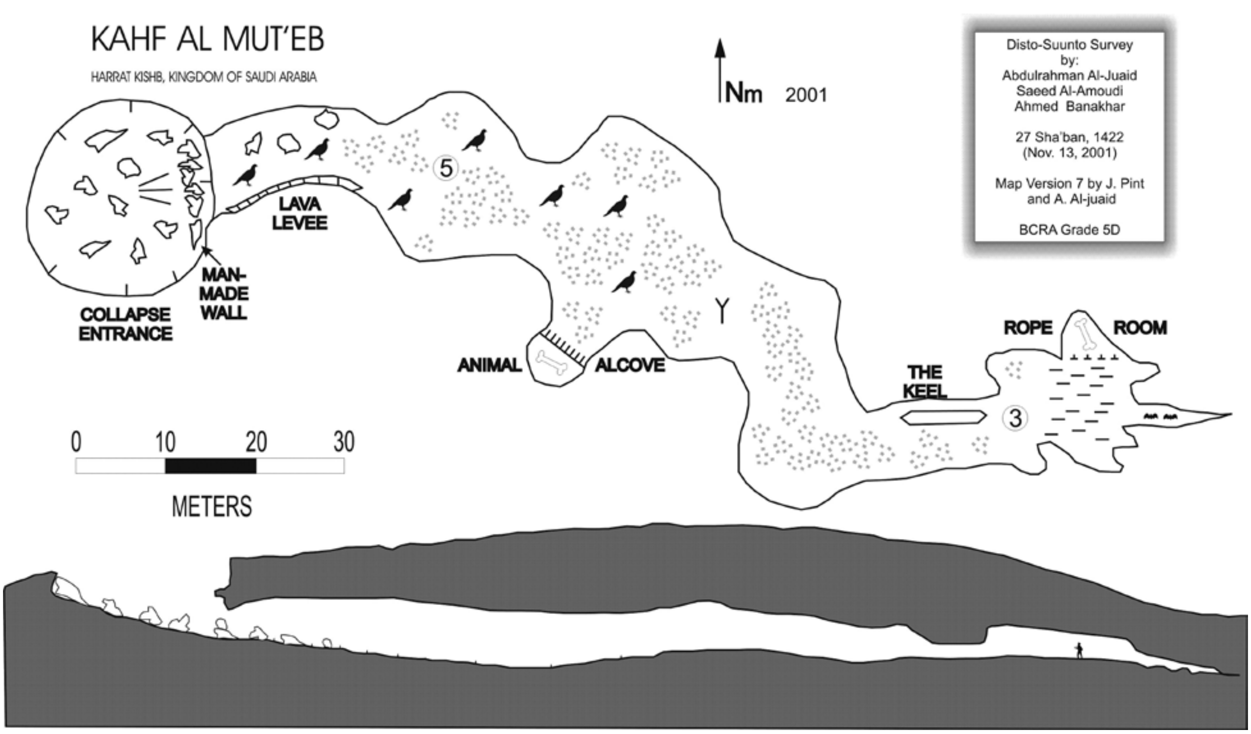

Fig. 2: map of Mut'eb Cave.

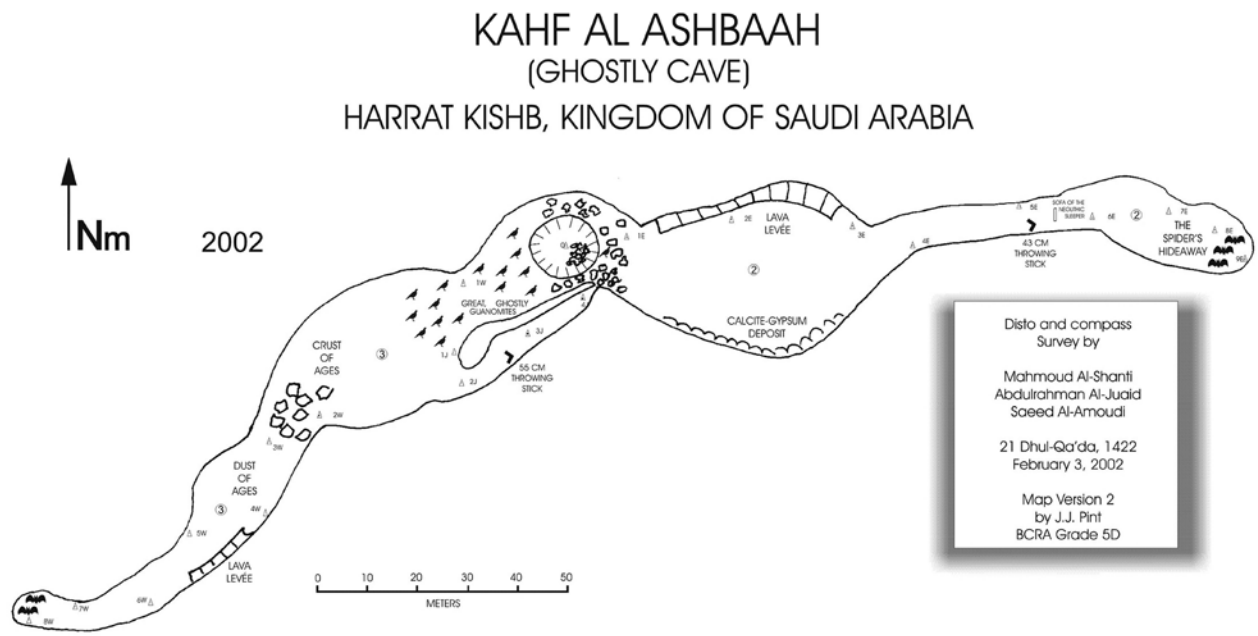

Fig. 3: map of Ghostly Cave.

Fig. 4: Throwing sticks found in Ghostly Cave are flat on the bottom and curved on top to provide aerodynamic lift.

have a maximum width of 30 m and vary in height from 1 to 3 m. Both passages have white, calcareous patches on the ceiling and a thick layer of powdery dust on the floor. Analysis of the dust showed high concentrations of calcium, phosphate and potassium salts. Bats are found at both extremes of the cave. Two flat, L-shaped wooden throwing sticks were found in dark areas of the two passages, resembling similar instruments depicted in Neolithic rock art found in Saudi Arabia. See Fig. 3 and 4 (Roobol *et al*., 2002; Pint and Pint, 2005).

Comments

Man-made constructions and two ancient throwing sticks were found in this isolated and difficult-to-enter cave. Digging in the sediment which completely covers the cave floor may produce historically or archeologically important finds. As noted in the comments on Mut'eb Cave, Ghostly Cave is located approximately 55 km east of the celebrated Darb Zubaydah (see Fig. 12).

DAHL FAISAL

Dahl Faisal is registered as number 162 in Pint, 2002 and is located at 23°11'N, 41°27'E.

Geological setting

The cave is found in a nearly flat-lying "whale-back" lava flow of the Jabal Zuwayr volcano. The flows of this volcano consist mainly of basanite and alkali olivine basalt with small volumes of hawaiite, phonotephrite and phonolite and are located in the northern portion of the Hil Basalt.

Description

Dahl Faisal is 22 m long. The cave is entered through a smooth, 3-m-long pipe, 80 cm diameter at its narrowest

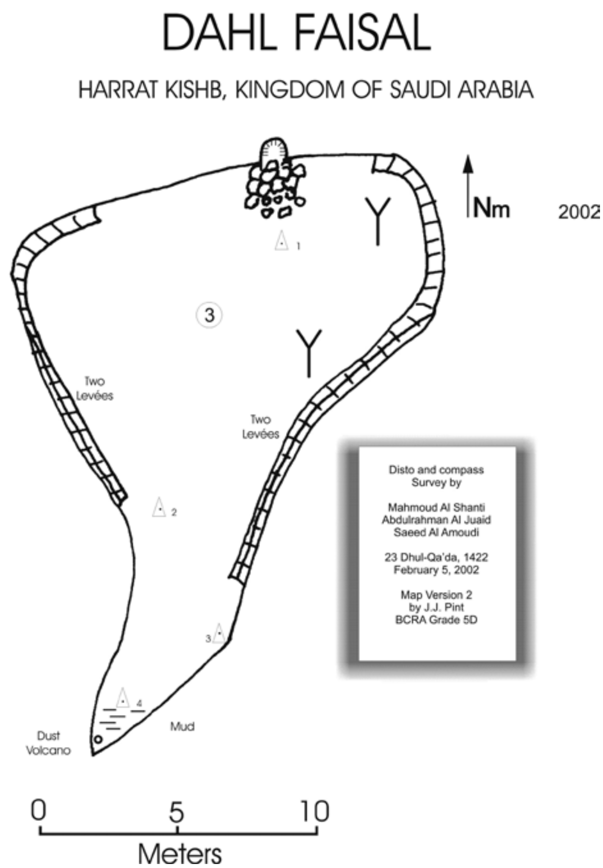

Fig. 5: Map of Dahl Faisal.

Fig. 6: Collapse Structure 6 of the Jebel Hil lava tube, looking west, showing the upper part of the lava tube with geologists standing on the roof.

point, oriented at a 60° angle. This appears to have formed when the cave was created. Below the entrance tube lies a heap of rocks apparently piled up by people using the cave in the past. Dahl Faisal consists of one room, 17 x 22 m, with a maximum ceiling height of 3 m. Sediment of unknown depth covers the original floor. The cave contains basaltic stalactites, stalagmites and lava levées. Desiccated animal scat apparently from wolves, hyenas and foxes was also found. See Fig. 5 (Roobol *et al.,* 2002; Pint and Pint, 2005).

Comments

Dahl Faisal is located 60 km east of Darb Zubaydah and about 70 km southeast of Mahad adh Dhahab, an operating gold mine and reputedly the site of one of King Solomon's Mines. See Fig. 12. Carbon-14 dating of wood from fires used for smelting suggests that the mines are 3,000 years old. This information, together with historical studies, indicate that gold, silver and copper were indeed recovered from this region during the period considered by some to be the reign of King Solomon: 961-922 B.C. (Kirkemo *et al.,* 1997, Levy *et al.,* 2004). Evidence of human use and the proximity of the cave to known historical sites, suggest that it could contain artifacts.

JEBEL HIL LAVA TUBE

This lava tube extends westwards from Jebel Hil. Along its length are aligned small rootless shields, collapse holes, subsided areas and one area of local updoming. Twelve such features were located, one of which is shown in Fig. 6. The lava tube is up to 20 m high and the depth of its floor beneath the surface varies from 28.5 to 42.5 m, measured by Disto Laser Measuring Device at each hole. The surface features of this lava tube were mapped and described, and they suggest that the tube is at least 3 km long. However, the cave itself was not entered. A detailed map and description of these features are given in Roobol *et al.*, 2002.

OTHER CAVES LOCATED ON HARRAT KISHB

Two other lava caves, First Cave and Bushy Cave were also located during the Kishb surveys. The entrance to First Cave is a collapse 20 m deep in what appeared to be a lava tube. It was not entered due to apparent instability of the entrance walls. Bushy Cave is a nearly round room 12 x 13 m, possibly formed by a gas bubble. It was sketched, but not surveyed.

THE SHUWAYMIS EXPLORATIONS

A reconnaissance for caves in Harrat Ithnayn and northern Harrat Khaybar was undertaken by J. and S. Pint, November 6 to 10, 2002. The head of the local school district, Mamdoah Al-Rashid showed them Dahl Rumahah in northern Harrat Khaybar and Kahf Al Shuwaymis in Harrat Ithnayn. Both caves were briefly entered and photographed. April 14-17, 2003, J. Pint and M. Al-Shanti led a trip to this area. Kahf Al Shuwaymis was surveyed as well as collapses and other features between the cave and the source volcano, Hazim al Khadra. Sept. 14-17, 2003, the same team returned to the Shuwaymis area to map Dahl Rumahah. No geological report on the Shuwaymis explorations was published by Saudi Geological Survey due to the cutting of funding in 2005.

KAHF AL SHUWAYMIS

Kahf Al Shuwaymis or Shuwaymis Cave is registered as number 177 in Pint, 2002 and is located at 26°14'N, 40°07'E.

Geological setting

This cave is located at the foot of Hazim Al Khadra Volcano in Harrat Ithnayn, which is a lava field centered 240 km north-northeast of Medina. This lava is mildly alkaline with low Na and K contents and its age ranges from ~3 million years to present. The cave is entered through one of at least seven collapses located in a roughly straight line 2.5 km long with a bearing of 164° from the center of the volcano.

Thermal activity, manifested in fumaroles emanating from shelter caves, was noted along this line, at a distance of 560 m from the lip of the volcano and 2.1 km from Kahf Al Shuwaymis.

Description

The cave is 530 m long. The entrance is a collapse hole 15 m in diameter overlooking the floor of a horizontal passage 5 m below. A steep breakdown slope leads to a mostly south-trending passage varying in width from 4 to 15 m. with a typical height of about 10 m. Speleothems are limited to lava stalactites under 5 cm in length. There are at least four caches of animal bones, presumably carried into the cave by hyenas. A narrow channel of sand runs almost the entire length of the cave, indicating water flow in the past. Air currents entering the cave were noted from the east wall near station 12 and from the floor near station 17. There is a small, parallel upper passage between stations 8 and 9. Evidence of present-day, small-animal activity was noted in this passage. Radon gas levels of 17.4 Pci/L and 10.2 Pci/L were measured inside this cave. The cave map is shown in Fig. 7 (Pint, 2004).

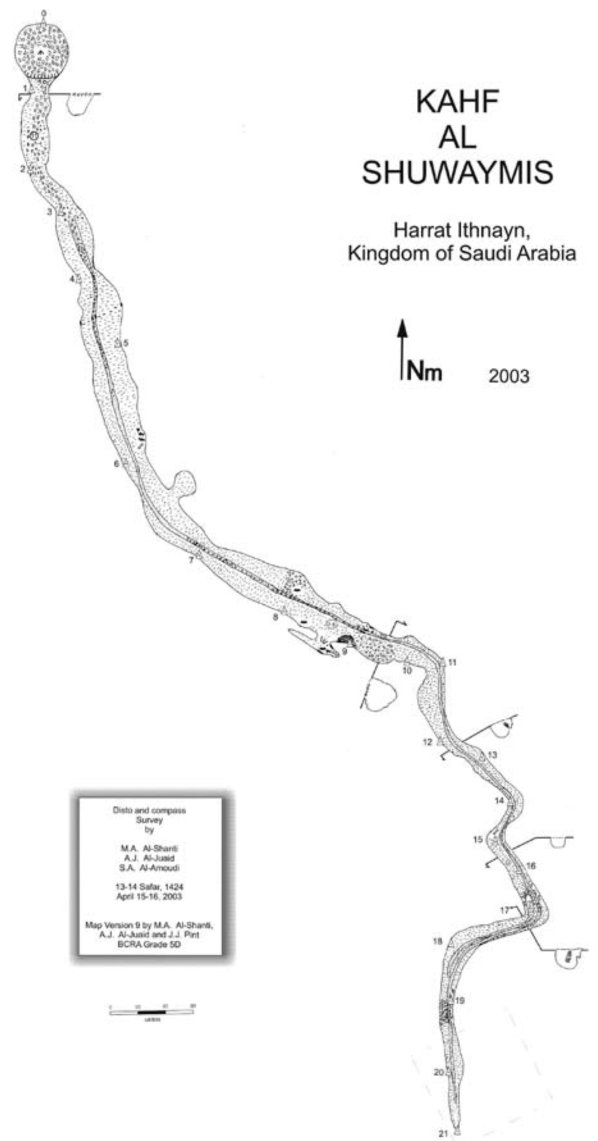

Fig. 7: Map of Kahf al Shuwaymis.

Comments

Archeologist Marian Bukhari briefly visited this cave in 2005. She states that the cave was used as a dwelling and may contain burial pits (Bukhari, 2006). It should be noted that this cave lies only 26 km northeast of a major Neolithic rock-art site. Petroglyphs from the site are shown in Fig. 8.

DAHL RUMAHAH

Dahl Rumahah (also spelled Romahah) is registered as number 176 in Pint, 2002 and is located at 25°56'N, 39°54'E.

Fig. 8: Ostriches, camels and Nabatean script on a sandstone cliff located 26 km from Kahf Al Shuwaymis.

Geological setting

This cave is located 169 km NNE of Medina in the northern part of Harrat Khaybar, part of an area comprising 20,560 km² of lava flows. The lavas and volcanoes in Harrat Khaybar are mildly alkaline with low Na and K content and include alkali olivine basalt (AOB), hawaiite, mugearite, benmoreite, trachyte and comendite. The age of the Khaybar lavas ranges from ~5 million years old (orangish flow field) to post-Neolithic (reddish-orange lava flows), to historic (black lava flows). Rumahah Cave is found in a black flow.

Description

The cave is 208 m long and has a horizontal entrance 1 m high by 1.5 m wide, set in a small depression. A long, low wall outside the entrance channels rainwater into the cave, which local people say was used as a reservoir. Most of the cave is a single, nearly flat, northwest-trending passage from 1.5 to 7 m wide and 2.5 m high. Rooms north of station 7 and south of station 11 terminate in very low crawls which may be connected. In September of 2003, it was found that dry sediment covered the floor of the southeast part of the cave while mud floored the northwest portion and occurred along part of the eastern wall. Water droplets and cave slime cover the ceiling at the far northwestern end of the cave. A natural bridge 1.5 m thick crosses the passage near its western end. Calcium-and-carbonate-rich percolation water leaked through ceiling cracks, producing white stalactites, curtains and flowstone. There is a large area of bones, including hedgehog and porcupine quills, mixed with desiccated hyena, wolf and fox coprolites. The highest radon level noted in Saudi caves was found in Rumahah: 119 Pci/l. The cave's temperature was measured at 25°C. Within a period of four hours the relative humidity rose from 68% to 74% at one point in the cave. The cave map is shown in Fig. 9 (Pint, 2004).

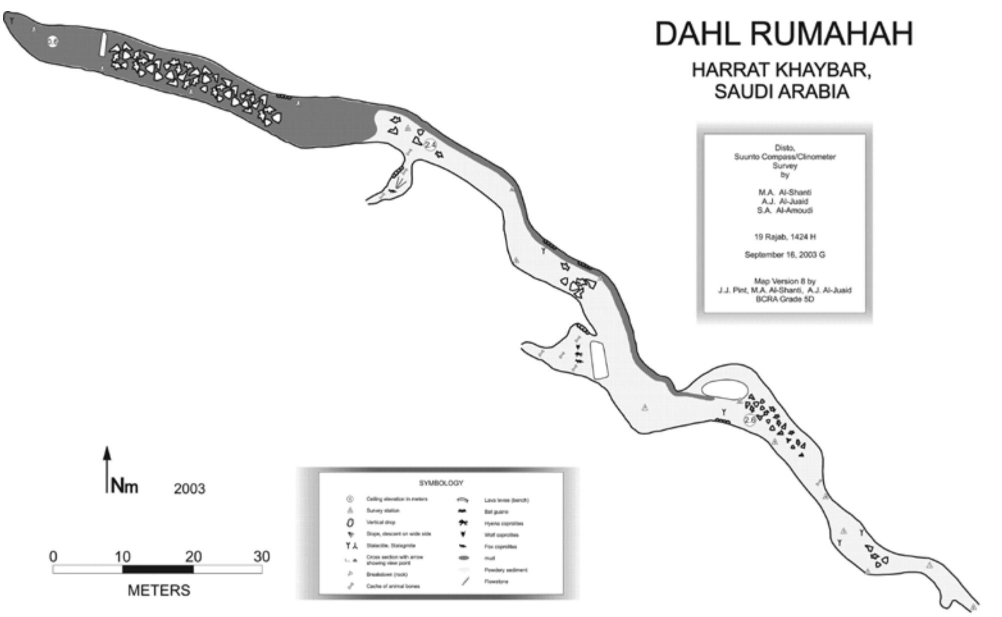

Fig. 9: Map of Rumahah Cave.

Comments

The radon level found in this cave seems high for a lava tube. It is possible that radon gas is entering the cave through cracks in the floor. The complete skeleton of an unknown animal is found in this cave, cemented to the floor by calcitic speleothems. There is evidence (including construction of a water-retaining wall) that this cave has long been used as a water reservoir. It should be noted that this cave lies only 22 km south of a major Neolithic rock-art site and is located roughly 126 km east of the old Nabatean Incense

Trail between Yemen and Petra. A paleontological and archeological survey of the cave should be undertaken.

THE HIBASHI STUDIES

Six field trips to Hibashi Cave in Harrat Nawasif/Al Buqum took place between January 2003 and June 2004, led by J. Pint and/or M. Al-Shanti. Samples of cave formations and debris were collected and sent to cave mineralogist Prof. Paolo Forti for analysis. Due to the many unusual and some rare secondary minerals found in the cave, Ghar Al Hibashi was added to the list of the ten mineralogically most important lava caves in the world (Forti *et al*., 2004; Forti, 2005).

Dr. Peter Vincent and Fayek Kattan participated in a visit to the cave on August 31, 2003 to take samples of the sediment overlying the original cave floor, for age-dating by Optically Stimulated Luminescence (OSL). A sample from the human skull found lying on the surface, deep inside the cave, was sent out for carbon-dating.

Redeposited loess (10 micron mean particle size) covers most of the cave floor. Researchers planning for the exploration of Martian lava tubes are using photographs and maps of Hibashi cave to produce robotic motion simulations for testing the capabilities of microrobotic designs to navigate inside the caves of Mars (Pint *et al*., 2005).

HIBASHI CAVE

Hibashi Cave or Ghar Al Hibashi (also spelled Hebashi) is registered as number 180 in Pint, 2002, and is located at 21°08'N, 42°08'E.

Geological setting

Ghar Al Hibashi lies near the center of Harrat Nawasif/Al Buqum, a group of lava flows located east of Makkah (Mecca). These titaniferous, olivine basalts are described as gray to dark gray, vesicular, medium-grained and prophyritic (Ziab and Ramsay, 1986). Pint *et al*., 2005, speculate that Ghar Al Hibashi may lie in basalt dated at ca. 1.1 million years by Hötzl *et al*., 1978.

Description

The cave is 689.5 m long. The cave entrance is a collapse 14 m in diameter located in a slightly elevated area of a major basaltic flow emanating from a large crater to the southeast. A steep slope leads down to a gallery which intersects the east-west-oriented main passage of the cave. This passage is typically 12 m wide, increasing to 33 m at its eastern end. The height ranges from <1 m to >9 m. The cave map is shown in Fig. 10.

The floor of Hibashi Cave is mostly covered with as much as 1.5 m of loess (having lain up to ca. 5800

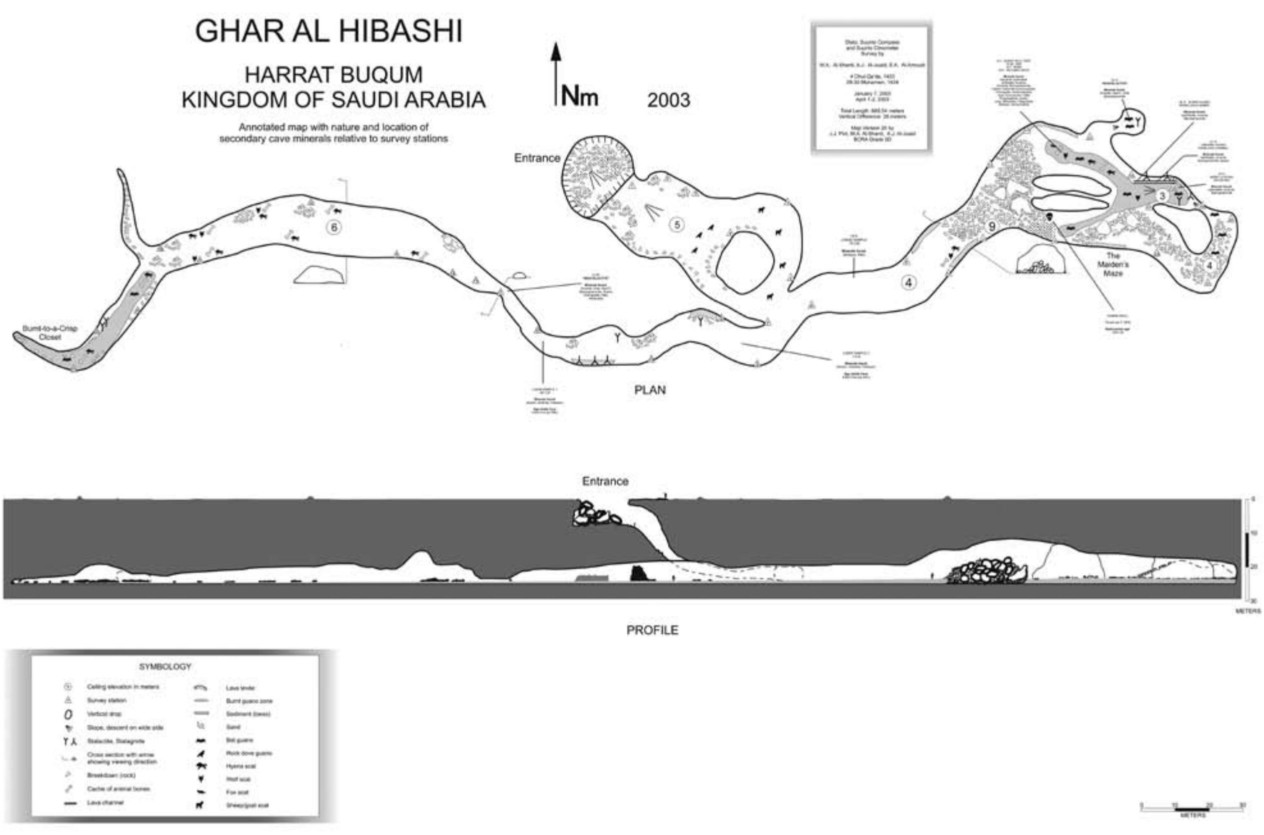

Fig. 10: Map of Hibashi Cave.

years inside the cave, according to OSL dating), underlying beds of burnt bat guano at the extreme ends of the main passage. Volcanic levees, stalactites and stalagmites are common. At least 19 different minerals were found in the cave, three of them being extremely rare organic compounds related to the guano combustion. Bats and small animals live in the cave. Bones, desiccated animal scat and a human skull ca. 425 years old (Fig. 11) were also found in the cave (Forti *et al.*, 2004; Forti, 2005; Pint *et al.*, 2005; Pint, 2005).

Fig. 11: Part of a human skull found inside Hibashi Cave and carbon dated at 425±30 years BP.

Comments

The well-preserved scat of hyenas, wolves and foxes is found throughout the cave. Studies of plant material and other substances contained in these coprolites could be rewarding. Phytoliths preserved in the plant material may be used for identifying the plants and may shed light on the process of desertification which has taken place on the Arabian Peninsula. A wall built inside the cave indicates that it was used by humans at some point. Archeologists, paleontologists and historians may wish to explore what may be hidden in the thick bed of loess covering the cave floor.

OTHER INVESTIGATIONS

On May 29 and 30, 2001, J. Pint flew over parts of Northern Harrat Rahat by helicopter. Pint noted areas of Pahoehoe lava at 24° 15' N, 39° 40' E; 22° 34' N, 39° 20' E and 24° 28' N, 39° 44'E and noted what appeared to be collapse entrances to lava caves at 24° 17' N, 39° 41' E and 24° 21' N, 39° 42' E. Most of these locations may be difficult to access by vehicle or on foot. None of the sites observed from the air during this field trip have yet been visited.

In February of 2003, an attempt was made to survey Dahl Um Quradi, a lava tube located in southern Harrat Khaybar. J. Pint and M. Al-Shanti led this field trip with J. Shawali acting as guide. Just outside the cave entrance, SGS geologist Saeed Al-Amoudi was seriously injured and had to be rescued by helicopter, resulting in the cancellation of the survey. However, it was noted that the cave has a walk-in entrance measuring 2 x 3 m and a vertical (collapse) entrance 4 m in diameter and ca. 5 m deep. This lava tube may be 100-200 m long. Jamal Shawali stated that there is another lava tube in the area, but this could not be visited.

In January, 2004, J. Pint, S. Pint and A. Gregory travelled to the center of Harrat Khaybar. The entrances to several lava tubes on the flanks of the basaltic stratovolcano Jebel Qidr were observed and photographed. According to Roobol *et al.* (2002) this volcano may have last erupted in 1800 A.D., suggesting that lava caves in this flow may be among the youngest and most pristine in Saudi Arabia.

In May of 2004, a search for lava caves in Harrat Harrah, in the extreme northwestern corner of Saudi Arabia, was undertaken by an SGS team led by Mahmoud Al-Shanti. This same lava flow extends across the border into Jordan, where several lava tubes have been found and studied (Kempe *et al.*, 2004; Kempe and Al-Malabeh, 2005). It was therefore hoped that lava caves would also be found on the Saudi side. Although no noteworthy caves were encountered, a well 13 m wide and 24-25 m deep was found on a small basalt hill. Ancient script – apparently Thamudic—covers many rocks near the cave entrance suggesting that this well may have been in use at least 2,000 years ago. Due to the instability of the well's walls, it was not entered. The location of the well is given in Pint, 2002.

FUTURE POSSIBILITIES

POTENTIAL FOR THE FURTHER DISCOVERY AND TOPOGRAPHY OF LAVA CAVES

Saudi Arabia has at least 80,000 km^2 of lava fields, roughly divided into twelve major *harrats*. During a short period of four years, six of these *harrats* were visited and in each of them some feature of interest to vulcanospeleologists was observed. The core team which located and/or entered these cavities consisted of only five individuals (J. Pint, M. Al-Shanti, S. Al-Amoudi, A. Al-Juaid and S. Pint). It can only be concluded that with more time and/or more personnel, many more lava caves will be found in Saudi Arabia. This assertion, in the case of Harrat Khaybar, is backed up by the many references to lava-tube collapse holes in Roobol and Camp (1991a), including descriptions of numerous collapses on whale-back formations up to 25 km long, situated up to 25 km from

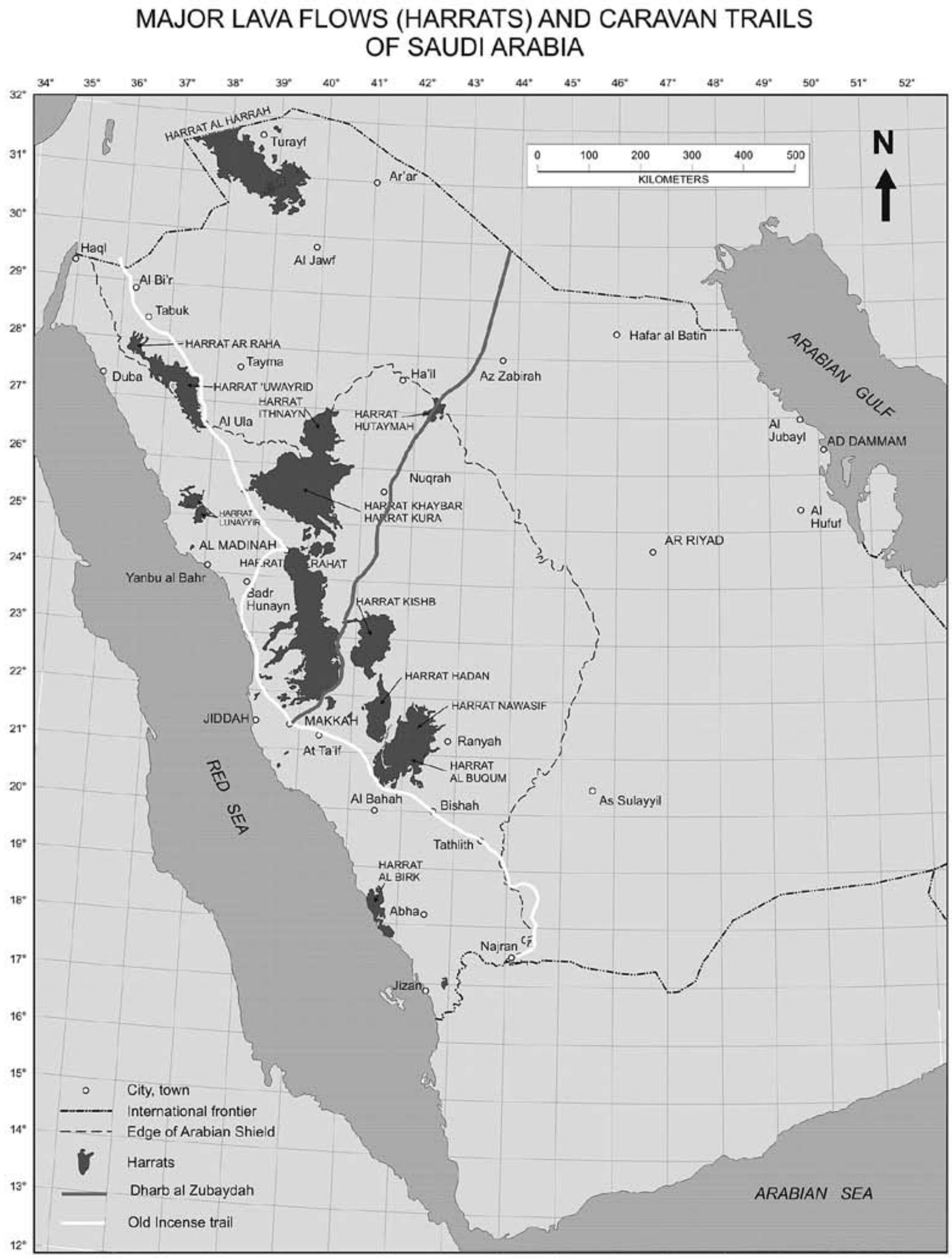

Fig. 12: Map of two ancient caravan trails in Saudi Arabia, showing lava fields. After Hussein Sabir, 1991.

the source volcanoes, indicating a potential for lava tubes up to 50 km long in Saudi Arabia. To these collapses may be added the lava tubes observed in southern and central Harrat Khaybar (mentioned above under Other Investigations) but not yet explored. At present the record for longest mapped lava cave in the Middle East is held by Al-Fahda Cave, 923.50 m long, in Jordan (Kempe and Malabeh, 2005).

POTENTIAL FOR NEW SPELEOLOGICAL STUDIES

• **Mineralogy:** Significant and unusual cave minerals were found in Hibashi Cave (Forti *et al.*, 2004; Forti, 2005) but such studies have yet to be undertaken in other Saudi lava caves.

• **Archeology:** Saudi lava caves lie near ancient sites of human habitation as well as adjacent to several ancient caravan trails (Fig. 12). All mapped lava caves contain structures or artifacts indicating use or visits by humans in the past. The only recorded visit to a Saudi lava cave by an archeologist (Bukhari, 2006) revealed indications that the cave may have been used as a dwelling and may contain burial sites. A search of archeological journals in February of 2006 suggests that few if any formal archeological studies have ever taken place in Saudi lava caves.

• **Biology:** Many lava caves were formed a million or more years ago and are located in remote areas of difficult access. Speleologists have found numerous indications that a variety of living creatures inhabit or inhabited the Saudi lava caves thus far explored (Roobol *et al.*, 2002; Pint *et al.*, 2005). A February 2006 search of biology journals suggests that no biological studies have ever been carried out in any Saudi lava cave.

PROBLEMS RELATED TO LAVA-CAVE STUDIES

In some parts of the world, the scientific study of caves has a long history and over the years, organizations dedicated to speleology were founded in the private sector, the public sector or both. In Saudi Arabia, however, public realization of the nature, extent and resource value of the Kingdom's caves (limestone, lava and others) is a very recent phenomenon. Saudi Arabia has no laws specifically related to caves and no private or government organization specifically concerned with speleology. Many of the speleological studies carried out in Saudi Arabia were done by foreigners living in the country for only a few years. For the most part, the results of these studies were not properly recorded.

Recent speleological work by a semi-government organization (the Saudi Geological Survey) has laid an excellent foundation for speleology in Saudi Arabia. However, its work has been somewhat limited to the field of geology, which is only one of the several sciences included under the umbrella of speleology. Speleo-archeology and biospeleology, for example, have been neglected. The formation of a Kingdom-wide speleological organization, whether academic, governmental or recreational, might provide the coherence and stability that the Kingdom of Saudi Arabia needs for a sustained study of its caves.

CONCLUSIONS

It is likely that Saudi Arabia's lava fields contain a great many caves and possibly some of the longest lava tubes in the world. It is also likely that archeological, mineralogical and biological cave studies (among others) will yield important discoveries. Reconnaissance for caves in the lava fields of Saudi Arabia should, therefore, be resumed. The establishment of a Kingdom-wide organization dedicated to speleology may foster studies in all branches of cave science and facilitate the preservation and dissemination of the resultant findings.

ACKNOWLEDGEMENTS

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PROTECTION OF KARST IN THE PHILIPPINES
VARSTVO KRASA NA FILIPINIH

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Abstract UDC 551.44:502.7(599)
Sonata Dulce F. Restificar, Michael J. Day, & Peter B. Urich: Protection of Karst in the Philippines
The article presents an overview of the current status of karst protection in the Philippines. Prior studies indicate that of the 35,000km^2 of karst landscape in the country, about 29% is protected . However, protection of karst has not to date been a priority of the Philippine government, and the country has no existing legislation that is directly decreed for protection and conservation of karstlands. Most contemporary karst protection is indirect, in that the karst is located within protected areas established for other, although often related reasons, such as ecological conservation, water supply protection and tourism. However, it appears that the Philippine government is gradually recognizing explicitly the need to protect karst landscapes. The establishment of the National Caves and Cave Resources Management and Protection Act in 2001 and the inclusion of karst water resources in the country's National Action Plan (NAP) under the United Nations Convention to Combat Desertification (UNCCD) are significant steps towards explicit protection of karst areas. Although the existing legislation only addresses specific facets of karst landscape, it may stimulate additional programs and legislation that will more broadly protect karst landscapes nationally.
Key words: Philippines, karst, caves, protected areas, environmental legislation.

Izvleček UDK 551.44:502.7(599)
Sonata Dulce F. Restificar, Michael J. Day & Peter B. Urich: Varstvo krasa na Filipinih
Članek predstavlja pregled stanja zaščite krasa na Filipinih. Prejšnje raziskave kažejo, da je zaščitenega 29% od 35.000 km^2 filipinskega krasa. Vendar pa do sedaj zaščita krasa ni bila prednostna naloga vlade in država nima zakonodaje, ki bi izrecno zahtevala zaščito in ohranjanje kraške pokrajine. Današnja zaščita krasa je posredna, ko je kras v zaščitenih področjih, razglašenih zaradi drugih, čeprav pogosto podobnih razlogov, kot so ekološka zaščita, zaščita pitne vode ali turizem. Vseeno pa kaže, da filipinska vlada postopoma spoznava pomen neposredne zaščite kraške pokrajine. Pomembni koraki k zaščiti kraških področij so ustanovitev National Caves and Cave Resources Management (Državne uprave jam in jamskih virov), Odlok o zaščiti iz 2001 in vključitev kraških vodnih virov v National Action Plan (Državni izvedbeni plan) v okviru United Nations Convention to Combat Desertification (Listina ZN za boj proti dezertifikaciji). Čeprav obstoječa zakonodaja upošteva samo določene poteze kraške pokrajine, lahko vzpodbuja dodatne programe in akte, ki bi omogočali celovitejšo zaščito kraške pokrajine v državnem okviru.
Ključne besede: Filipini, kras, jame, zaščitena področja, okoljska zakonodaja.

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INTRODUCTION

The Philippines' natural resources have long been stressed (Ong *et al.* 2002), and deforestation, degradation of land and water resources, and air, water and soil pollution are among the serious environmental problems that the country currently faces. Recognizing this, the Philippine government has passed legislation and instituted programs designed to preserve its remaining natural resources and to rejuvenate the environment. This legislation and the resource protection and conservation programs apply to the broad spectrum of national natural resources, including forest, marine and aquatic resources, wildlife, and natural landmarks, but they often lack a sound geomorphological basis.

The Philippines contains a diverse array of tropical karst landscapes that cover about 10% of the total land surface (Piccini & Rossi 1994; Balázs 1973). Despite this, the country has no legislation that is specific to the protection and conservation of these distinctive and significant physical resources. The inclusion of karst protection in the country's resource conservation effort would enhance the emerging resource protection program by explicitly including a landscape resource that differs from others in its geomorphology and hydrology. Moreover, other critical components of the national ecosystem would also be protected since the conservation of karst landscapes will concomitantly protect watersheds and habitats of unique wildlife, especially the cave-dwelling species whose existence depends on the karst.

In this paper we provide an overview of environmental and resource protection in the Philippines, and assess the extent of karst protection in the country. We examine the legislation passed by the Philippine government in order to conserve natural resources and to protect the environment, and we identify legislation that directly or indirectly protects karst landscapes. We conclude with a brief outline of the karst areas that are currently being afforded protection.

PROTECTED AREA LEGISLATION: A HISTORICAL PERSPECTIVE

The enactment of Executive Order No. 33 on April 25, 1910 marked the beginning of a conscious effort to protect the Philippines' physical patrimony. Executive Order 33 created the first park in the country – the Rizal National Park in Zamboanga, which is established in honor of the country's national hero (PAWB 1989). The 1930s witnessed the Philippine National Park Movement, pioneered by then Senator Camilo Osias and Forestry Director Arthur Fisher, who explored the country, identifying natural wonders that should be set aside for public enjoyment (PAWB 1989). The Philippine's first legislation regarding park establishment and management was established in 1932, when Act No. 3915, entitled "An Act for the Establishment of National Parks, Declaring such Parks as Game Refuges and for Other Purposes", passed on February 01, marking the formal beginning of the country's resource conservation effort. Act 3915 defined a national park as "a portion of the public domain reserved or withdrawn from settlement, occupancy, or disposal under the laws of the Philippine Islands, which because of its panoramic, historical, scientific or aesthetic value, is dedicated and set apart for the benefit and enjoyment of the people of the Philippine Islands" (WCMC 1992). The Act became effective in 1934 through the issuance of Forestry Administrative Order No. 7, entitled the National Park Regulations, which specified the management, development, conservation and use of national parks (PAWB 1989).

In 1975, the National Park Regulations were updated through Presidential Decree 705, or the Revised Forestry Code of the Philippines. The Revised Forestry Code included a provision for the allocation of forestland for purposes such as national parks, national historical sites, game refuge, wildlife sanctuaries and forest reserves. The Code was subsequently amended in 1978 by Presidential Decree 1558 (PAWB 1989), and in 1981 the Code was further amended by Presidential Decree 1559 in order to "… further strengthen the code to make it more responsive to present realities and to the new thrust of government policies and programs and forest development and conservation…" among others. In addition, the 1981 revision provided an updated definition of a national park: "a forest land reservation essentially of primitive or wilderness character which has been withdrawn from settlement or occupancy and set aside as such exclusively to preserve the scenery, the natural and historic objects and the wild animals or plants therein, and to provide enjoyment of those features in such a manner as will leave them unimpaired for future generations."

From 1932 to 1952, the Bureau of Forestry in the Department of Agriculture and Natural Resources (DANR) was responsible for national parks administration (WCMC 1992). In 1952, the Commission of Parks and Wildlife was created under Republic Act No. 826, and was placed under the control and supervision of the President of the Philippines (PAWB, 1989). This Republic Act was amended several times through Executive Orders, Letter of Implementation, and Presidential Decrees (WCMC 1992). In 1987, through Executive Order No. 192, the Department of Environment and Natural Resources (DENR) was created and was vested with primary institutional responsibility for the management of national parks, reserves and other protected areas. Executive Order 192 also created six staff bureaus within the DENR, among which the Protected Areas and Wildlife Bureau (PAWB) was given the primary responsibility of managing the country's protected areas as well as the conservation of biodiversity, genetic resources, and endangered wildlife resources.

CONTEMPORARY PROTECTED AREA LEGISLATION

The Philippine Constitution mandates the State "to protect and advance the right of the people to a balanced and healthy ecology" (Tan 1998). This duty is codified in the Philippine Environmental Policy, which is the national blueprint for environmental protection (Tan 1998). This Policy, together with the Philippine Environment Code, which contains the basic principles regarding the country's environmental and natural resource concerns, represents the basic law pertaining to the Philippine environment (Tan 1998). The Philippine government's commitment to environmental and resource protection is manifested in the 1990 Philippine Strategy for Sustainable Development, which includes "a clear commitment on the behalf of government to establish protected areas as the principal instrument for conservation" (WWF 1991 in WCMC 1992).

Republic Act No. 7586, also known as the National Integrated Protected Areas System (NIPAS) Act, was passed in 1992 to make provision for the establishment of integrated protected areas system as well as to "replace the fragmented and obsolete legislative foundation of protected areas in the Philippines" (Pollisco 1995). The NIPAS Act of 1992 established the National Integrated Protected Areas System (NIPAS) that "shall encompass outstanding remarkable areas and biologically important public lands that are habitats of rare and endangered species of plants and animals, biogeographic zones and related ecosystems, whether terrestrial, wetland or marine, all of which shall be designated as protected areas." The management and administration of NIPAS was placed under the DENR through the Protected Area Management Board (PAMB). The NIPAS Act mandates that a PAMB should be created for each established protected area, with each PAMB being composed of the following members: the Regional Executive Director, a representative of the regional government, a representative from the municipal government, a representative from each barangay covered by the protected area, a representative from each tribal community, at least three representatives from Non-Government Organizations and/or the local community, and a representative from other departments or national government agencies involved in protected area management. Each board member serves for a term of five years.

Eight categories of protected areas were established under the NIPAS Act: strict nature reserves; natural parks; natural monuments; wildlife sanctuaries; protected landscapes and seascapes; resource reserves; natural biotic areas; and other categories established by law, conventions or international agreements to which the Philippine Government is a signatory. As of 2004, about 5.1 million hectares or about 17% of the Philippines' total land area is classified as protected (DENR 2004). The country has 293 protected areas; of which 209 are created under the initial components of the system and 84 were created under the NIPAS system (DENR 2004).

DISTRIBUTION OF KARST

The Philippines contains a wide array of tropical karst landscapes. The most significant karst areas are on the larger islands, with the most extensive being the Calbiga Karst on the island of Samar. There are also significant karst areas in the Cagayan, Kalinga-Apayao, Ilocos and Bicol regions of Luzon, on Bohol and Cebu in the Visayas, and in Negros, Davao and Cotabato in Mindanao (Fig. 1). The karst areas vary considerably in terms of landforms and age, although most of the karst is formed in Tertiary and Quaternary carbonates (Balázs 1973). The most striking surface karst landforms are steep-sided karst towers, which are exemplified by the towers of Coron Island in northern Palawan and on the west coast of Palawan. Pinnacle karst is also developed in Palawan (Longman & Brownlee 1980). Dome-shaped karst hills dominate the karst landscape of the island of Bohol, and there are also locally numerous dolines, dry valleys, poljes and caves. The longest reported cave extends to about 15

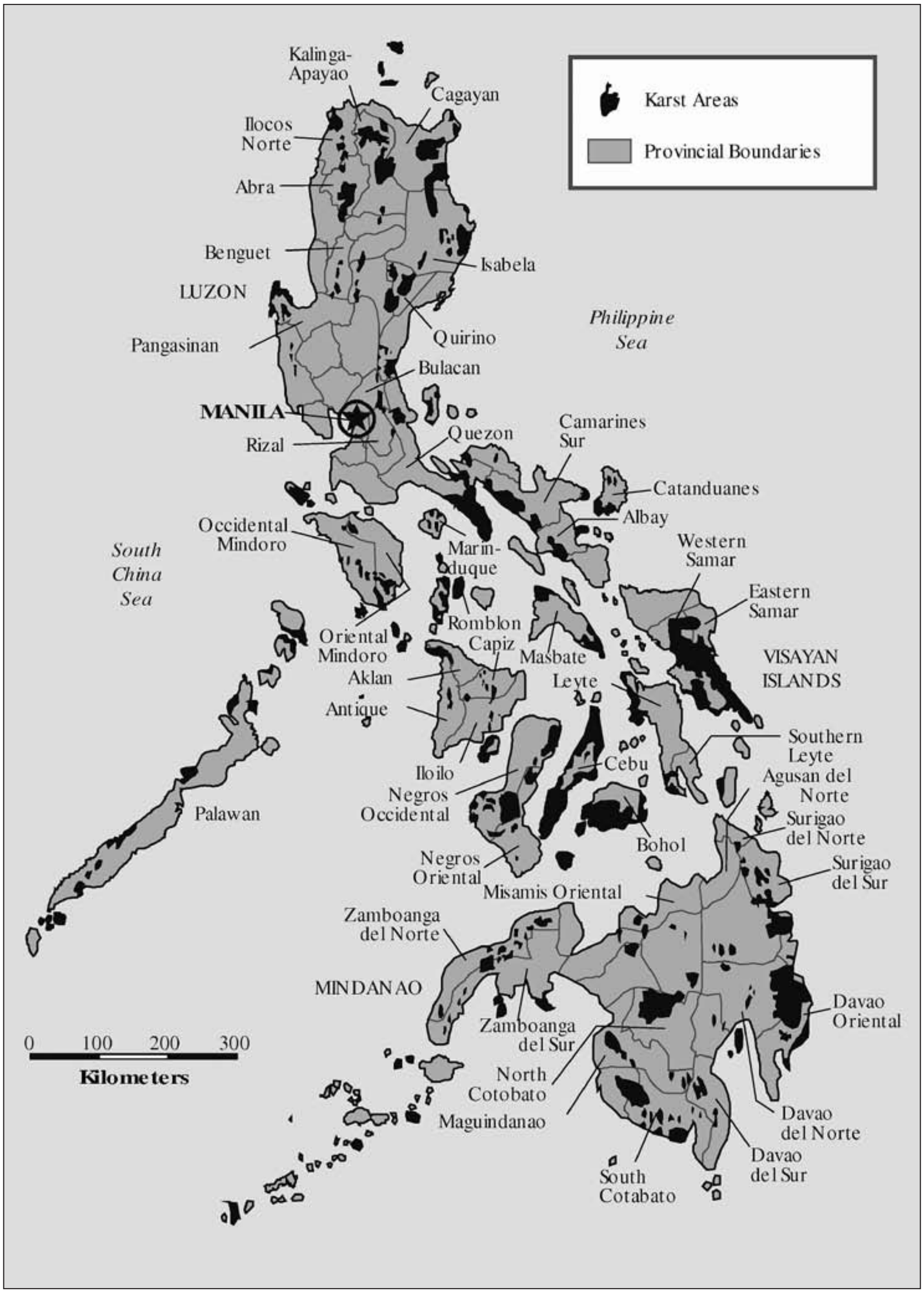

Fig. 1: Karst areas in the Philippines (based on Balázs 1973)

km – and the deepest cave reaches a depth of about 163 m (Urich 1996).

PROTECTION OF KARST

Day & Urich (2000) reported that the Philippines protects about 29% of its total karst landscape. Protection of karst areas has not, however, been a deliberate policy on the part of the Philippine government. The country has no existing legislation that directly addresses the protection and conservation of karst areas, and karst protection is largely effected through indirect means, that is karst happens to occur within areas designated for protection on the basis of other, although perhaps related criteria. Some existing karst areas are protected essentially because of their aesthetic and therefore tourism value, while others fall within nature or resource reserves, natural parks and monuments, wildlife sanctuaries or protected landscapes and seascapes. Recently, however, it appears that the Philippine government is beginning to recognize explicitly the importance of protecting certain karst areas and components. One significant step was undertaken by the government to protect the country's caves through the issuance of DENR Department Administrative Order No. 4, Series of 1994, which established the Cave Management and Conservation Program (CMCP). The CMCP is intended to protect and safeguard the country's caves through various programs including policy development, research, human resource development, information, education and communication campaigns, and community and stakeholder involvement in management and conservation (PAWB 2004a). The CMCP is also more broadly significant particularly in the context of protection of karst because "…almost all caves in the Philippines are formed in limestone" (Bacalian 1993). One of the initial components of CMCP is the assessment of the state of Philippine caves, which produced an initial inventory of about 2,466 caves in 35 of the country's 76 provinces (Bacalian 1993). In the implementation of the CMCP under the NIPAS Act, three caves have been proclaimed as protected areas: Calbiga Protected Landscape, Pamitinan Protected Landscape, and Peñablanca Protected Landscape (PAWB 2004a).

In 2001, efforts to protect, conserve and manage the country's caves and cave resources were further strengthened via the passage of Republic Act No. 9072, which is also known as the "National Caves and Cave Resources Management and Protection Act". The implementation of this Caves Act is directed through multiple agencies whose main functions are as follows:

1. *DENR:* permit issuance, information dissemination and education campaign;

2. *Department of Tourism:* promotion of caves classified as ecotourism sites, and visitor management;

3. *National Museum:* protection and management of caves with cultural and archeological features;

4. *National Historical Institute:* protection of sites with historical value;

5. *Local Government Units;* and,

6. *Palawan Council for Sustainable Development:* in the case of Palawan Province.

One of the provisions of the Caves Act is the continuing inventory of the country's caves. As of 2003, the cave inventory listed 1,525 caves (PAWB 2004b), only 204 of which have been studied in detail. There is some duplication in terms of provisions between the Caves Act and the NIPAS Act; for instance, 87 of the caves listed under the former also fall under the Integrated Protected Area Program (IPAP).

The Caves Act's role in terms of protecting the karst landscape is limited at best. It is intended mainly for the management and conservation of a wide mélange of the country's caves and cave resources and it is not directly targeted toward the protection of broader karst landscapes. Although the Act may serve to protect individual caves in karst areas, it is not specifically decreed for their protection. However, other legislation does exist that indirectly protects karst landscapes:

1. Republic Act 9147 or the "Wildlife Resources Conservation and Protection Act" aims to conserve the country's wildlife resources and their habitats, and can be used to protect wildlife resources in specific karst areas.

2. Republic Act 7942 or the "Mining Act" contains provisions relating to areas closed to mining operations. These include all areas under NIPAS, which includes several karst areas.

3. DENR-DOT Memorandum Circular 98-02 (Guidelines for Ecotourism Development in the Philippines) and Executive Order No. 11 (Establishing the Guidelines for Ecotourism Development in the Philippines) provide guidelines for the management of caves used for ecotourism activities.

4. Republic Act 4846 or the "Cultural Properties Preservation and Protection Act" may be invoked to protect cave resources of cultural significance.

The Philippine Government is a signatory to the United Nations Convention to Combat Desertification (UNCCD), which is a United Nations agenda aimed at combating desertification and at mitigating the effects of drought in countries experiencing serious drought and/or desertification. UNCCD was ratified by the Philippine Senate in February 2000 and came into full force in May of the same year. UNCCD requires each signatory nation to prepare a National Action Plan (NAP), which is one of the key instruments in the Convention's implementation (UNCCD 2004). The Philippines' proposed National Action Plan is designed as a Convergence Plan of Action of the National Government for combating land and water degradation and desertification, and for reducing poverty (Concepcion 2004). The implementation of the plan will involve the participation of the Department of Agriculture (DA), the Department of Agrarian Reform (DAR), the Department of Science and Technology (DOST), and the DENR. One of the six Community-Based Thematic Programs included in the NAP is "Participatory Management of Karst Water Resources in Small Islands", and this program potentially will have a direct impact on karst water resource conservation nationally.

PROTECTED KARST AREAS

At the national scale, there is surprisingly limited information about many protected areas that do or may include karst, so here we focus on those major karst areas that are known to be protected. In this context, twenty-three karst areas in the country are currently known to have protected status (Table 1). These are areas whose

Protected Karst Area	Location	Karst Features
National Parks		
1. Balbalasang-Balbakan	Kalinga-Apayao	Caves with outstanding stalactites and stalagmites, karst tower
2. Callao Cave	Cagayan	9-kilometer long cave with an active stream
3. Hundred Islands	Pangasinan	Caves, some caves are underwater
4. Minalungao	Nueva Ecija	Cathedral-like caves
5. Biak-na-Bato	Bulacan	Several caves with rivers
6. Mt. Banahaw-Mt. Cristobal	Laguna and Quezon	Series of caves
7. Libmanan	Camarines Sur	Several caves, series of crystal caverns and cataracts
8. Mt. Isarog	Camarines Sur	Series of crystal caverns
9. Caramoan	Camarines Sur	Cave
10. Bulusan	Sorsogon	Limestone formations
11. Puerto Princesa Subterranean River	Palawan	Several caves, sinkholes, karst tower, karren, 8-kilometer long St. Paul Cave with tidal underground river, pinnacle karst
12. Bulabog-Putian	Iloilo	Caves, springs
13. Guadalupe Mabugnao-Mainit	Cebu	Interconnected caves
14. Sudlon	Cebu	Cave system
15. Kuapnit Balinsasayao	Leyte	Caves
16. Sohoton Natural Bridge	Samar	Stone bridge, cave with cathedral-like chamber and underground river, caves are typically phreatic
17. Initao	Misamis Oriental	Caves
18. Mt. Kitanglad	Bukidnon	Caves
Protected Landscape		
1. Pamitinan	Rizal	Caves
2. Calbiga	Samar	Cave system with 3 prominent caves, sinkholes, cave with active stream, uvalas, underground rivers, cockpits, karst plateau
3. Rajah Sikatuna	Bohol	Caves, sinkholes, isolated mogotes
4. El Nido	Palawan	Cave, marine karst tower
Natural Monument		
1. Chocolate Hills	Bohol	Conical karst hills, polje

Tab. 1: Protected karst areas

karst landscapes are recognized as such and whose protected status is clear (Fig. 2). The following summarizes some of these known protected karst areas.

Puerto Princesa Subterranean River National Park (PPSRNP) in Palawan features a spectacular karst landscape. "More than 90% of the park comprises sharp, karst limestone ridges around Mount St. Paul which is itself part of a series of rounded, limestone peaks aligned on a north-south axis, along the western coast of Palawan" (WCMC 2000). The principal feature of PPSRNP is its more than 8-kilometer long underground river (Fig. 3). A distinguishing feature of this underground river is that "it emerges directly into the sea, and that the lower portion of the river is brackish and subject to tidal influences" (IUCN 1999). In 1991, the Philippine Government nominated PPSRNP as a UN Natural World Heritage Site but the nomination was deferred upon the recommendation of IUCN since the proposed area was deemed

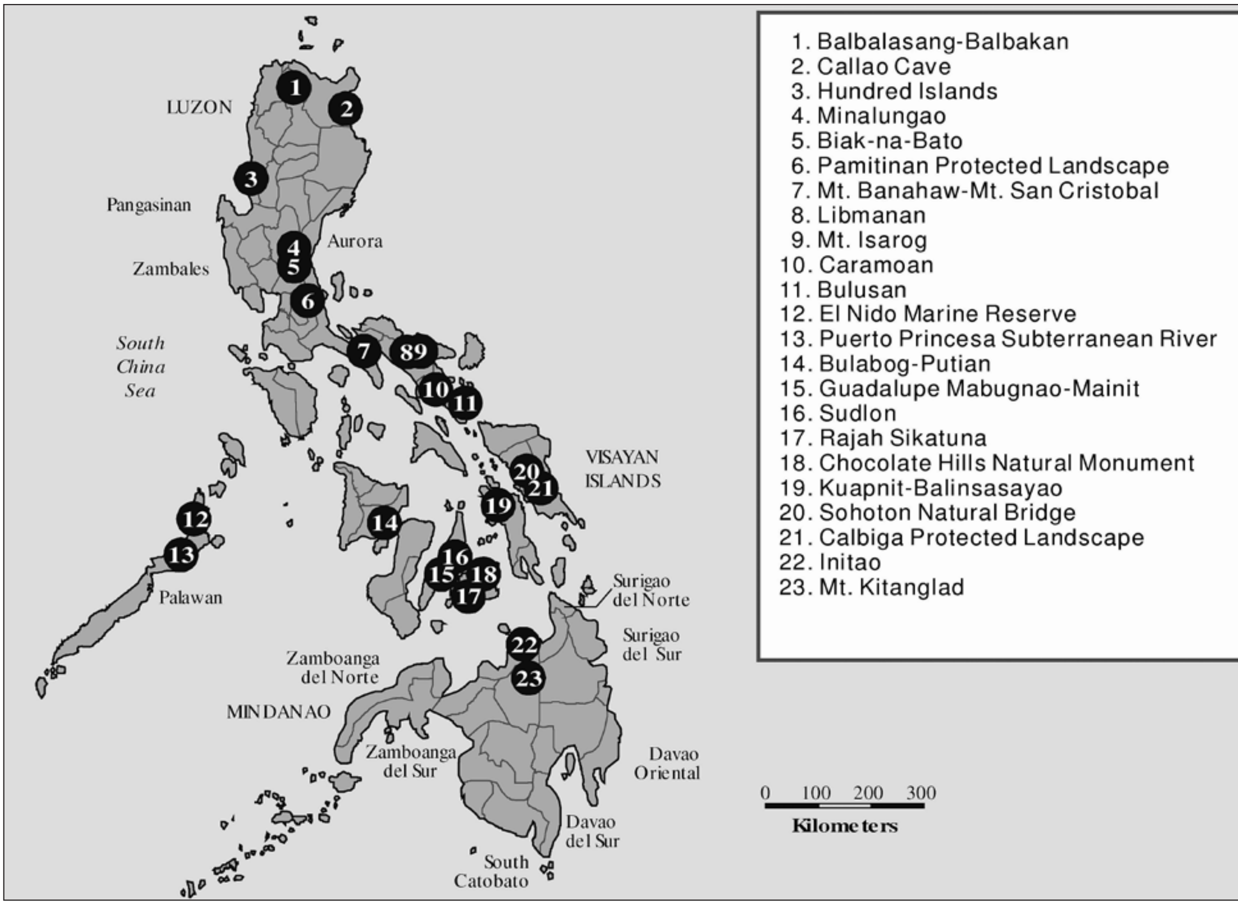

Fig. 2: Protected karst areas in the Philippines

too small by the IUCN Technical Evaluation Team to adequately protect its underground river watershed and to ensure the long-term viability of its significant biodiversity (PPSRNP 2000; IUCN 1999). In 1999, the area of the park was increased from its original mere 3,901 hectares to 22,202 hectares through Proclamation Order No. 212 (DENR 2000). This paved the way for its inscription as a Natural World Heritage Site in November of that year. The expansion of its boundary, however, brought some consequential resource use conflicts between the mandates of the park and the livelihood needs of the people whose lands have been included in its expanded boundary (Restificar 2004). Its importance as a distinctive geological feature is further recognized in 2004 when the National Committee on Geological Sciences (NCGS) declared it as a National Geologic Monument.

Samar Island Natural Park (SINP), which covers an area of about 333,300 hectares, including 37 municipalities and one city, was in 2003 declared a protected area under the NIPAS Act (Labro 2003). Several of the country's most significant karst landscapes are located in

Fig. 3: The outflow of the St. Paul Cave underground river

this area, in particular the Calbiga karst, which is one of the largest known karst areas in the country (eLGU 2004; IUCN Karst Project: Philippines undated). The Calbiga karst covers an area of about 900 km^2 (Balázs 1973) and, within this, the Calbiga Cave Protected Landscape, which was included in the NIPAS list in 1997, covers an area of 2,968 hectares (PAWB 2004c). The Calbiga Cave Protected Landscape includes 12 caves, the largest of which is the 5 km long Langun-Gobingob System (eLGU 2004; IUCN Karst Project: Philippines undated). Sohoton Natural Bridge National Park also includes Pahulugan Cave, Sohoton Cave and Bugasan Cave plus spectacular limestone formations, including the limestone bridge whence the name Sohoton (which means "to pass through") was derived (PAWB 1997).

Conical karst hills, which are aptly called Chocolate Hills, are the most dominant feature of the karst landscape of central Bohol (Fig. 4). The Chocolate Hills Natural Monument, covering an area of about 1,776 hectares, was inscribed as a National Geologic Monument in 1988 by NCGS, and as a protected area under NIPAS in 1997. The Chocolate Hills Natural Monument consists of about 1,268 more-or-less symmetrical, haycock-shaped hills that rise some 30 meters above the surrounding ground. The plains around these conical hills have been transformed into thriving rice-growing landscapes that are "connected to the less accessible mountain tracts" by "karst-springs at their foot" supplying water for irrigation (Urich 1989; Uhlig 1987). However, "Bohol's 500-year history of sustained karstland occupation is seriously threatened today by the pressures of population, inappropriate application of agricultural technologies, and civil strife" (Urich 1993).

Fig. 4: The Chocolate Hills of Bohol

The Rajah Sikatuna National Park in Bohol is one of the most recent additions to the country's list of protected karst areas. The Park was established in 1987 and was assigned an area of 9,023 hectares (PAWB 1997). "The Park's geology is based on two distinct units: Pliocene to Pleistocene-aged limestone in the west and Late Miocene-to-Pliocene-aged limestone in the east and northeast" – wherein two distinct suites of karst landform have developed (Urich & Bliss 1992). The younger limestone is dissected by discontinuous valleys, cockpits, isolated mogotes and extensive corrosion plains, while the Miocene-aged limestone is dominated by interfluvial valleys and extensive ridges, although both geologic units express similar subterranean and micro-karst features such as caves, sinkholes, subsurface drainage, estavelles and swallets (Urich & Bliss 1992). In 2000, the area was de-listed as a National Park and was designated a Protected Landscape instead. This change was made because the large number of people resident within its boundaries prevented the area meeting the criteria of a National Park. The area of the Rajah Sikatuna Protected Landscape is currently about 10, 452 hectares (PAWB, 2005).

The Hundred Islands of the Lingayen Gulf consist of the lower rocks of the "Kegel" karst type (Uhlig 1980). The Hundred Islands National Park consists of about 123 islands and covers an area of 1,676 hectares. The Hundred Islands was declared a national park in 1983 (PAWB 2004d), and a National Geological Monument in 2001 (NCGS 2001). It is a resort area that has a vibrant tourism industry.

END NOTES

1. A barangay is the smallest political unit in the Philippines.
2. One of the programs of the National Committee on Geological Sciences (NCGS) is the establishment of National Geological Monuments, which aims to ensure the protection and preservation of the country's geological structures and features with high scientific, educational or aesthetic value as well as to promote awareness of geology among the public (Virtucio undated).
3. The Regional Executive Director (RED) is a DENR official. REDs are designated as Chairmen of the PAMBs under the NIPAS Act of 1992.

POVZETEK

Do sedaj varstvo krasa ni bila prednostna naloga filipinske vladne politike, čeprav se to pričenja spreminjati. Čeprav se v tej državi zakonodaja le malo neposredno ukvarja z varstvom in ohranjanjem kraških področij, jih je nekaj zaščitenih posredno, ker so vključena v področja, zaščitena iz drugih razlogov. Nekaj kraških področij je zaščitenih zaradi estetskih in turističnih vrednot, nekaj drugih pa je vključenih v parke in rezervate.

Na Filipinih je sicer malo kraških področij, ki so prepoznavna zaradi kraških značilnosti in pomena za kras, vendar jih je vedno več posredno zaščitenih zaradi vedno boljše okoljske zakonodaje. Še več, kaže, da filipinska vlada priznava pomen neposredne zaščite krasa. Sprejem Zakona o urejanju in zaščiti jam in jamskih virov ter podpis Konvencije Združenih narodov o boju proti napredovanju puščav (UNCCD) sta pomembna koraka filipinske vlade, ki bosta neposredno koristila kraškim področjem. Čeprav se ti pravni akti ukvarjajo le s posebnimi kraškimi oblikami, lahko vodijo v programe in dodatne akte, ki bodo neposredno zaščitili kras po vsej državi.

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THE STORY OF THE 1833 FERCHER SURVEY, POSTOJNSKA JAMA, CONTINUES: AN ADDITIONAL DOCUMENT AND NEWLY DISCOVERED INSCRIPTIONS

ZGODBA FERCHERJEVE IZMERE POSTOJNSKE JAME (1833) SE NADALJUJE: DODATNI DOKUMENTI IN NOVO ODKRITI NAPISI

by
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Abstract: UDC 551.442(497.4 Postojna)(091)
Stephan Kempe & Hans-Peter Hubrich & Klaus Suckstorff: The story of the 1833 Fercher survey, Postojnska jama, continues: An additional document and newly discovered inscriptions
Publications, archived documents and inscriptions help with the reconstruction of the history of Postojnska jama. Until recently, the circumstances of the first mayor cave survey ever undertaken were not well known. It is the so called Fercher Survey conducted in winter 1833; a cooperation between the Mine Office in Idrija and the Cave Administration that surveyed the entire cave known at the time. Documents from the Archive of the Karst Research Institute and an inscription in the Tartarus of Postojnska jama gave a first insight into this story (Kempe, 2005). The survey suggested that (in what is now Male jama) a connection could be blasted to shorten the visitor route. Now a further letter dated 5th September, was found shedding light on this mining attempt begun in summer 1833. In the letter the Cave Administration massively attacks the Mine Office. They claim that either the survey was not accurate or that the breakthrough was attempted at a wrong site. In consequence they demanded their expenses back, threatening with an investigation by the precinct administration. We also found three more inscriptions of the Fercher Party, in Pisani rov and in the Old Cave, one by Fercher and two by the miner Tracha.
Key words: history of cave survey, Fercher, Postojnska jama, Slovenia.

Izvleček: UDK 551.442(497.4 Postojna)(091)
Stephan Kempe & Hans-Peter Hubrich & Klaus Suckstorff: Zgodba Fercherjeve izmere Postojnske jame (1833) se nadaljuje: dodatni dokumenti in novo odkriti napisi
Objavljena dela, arhivirani dokumenti in napisi pomagajo rekonstruirati zgodovino Postojnske jame. Do nedavna so bile okoliščine prve velike jamske izmere še ne dovolj poznane. Gre za t.im. Fercherjevo izmero v zimi 1833: v sodelovanju med Rudniškim uradom v Idriji in Jamsko upravo je bila izmerjena celotna do tedaj znana jama. Na podlagi dokumentov iz arhiva Inštituta za raziskovanje krasa in napisa v Tartarju (Postojnska jama) je bil mogoč prvi vpogled v to zgodbo. Na podlagi izmere je bil svetovan (v današnjih Malih jamah) preboj s pomočjo miniranja, ki bi obiskovalcem skrajšal pot. Najdeno je bilo pismo datirano s 5. septembrom, ki meče novo luč na ta rudarski podvig v začetku poletja 1833. V tem pismu Jamska uprava hudo napada Rudarski urad. Zatrjujejo, da bodisi izmera ni bila pravilna ali pa je bil preboj napravljen na napačnem mestu. Zato zahtevajo nazaj plačilo stroškov ter grozijo s preiskavo preko ustrezne instance. Odkriti so bili še trije novi napisi Fercherjeve skupine, v Pisanem rovu in v Starih jamah, eden od samega Fercherja in dva od rudarja Trahe.
Ključne besede: zgodovina merjenja jam, Fercher, Postojnska jama, Slovenija.

INTRODUCTION

The reconstruction of the history of the discovery of Postojnska jama rests on the study of publications, archived documents and inscriptions in the cave (among others: Shaw, 1992; Shaw & Čuk, 2002; Kempe, 2003,

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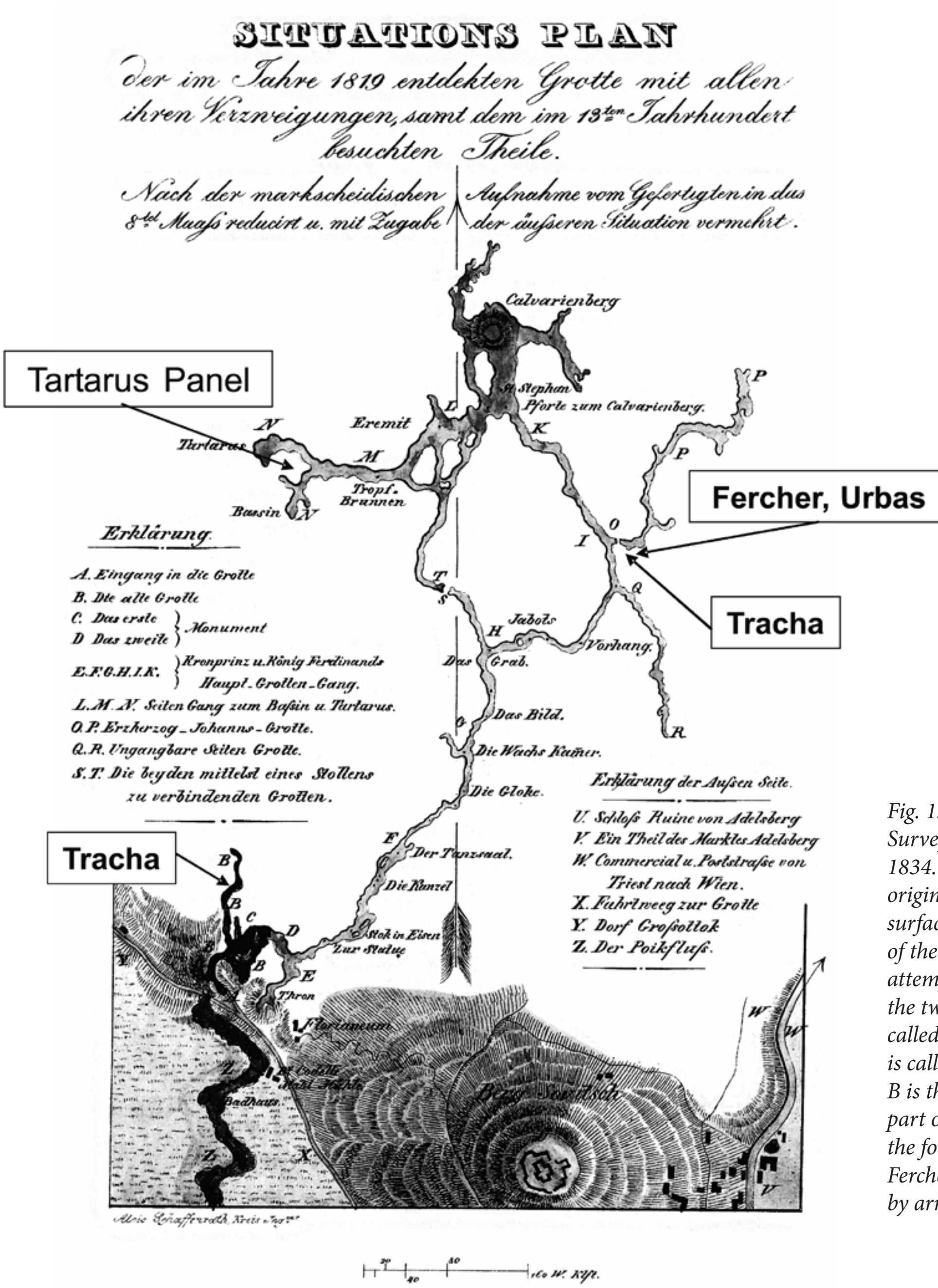

Fig. 1: Reduced map of the Fercher Survey, published by Schaffenrath, 1834. Schaffenrath reduced the original map to 1/8th and added the surface topography in the lower part of the map. The letters T-S mark the attempted breakthrough between the two passages which today are called Male jama. The passage O-P is called today Pisani rov. Passage B is the Name Passage in the old part of the cave. The locations of the four known inscriptions of the Fercher Survey team are indicated by arrows.

2005; Kempe *et al.*, 2004; Kempe & Henschel, 2004). Specifically the years immediately after the discovery of the main passage are not documented clearly in spite of the publications of Volpi (1821), Bronn (1826), Hohenwart (1830, 1832a,b), Schaffenrath (1834), and Schmidl (1854, 1858). Particularly the circumstances of the survey of the cave in 1833, the so-called Fercher Survey, remained unknown (Fig. 1). It was the largest highly professional survey conducted up to that point, with the Lee Survey of Mammoth Cave following a year later (Shaw, 1972). The publication of the Tartarus Panel, on which the members of the survey team left their names, gave opportunity to search for associated documents in the archive of the Karst Institute and of the Mines at Idrija. Four letters and notes have been found by the librarian of the Karst Institute, Maja Kranjc. These German language letters were written in Current handwriting, in use at the time for official documents. These letters have been transcribed and analyzed (Kempe, 2005). They show that the Grottenverwaltung (Grotto Commission) had asked the Bergamt (Mining Office) at Idrija for help with the survey. Accordingly the Bergamt had sent "Marktscheider" (surveyor) Michael Glantschnigg, "Huttmann" (mine supervisor) Johann Fercher, "Gehülfe" (helper) Aloys Urbas, "Fuhrmann" (coach man) Johann Leskovitz, "Bergmann" (miner) Johann Wruss and "Bergmann" Valentin Tracha to conduct the survey. Fercher, Urbas, Wruss and Tracha inscribed their names during the survey at the south-hand branch of the Tartarus on February 7th, 1833. Glanschigg and Leskovitz seem not to have been active in the cave. One of the results of the survey was that the two passages, today forming the Male jama, ended very closely to each other. The Grottenverwaltung therefore asked for help once more and the Bergamt sent Tracha on July 11th with a supply of 50 pounds of black powder in order to open up this blockage between the passages. This attempt, however, failed and the Grottenverwaltung apparently complained about the inaccuracy of the survey with the Bergamt. This upset Fercher and he immediately wrote a rather angry letter on September 8th to the Bergamt that transmitted it immediately to the Grottenverwaltung (document 986). Now the letter of the Grottenverwaltung, dated September 5th was relocated in the Archive of the Karst Institute (Appendix 1) by Trevor Shaw and is transcribed here for the first time. In addition we found three further inscriptions of members of the Fercher party in different parts of the cave.

THE LETTER OF THE GROTTENVERWALTUNG

The letter is labeled "GV 52", "GV" standing for "Grottenverwaltung", dated September 5th, 1833, and is addressed to the " löbliche k.k. Bergamt" at Idrija, i.e. to the "honorable Imperial-Royal Mining Office" at the mercury mine at Idrija. Throughout the letter, this address is repeated several times shortened to "löbl.". Never a specific person, such as Fercher or Bergrat Prettmann (who signed two of the previous letters from Idrija; Kempe, 2005), is addressed directly. This is a specific characteristic of what is called (derogatorily) "Amtsdeutsch", the impersonal style of German-speaking administrations. It signals the power of the speaker as an official of state towards a "subject". Similarly, the signature of the letter is abstracted; here we think it should be read as "Letz" or "Betz", but it may also be abbreviated and stand for "Lenertz", (compare signature below No 57 GV, Oct. 8th, 1833, in Kempe, 2005), reminding of signatures of medical doctors in today's society. There are other illegible words in the letter, some of which we were able to deduce from the context, others remain illegible; luckily these are not essential for understanding the content. The entire note consists of ca. 2900 letters (without blanks) but has only eight sentences! Long and complicated sentences are another feature of "Amtsdeutsch" and even more so of the written German at the beginning of the 19th century. Another peculiarity of the letter is the largely missing commas that make reading difficult. In order to make discussion of the text easier, we have inserted numbers in parentheses at the beginning of each of the eight sentences.

The entire letter is carefully crafted, starting with some compliments but ending with the demand to reimburse the Grottenverwaltung for the funds spent on the failed Male jama connection. One cannot avoid the impression that the Grottenverwaltung actually tries to blackmail the Mine Office!

Sentence (1) is the opening of the game: It states the fact that the Grottenverwaltung, trusting the Fercher survey, has "allowed" continued work at the potential connection. We learn that actually three persons are involved in this work, one mining official ("Bergbeamter") and two miners ("Bergarbeiter"). From Idrija office Note 747 we originally thought only one miner (Valentin Tracha) was commissioned to do this work (Kempe, 2005). We also learn that this work seems to have been going on continuously since early July. Twice the Idrija office is pacified by expressions like "gefällige Mitwirkung" and "Gefälligkeit" implying that the Grottenverwaltung is grateful for the help obtained in the matter.

Sentence (2) prepares for the attack: It states that the "Herr Kreishauptmann" (abbreviated) (Graf zu Brandis[4]) became suspicious ("Mißtrauen… eingeflößt") because the breakthrough hasn't yet been made even though the survey ("nach dem Plan") showed only a thin layer ("dünne Schicht") which needed removal. This mistrust was further nourished by remarks of Fercher that he made during his last visit when he commented on the state of progress ("Mittheilungen …. über den Stand der dießfälligen Arbeiten"). It is interesting to note that Fercher here carries the title of a "prov. Oberhutmann" in contrast to document Idrija 429 in which he is listed simply as "Hutmann" (Kempe, 2005; Appendix). Possibly Fercher had received a pay

[4] Alois Schaffenrath dedicated his guide to the cave in which he reproduced the Fercher Survey in 1834 to "Seiner Hoch- und Wohlgeboren Herrn Clemens Grafen zu Brandis, Freiherrn zu Leonburg, Forst und Fahlburg, k.k. wirklichem Kämmerer Seiner Majestät, Gubernialrath und Kreishauptmann zu Adelsberg"; accordingly Brandis was Kreishauptmann and Kommissionspräses in 1834 and most probably also in 1833."

raise and had advanced from mine supervisor to mine superintendent in the summer of 1833. The "prov." in front of the title may be interpreted as "provisional". This implies that Fercher had not yet fully attained his new status, and that he might, by the criticism in the letter, have felt that this raise in status could be endangered, causing him to be specifically upset.

Sentence (3) shows the ammunition available: The Kreishauptmann asked the county civil engineer (possibly A. Schaffenrath) to do a survey of the ongoing connection job. The engineer made a rough sketch ("Croquis") of the situation in the cave that originally accompanied the letter but apparently now is either lost or misplaced. That map showed that the breakthrough attempt was not started at the place suggested by the Fercher Survey. As a consequence the "Bergbeamter" leading the work was questioned or better "interrogated" ("einvernommen").

Passage (4) relates what the Bergbeamte said in his defense: He claims that he had been instructed by a Mr. "Bergschaffer" (if this is a title or a family name remains unclear) before he left, that he was to follow only his "hearing" ("sich nur an das Gehör zu halten"), because the map may not be trusted entirely. The hearing then led him to the spot where they have started the actual breakthrough attempt.

Now the attack commences packed into one very long and winding sentence (5): Even though the Kreishauptmann in his function as the chair of the cave board ("Grottenverwaltungskommission") thanks the Bergamt many times ("erkennt in vollem Maße die Gefälligkeit an") for sending the k k (kaiserlich – königlich) mine officials to survey the cave and to attempt the breakthrough, a public institution ("unter öffentlicher Aufsicht stehender Fond"), such as the cave foundation, cannot possibly pay for a survey which is not correct ("Plan … der nicht richtig ist") or for a connection which is guided simply by hearing, because sound may be misguided by the joints in the rock. In other words: the cave administration is boldly asking their money back for both the survey and the mining attempt! From Note Idrija 429 we know that the expenses for the survey amounted to 173 f. 32 Kr.[4] or ca. 1750 € in today's money and from Note Idrija 747 we learn that Tracha had obtained a minimum of 50 pounds of black powder at 16 f. 40 Kr. (Kempe, 2005). How much the miners were paid, in addition to the powder, is not known, but easily their costs could have doubled the amount charged for the survey.

The next sentence (6) is advancing one more argument, thereby making the claim inevitable: It explains that the cave administration is fully liable to the province board ("Bezirkspräsidium") and that they must submit invoices to them according to the bylaws. It would therefore not be possible to justify expenses with such negative results and the province board would most probably make those persons accountable ("zur Verantwortung ziehen") who carry the responsibility for the failure. This circumstance the mine administration would certainly understand… ("Es dürfte der Einsicht des löblichen Bergamtes nicht entgehen").

After maneuvering the Idrija administration into such a tight corner a helping hand is offered in sentence (7): In order to prevent the investigation by the higher administration it is suggested to the Bergamt that they make those persons accountable (without the pressure of the superior administration) who carry the responsibility for either the inaccuracy of the map or the failure of the breakthrough. They should also calculate the cost of the connection passage, which so far has not reached more than one "Klafter" (ca. 2 m) in depth even though the miners have been working in two daily shifts.

In the final sentence (8) the cave administration sets a time line for the response: The result of the demanded official act ("gefälligst einzuleitenden Amtshandlung") are to be related as soon as possible ("in möglichst kürzester Zeitfrist") in order to issue orders that minimize ("mindest lastspielige Weise") the costs for the cave fund.

All in all, and in spite of the many polite and flowery phrases, this is a rock-hard letter, very hostile and not at all timid towards the Idrija administration. One has to wonder about it because it must surely pollute any further cooperation between the two administrations. After all, the Idrija mine did not ask for the full expenses of the survey earlier in the year but only for travel expenses ("Reisespesen") of the participants (Kempe, 2005). Even if there would be small inaccuracies in the survey, the Fercher map is far superior to the previous Foyker map (about which little is known; Hohenwart, 1830) that covered the main passage only. Even thinking about demanding this money back is rather unscrupulous. It must have been clear that this letter also ended any further attempt of the Idrija mine staff to open the connection.

Apparently the mine administration passed the letter of the Grottenverwaltung directly to Fercher. His angry and upset response of September 8th to the Bergamt that transmitted it in turn to the Grottenverwaltung is preserved (Kempe, 2005, Appendix). In it Fercher avoids any answer with regard to the financial demands (which probably was the best strategy), rather he points out that the survey was not meant to be of the highest precision and that it was not made to accurately predict the distance between the two passages (simply because it was not known before that they would end so near to

[4] 1 f. = 1 Gulden = 60 Kreuzer, Kr.

each other). He also points out that the breakthrough might be somewhat longer than expected from the map, but that it will be completed sooner or later. In order to settle the dispute he suggested to the mine administration that the passages in question should be resurveyed. This would yield the exact distance to be drilled though. Furthermore he estimated that the break-through could be done at a cost of 50 Gulden per Klafter by two miners without supervision. This sounded like a very logical plan that, however, was not pursued since the work on the connection apparently was abandoned for several years. In expectation of the visit of Emperor Franz Josef and Empress Elisabeth, March 11th 1857 the breakthrough was finally completed in 1856 and is about 12 m long (Hitzinger, 1866).

It is a pity that we do not know how this dispute between the two administrations was finally settled, but one can guess that the mine administration did not refund any of the expenses.

NEWLY DISCOVERED INSCRIPTIONS OF THE FERCHER SURVEY

Apart from the additional letter, we found further evidence of the work of the survey team in Postojnska jama itself. These are three inscriptions, which, together with the Tartarus Panel (Kempe, 2005) form an interesting historic monument. All are written in pencil and relatively small.

The first inscription, written in Latin letters, was found by us on July 19th, 2005, a few meters beyond the formerly gated entrance to Pisani rov (Colourful Passage) on the right-hand side (south-wall), about 1.8 m above the floor. It was written by Johann Fercher himself (Fig. 2) in three lines and reads: "Aufgenohmen in Monat Jäner 1833 Johann Fercher Aloys Urbas", followed by a small flourish. In modern German it should be spelled "aufgenommen im Monat Jänner 1833", with "Jänner" being the Austrian equivalent of the High-German "Januar". Translated, the inscription reads: "surveyed in the month of January, 1833". On the Tartarus Panel (Kempe, 2005) Fercher used the same term "aufnehmen" for "to survey". There the inscription is dated to February 7th, 1833, showing that the Pisani rov was surveyed earlier and that the survey party apparently worked their way inward, including all the side passages. It is interesting that only two of the survey team left their names here, implying that they may have split up in groups to proceed more rapidly.

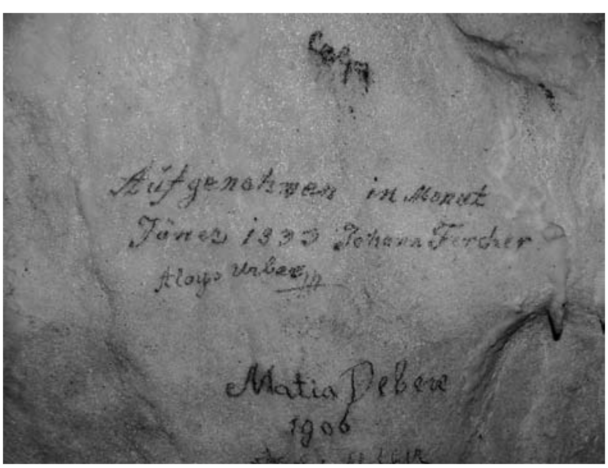

Fig. 2: Pencil inscription of Fercher and Urbas on the south wall at the beginning of Pisani rov, ca. 10 m from the former gate. (Photo: Kempe).

The second inscription is found a few meters inside the Pisani rov entrance on the same wall (Fig. 3). It is written in Current and reads: "Traha Valentin Zimmermann und Hauer in Idria (?), Zinnober(sublimierer)" with the last part of the word being almost illegible due to dirt from a hand imprint of a careless visitor. It is interesting that Tracha spells his name "Traha" here but in the inscription of Figure 4 he writes "Troha", while in the documents he is clearly spelled as "Tracha". "Troha" would be the correct spelling in Slovenian while the same name in German would be spelled "Tracha" (pers. com.

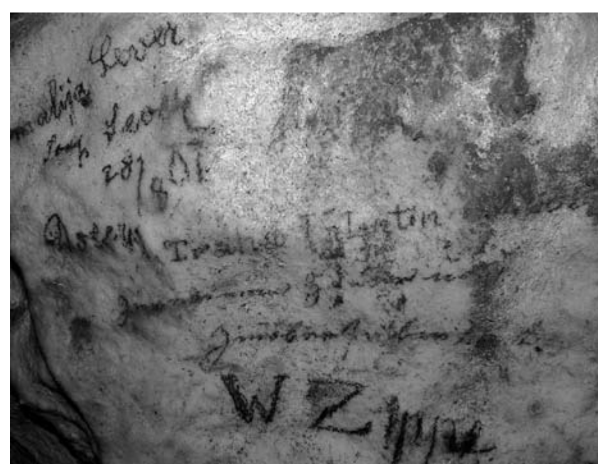

Fig. 3: Pencil inscription of Tracha on the south wall at the beginning of Pisani rov, ca. 5 m from the former gate. Part of the inscription has been obliterated by a hand imprint by a careless visitor. (Photo: Kempe).

A. Kranjc). The translation of the inscription is: "Valentin Tracha, carpenter and miner from Idrija, cinnabar sublimer". It is a pity that the inscription does not carry a date, but Tracha may have visited this part of the cave after the survey, intending to see it as well, possibly not having been part of the survey party. It is further interesting that he lists himself with his professions; apparently Tracha was a carpenter by trade and not a miner in the first place. Cinnabar is the main mercury mineral – mercury sulphide (HgS) – that was mined at Idrija. Apparently Tracha carried an additional mining title, being responsible for the sublimation process of the cinnabar or its quality supervision."

The third inscription is also by Tracha (Fig. 4), but it is situated in the Old Adelsberger Grotte, the Imenski rov. In the attempt (work still in progress) to document all of the epigraphs in the historic section of the cave on July 21st, 2005, we divided the walls of the passage into panels, counting them from the entrance (Panel 1) to the end. Among the many inscriptions of Panel 9 such as those of Schaffenrath 1829 and Löwengreif 1817, about 150 m from the passage entrance, Trocha's inscription written in Current is found, inscribed in a nice one-line frame, similar to the frame drawn around the Fercher party inscription on the Tartarus Panel. The text has three lines and reads: „Valentin Traha Zimmermann und Hauer zu Idria bei der Vermessung der Grotte teilgenommen". The last line was deciphered with some difficulty but is in itself logical. Here Tracha repeated once more his profession, but he does not do us the favour repeating the cinnabar-word, instead he states "participated in the survey of the cave". Interestingly he uses the word "Vermessung" instead of "Aufnahme" as Fercher did. We carefully inspected the walls of the entrance to the Nemški rov, hoping to find a Fercher signature as well, but failed to do so. Possibly this passage was among the first to be surveyed and Fercher did not have the idea as yet to leave a signature.

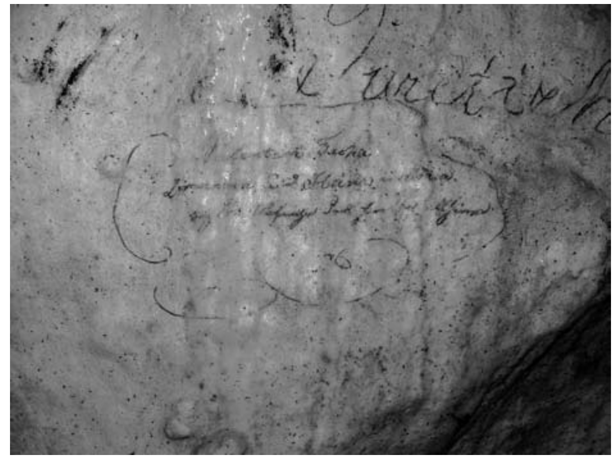

Fig. 4: Pencil inscription of Tracha on Panel 9 in the Old Cave (Imenski rov). (Photo: Kempe).

CONCLUSIONS

The newly deciphered letter from the Grottenverwaltung to the Idrija administration fills an important gap regarding the circumstances of the Fercher Survey and the failed attempt to break through the blockage of the Mala jama in 1833. In a sense it is very modern, since it is an attempt to claim something like a warranty, asking back money that – as is claimed – was spent on a bad product! The letter also throws light on the structure of the administration at the time and how official supervision was used as a powerful threat against an opponent. It is a pity that the story remains somewhat open-ended, but hope exists, that one or the other document will still turn up, illuminating the circumstances of the Fercher Survey further. It would be particularly interesting to find the two sketches which originally accompanied two of the notes.

The finding of three more inscriptions of the Fercher Party also gives hope that eventually even more epigraphs may be located, possibly one at every side-passage entrance. Since the pencil signatures are not very conspicuous, they may have been overlooked so far. The four inscriptions discovered as yet, are the most verbal of all of the inscriptions, carrying real information with regard to the history of the cave, not just stating that Mr. or Mrs. So-and-so have been there.

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Schmidl, A., 1858: Wegweiser in die Adelsberger Grotte und die benachbarten Höhlen des Karstes. – 2. Aufl., C. Gerold's Sohn, Wien, 93 pp, 3 Lithographs.

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APPENDIX

The following text has been transcribed from German Current handwriting. Numbering of the sentences and completions of words are inserted in parentheses. The German is very old-fashioned, enriched with expressions from mining language. It is not possible to translate the text in a way reproducing the style of the letter. Moreover it has orthographic (compared to today's German) and grammatical mistakes; commas are largely missing. For an explanation of the contents and meaning please refer to the text of the paper.

GV 52, den 5.9.1833

An das löbliche k.k. Bergamt zu Idria

(1) Im Vertrauen auf die Richtigkeit des durch gefällige Mitwirkung des löbl.(lichen Bergamtes) aufgenommenen Planes der hiesigen Grotte und auf die Zweckmäßigkeit der Einleitungen des durch die Gefälligkeit des löbl.(ichen Bergamtes) hierher abgesandten Bergbeamten mit 2 Bergarbeitern zur Ausführung des von der Grottenverwaltung beabsichteten Durchschlags hat man die Arbeiten bisher ihren Gang fortgehen lassen. (2) Die Länge ihrer Dauer im Vergleiche mit der dünnen Schicht die nach dem Plan zu durchschlagen war hat dem Herrn Kreishptm (Kreishauptmann) einiges Mißtrauen in diese Arbeit eingeflößt, welche durch die Mittheilungen des Herrn prov.(isorisch) Oberhutmanns Joh. Fercher bei seiner letzten Anwesenheit hier über den Stand der dießfälligen Arbeiten sehr vermehrt wurde. (3) Der zust(ändige) Kshptm (Kreishauptmann) fand sich nun veranlasst den hiesigen Kreisingenieur zu beauftragen über den Stand der Arbeit einen Plan aufzunehmen, und da dieser, wie aus beil.(iegendem) Croquis ersehen werden wolle, entnehmen läßt, daß die Arbeit ganz auf einer anderen Seite begonnen wurde als wo die bereits zu verbindenden Grotten zusammen treffen, so wurde der leitende Beamte über die Ursache davon einvernommen. (4) Er gab als Grund dafür an, daß er von Herrn Bergschaffer (?) vor seiner Abreise die Weisung erhalten habe, sich nur an das Gehör zu halten, indem der Plan nicht ganz verläßlich sey, ... da das Gehör ihn zu der Stelle, wo er anfing, geleitet habe, so habe er seine Arbeit dort begonnen. (5) Der zust(ändige) Kshptm (Kreishauptmann) als Vorstand der Grottenverwaltungskom (mission) erkennt in vollem Maße die Gefälligkeit des löbl.(ichen Bergamtes) in Absendung zweier k k Bergbeamten bei Aufnahme der Grotte das Vorangehen des Durchschlags, kann aber dabei nicht umhin lebhaft zu bedauern und dem löbl.(ichen Bergamte) sein Befremden auszudrücken, daß ein unter öffentlicher Aufsicht stehender Fond, wie es der Grottenfond ist, so bedeutend in Anspruch genommen werde sollte, um einen Plan zu liefern der nicht richtig ist, und zweitens auf das Gerathewohl hin nach dem bei Klüften so leicht zu täuschenden Gehör einen Durchschlag vorzunehmen. (6) Es dürfte der Einsicht des löbl. (Bergamtes) nicht entgehen, daß die Grottenverwaltung nicht im Stande seyn würde diese für ihren Fond nahmhafte Auslage bei solchem Resultate zu rechtfertigen, um das (?) B(ezirks?)präsidium, wenn ihm die Rechnungen, wie die Statuten der Verwaltungskom(mission) es vorschreiben, vorgelegt werden, wahrscheinlich welche Schuld daran tragen, zur Verantwortung ziehen werde. (7) Um dieser Compromittierung vor höheren Behörden vorzubeugen, wolle es dem löbl.(Bergamt) gefällig seyn, die Herren Bergbeamten denen entweder die Unrichtigkeit des Planes oder der Ausführung des Durchschlags zur Last fällt, schon dermahl[5], wo es noch ohne Einfluß der oberen Behörden geschehen kann darüber zur Verantwortung zu ziehen, und dabei auch gefälligst die Quantität der bisherigen Leistung bei dem Durchschlage, die kaum eine Vertiefung von einer Klafter beträgt, mit den Kosten dafür, die täglig doppelte Tagschichte für jeden Arbeiter betragen, in Verhältnis zu stellen. (8) Es wird sich erbethen das Resultat der gefälligst einzuleitenden Amtshandlung in möglichst kürzester Zeitfrist eher mitzutheilen um so schnell als möglich Verfügungen zu erlassen um auf eine für den Grottenfond mindest lastspielige Weise das beabsichtigte Ziel zu erreichen.

Signature: Letz or Betz or Letzner (compare Kempe, 2005)

Adel(sberg) den 5.9. (1)833

[5] dermahl = dermal: Austrian for „jetzt"

COBISS: 1.01

KARST RESEARCH IN THE 19TH CENTURY - KARL DEŽMAN'S (1821-1889) WORK

O RAZISKAVAH KRASA V 19. STOLETJU - PRISPEVEK KARLA DEŽMANA (1821-1889)

Stanislav JUŽNIČ[1]

Abstract UDC 551.44(091):929 Dežman K

Stanislav Južnič: Karst research in the 19th century - Karel Dežman's (1821-1889) work

Karel Dežman's research of the karst phenomena was examined. Among his works the cave research, description of Proteus, other cave animals and plants were found. A special concern was put on Dežman's sources dealing with Proteus research. As the custodian of the Land Museum of Ljubljana, Dežman promoted the Ljubljanian natural history research of his time. His scientific works are not very well known because he did not follow the political line of the official Slovenian national representatives.

Key words: Karel Dežman, karst, caves, Proteus, Carniolan Land Museum.

Izvleček UDK 551.44(091):929 Dežman K

Stanislav Južnič: O raziskavah krasa v 19. stoletju - prispevek Karla Dežmana (1821-1889)

Dežmanova raziskovanja krasa so pomembno poglavje zgodovine kranjskega naravoslovja. Med njimi so opisi jam, človeške ribice, druge kraške favne in flore. Posebna pozornost je posvečena Dežmanu in znanim opisom proteusa. Kustos Deželnega muzeja Karel Dežman je bil gonilna sila večine ljubljanskih naravoslovnih raziskav svojega časa. Slabo poznavanje njegovega dela je predvsem posledica njegovega političnega delovanja, ki ga je kmalu odtujilo poklicnim zastopnikom slovenskih narodnostnih prizadevanj.

Ključne besede: Karel Dežman, kras, jame, proteus, Kranjski Deželni muzej.

INTRODUCTION

Although Dežman was the most prominent natural history researcher in Ljubljana of his time, his work is now almost forgotten. Slovenes don't remember him because they consider his political positions at least unfriendly. Germans don't write about Dežman because he was obliviously not one of them. But politics should not effect decisively the greatness of Dežman archeological, botanical, or karst research, which we present in this treatise.

Dežman began his popular lecturing in Ljubljana immediately after he left a high school teaching post and became the custodian of Ljubljanian Land Museum in 1852. He delivered some popular lectures together with the Carinthian German Filip Paushitz (* May 26, 1824 Nötsch), professor of physics at Ljubljanian high school (Schmidt, 1966, 140-141).

Fig. 1: Karel Dežman.

In his very first published Acts of the Museum Society in 1856 the Museum curator, Karl Dežman (Deschmann, * January 3, 1821 Idrija; † 1889), shortly reviewed natural historical research in Carniola. More or less, it was a kind of biography of six distinguished Carniolan naturalists: Scopoli, Hacquet, Wulfen, Karl Zois, Žiga Zois, and Hladnik (Dežman, 1856, 9; Schmidt, 1963, 148).

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DEŽMAN ABOUT CAVES

On June 11, 1856 Dežman reported to Museum Society about his research of the cave Skednenca. He described other interesting natural historical samples found between Krim and castle of Mokrice under the Gorjanci hills. The entrance into Skednenca was a difficult one. The broken stones covered the main hall which had two holes, one of them used as the door. In the front face of the cave there was the lower much narrower port facing the south east side with many stalactites. The smaller entrance had star-like cupola place which ends into lower hollow slit of stone wall facing the open space. The cave was dry with some minor water from stalactite dropping into the basins. Dežman did not really like the scorpions, jags and mosquitoes at the cave. Three to four walking hours from the cave Skednenca (today in township of Ig catalogued as No. 353) you could reach Počivavnik near the mountain Osredek (1300 m) in Kamniške Alps. Dežman used to visit the farmer house "Pri Benkotu" on the foot of the Krim Hill. Around Mokrice (Mokrc) many places borrowed their names from the Turkish war times, among them "Krvave Peči" with several interesting botanical species (Dežman, 1862, 95-97).

Dežman frequently visited Kočevje, also as the elected political representative of the area. On April 14, 1858 Dežman showed to the Museum Society the red alumina stone which he recently picked up in Wicherle cave of Kočevje area. He claimed that no stone like that was ever found in any other Carniolan cave. The Vienna student Franc Erjavec (* 1834; † 1887), who later became pretty famous as a Slovene fiction writer, made a chemical analysis of the Dežman's stone. He found 8.05% of water, 10.74% of iron mine, 18.49% of alumina, 59.03% of flintstone, 2.83% of sand, and 0.83% of other ingredients, also with some traces of lime and magnesia. Museum Society members examined the possible technical and industrial use of Dežman's stone for the fabrication of bricks; therefore they also checked the homogeneity, granulation, and melting-point of the sample. They looked forwards for the more accurate final results, and everybody was curious about the possibility of making available lower price alumina with lower transport costs.

Dežman reported to the Museum Society about geology and flora of Kočevje area. He paid special attention to the formation of karst in Kočevje valleys under the castle Fridrichstein, at the area of Seele (Željne), Grafenfeld (Dolga vas) and Mosel (Mozelj) with many karst funnels called "Dolina" (valley) by domestic people. All area from Mozelj to the hill of Verdreng is covered with hundreds of dolinas. From the elevated points around Poljane (Pölland) you could see the landscape covered with so many holes as the sieve. Dežman compared the area of holes having regular conic shapes with similar sieves at the middle of Cerknica Lake, like Vodonos or Rešeto. Inner walls of those funnels are very flat, covered with the dense grass. Many karst plants grow there, among them the characteristic *Satureja pygmmaea Sieb.* around Mozelj. The system of holes dilled with water is situated under the surface. As Valvasor before him, Dežman was also interested in the wild romantic of Bilpa spring, Veliko and Malo Okno with many creeks between Bilpa and the castle of Kostel above the Kolpa River.

Dežman paid special interest to the Ledena jama (Eis Grotte, Ice Cave) in Kočevski Rog and other caves near Ober-Skrill (Zgorni Škrilj, Zdihovo). Ice caves are the real snow cellars. "After one and a half hour of walking from Kuntscher (Kunčar) Cave you can reach a snow hole in Kočevski Rog. It is the great cave overhang with rectangle stone walls approximately 200 m deep. On the bottom, you could find the ice even during the hottest summers". The charcoal-burners from Kočevski Rog use it as their water supply. Ledena jama in Kočevsko is situated pretty low above the sea level compared with others of its kind. The Kočevje area have the characteristics of Alp regions at the extraordinary low height.

At noon on September 23, 1858 Dežman measured the temperature +1.25°C (1°R) in the cave, while at the shadow around snow hole the thermometer raised even to +21.25°C (17°R). The cave ice was 20 m deep with more than 8 m of circumference. It had the structure similar to the ice in Kuntscher (Kunčer) Cave with more or less regular prismatic crystals of ice. The stone walls were covered with coral-like porcupines *Hydnum coralloides Scop.* and other alpine plant *Cystopteris montana L.,* otherwise found only at the heights 1000 m to 1800 m above the sea level.

During the high summer of 1857 the visitors were able to find at Kočevski Rog the representation of all four year seasons: winter ice, flowering spring *Ompholodes verna Mch.* in woods, the summer vapors, and the ripe autumn fruits (Dežman, 1862, 225-228). Later on May 6, 1883 Dežman wrote a long German letter on blue paper about Ledena Jama in Kočevje region.

Most of Dežman's writings about caves remained unpublished and are nowadays kept at the ARS (*Privatae a* archive of Karl Dežman, signature AS854, fascicle 13 "Speleology"). Among others, we could find there drawings of the cave Vihled (Wicherle) near Kolpa. Dežman visited the cave on September 9, 1850. His young friend, the medicine student Franc Serafin Plemel (* September 30, 1828 Bled; † June 21, 1852 Vienna), draw the picture of the cave for Dežman. Vihled is a cave above the village Bilpa (Wilpen) on the very border between domains of

Kostel and Polland, which were abolished as a remains of the feudal system just before Dežman's visit.

During their tour Dežman and Franc Plemel also visited the Selska (Seler) Cave near Verdreng in the former domain of Kočevje. Plemel did the drawing again on September 23, 1850. He finished the map which he began already two years ago on September 21, 1848, just after the Vienna July revolution that also had some echo at Kočevje. With Dežman's help Plemel expressed an excellent knowledge and skill. Plemel was a son of a farmer Matija. The family was very talented and later gave the very best Slovenian mathematician Josip Plemelj (* December 11, 1873 Grad on Bled; † May 22, 1967 Ljubljana).

Franc Plemel attended a local normal school between 1836-1840, a Ljubljanese high school (1840-1846) and the higher studies of philosophy (1846-1848). He learned physics from Janez Krstnik Kersnik. He attended the Dr. Anton Schubert's († april 21, 1851) lectures on natural philosophy four hours per week. Schubert used the Knor's zoology textbook, and botany and mineralogy textbook of Friederich Mohs (* 1773; † 1839) from Graz just before Dežman returned to Ljubljana in 1849 after his studies of medicine and a formal degree in law of Vienna University issued in 1849. When Dežman replaced gravely ill Schubert as a supplier on March 16, 1851 Franc Plemel was already studying medicine in Prague and Vienna. Plemel eventually died in Vienna during the fourth year of his studies. Unusually, he did not use Knafelj scholarship for his studies. He made several successful botanical tours and discovered many new plants.

His older brother, biologist Valentin Plemel (* January 7, 1820 Bled; † June 9, 1875 Koroška Bela), was ordained as the priest in Ljubljana on July 27, 1843. Valentin used Franc' innovations and presented a very good herbarium on Vienna World Exhibition in 1873. Dežman published some of Valentin's works in Acts of the Ljubljanian Museum Society. Alfonz Paulin (* September 4, 1853 Turniški Castle near Krško; † 1942) later used and further developed the Plemel brothers work.

Dežman visited many other caves in the region, but he left no other pictures of them. Besides Ledena Jama Dežman also wrote a letter about Vrlovka Cave at Kamanje near Ozalj at the road for Karlovac in Croatia on August 19, 1866. Vrlovka was well known hiding cave during Turkish wars and it was opened for tourists in 1928. Dežman also mentioned Vražna cave and finally wrote an undated letter about Postojnska cave on bright blue paper.

He published several Hochstetter's drawings of the Karst locations of their joint archaeology excavations (Dežman, Hochstetter, 1880) without specially pointing to any Karst peculiarities. Dežman's collaborator, the Viennese Professor on Polytechnic Ferdinand Knigt von Hochstetter (* April 30, 1829 Esslingen; † July 18, 1888 Vienna), published the research of Križna (Kreuzberg) Jama north of Lož at the next volume of *Memorials of Vienna Academy.* Hochstetter, Dežman, and their friends researched the cave in 1878 and 1879. The northern hall of the cave was called Dežman's hall until the end of Habsburg monarchy, as Dežman was the very first to put his foot in it. The southernmost part was named Hochstetter's Treasury. A skeleton was found 2 km deep in Mogrizer Höhle (Mokriška Jama) and it was carried to the Dežman's Museum of Ljubljana. They made a list of the animal skeleton parts found in Križna Jama. Hochstetter's assistant between 1878 and 1882, later Professor Josef Szombathy (* June 11, 1853 Vienna; † November 9, 1943 Vienna), drew the coloured map of the Križna Cave in August 1879. He used the proportion 1:1000 and he added several enlarged details of the cave to the next table. Next he draw the map of Mrzla Jama (Merzla, Kalte Grotte, Cold Cave), one of several with that name in Carniola. Fran and Matija Erjavec also participated in the research (Hochstetter, 1881, 294, 295, 302, 310, table II, table III).

Many friends helped Dežman in his cave research. Dežman's documents about caves are kept together with his writings about geography, descriptions of his Triglav climbing, the measurements of the heights in Carniola, hydrology, astronomy with letters and papers from Laibacher Zeitung, cosmology (with the description of the constellation of Serpents, the book of minister's advisor Marian Koile about the Passage Instrument published in Brno in 1863, the measurements of the telegraph officers in Postojna and Ljubljana, and also in Idrija by a priest Aischolze, Dežman's own description of the travelling Passage Instrument with two beautiful technical drafts at the end), mineralogy, the manuscript copies of the third part of Hacquet's *Oryctographia Carniolica oder physikalische Bescheibung des Herzogthums Krain, Istrien und zum Theil der benachbarten Länder* (1784), geological excursion, seismology, speleology, the agriculture lectures of Ljubljanian professor Hlubek, mineralogy, chemistry, and at the end even some mathematical calculations with triangles and square roots.

Dežman's inventory of the Dol Archive and documents about his purchase of it for Rudolphinum are kept together with his manuscript autobiography, a letter to his friend J. Braun of Kočevje, and Dežman's documents connected with the Central office for Meteorological and Magnetic measurements at Vienna. For several decades he and his sister Serafina measured the Ljubljanian weather conditions for the Vienna Central office (ARS, *Privatae a* archive of Karl Dežman, signature AS854, fascicle 1).

DEŽMAN ABOUT PROTEUS AND OTHER CAVE ANIMALS

The *Proteus anguinus* was one of the main topics on the regular monthly meetings of the Carniolian Museum Society. Dežman published some of his research of the cave plants and animals in his reports on the monthly meetings of the Museum Society. Most of Dežman's field research took place in Kočevsko, where he also used to win the pools. He became the honor citizen of Kočevje, as he was named earlier in his native Idrija (1861) and Tržič. He found several black *Proteus* in Kočevsko caves. Most of Dežman's writings about zoology, karst and *Proteus* remained unpublished and are nowadays kept in ARS (*Privatae a* archive of Karl Dežman, signature. AS854, fascicles 12 and 13).

On January 14, 1857 Dežman reported to the Museum Society about the so-called hollow rubble from the fossil hills discovered by the Professor Franc Unger (* November 30, 1800 castle Amthof near Lučane (Leutschach) in Styria; † February 13, 1870 Graz). Unger classified it into the family of algae. Dežman also showed to the audience the example of Laurenti's book, *Synopsis reptilium,* where the very first description of the Carniolan *Proteus* was published.

In his famous book, an Austrian Joseph Nicolas Laurenti (* December 4, 1735; † February 17, 1805), defined thirty kinds of reptiles and discussed their poisonous functions. Dežman certainly did not purchase the first edition. He used fifty years later reprint, may be from the Erberg's Dol collection which he later bought for *Rudolphinum.*

Dežman also pointed to the Society publics the examples of ice diver *Colymbus glacialis* and arctic diver *Colymbus arcticus.* Both were caught in December 1857 in Cerknica Lake (Dežman, 1862, 105).

On February 19, 1858 Dežman reported about *Gordius aquaticus L.* which was found in drinking water in Trebnje. It was several centimeters long and the craftsman Klebel recently brought the sample right to Dežman's Museum. Dežman also showed the samples of black coal which the student Alfons Müllner found in Alps (Dežman, 1862, 220-221). The able young Müllner later eventually replaced Dežman as the Museum curator, but he never became his equal in karstology.

PRINTINGS ABOUT PROTEUS

Dežman's writings about zoology and botany are kept in separate fascicle in ARS and are of special interest for Slovene karstology. Among the last manuscripts there is a very interesting bundle about *Proteus*. Dežman's wrote sixteen pages of the A4 format letter about *Proteus*. It began with the list of the few tens of recent books and articles about Proteus which Dežman came across while reading secondary sources. Among the books in *Rudolphinum* Dežman kept Laurenti's 1818 book that Dežman showed to the Museum Society in Ljubljana, but he did not list it in his manuscript dealing just with recent literature. In the last botanical book of the fascicle the photography on glass is kept wrapped into a black paper following the habit of their time. The Photography is well preserved with just a little damage at one corner. There is no comment about the date of photographing, its contents or use. We can still recognise four bean-like pictures in natural dimensions, two as negatives and other two as positives. That was probably one of the earliest photographs made for the natural history scientific purposes in the area of today's Slovenia.

Dežman listed following books and articles about *Proteus*, with some biographical and bibliographical data added for this research:

Blainville, H.M.D. de, 1819: *Dictionaire des sciences naturelles.* 1-14. Levrault, Strassbourg. Reprint: 1820: Isis. 570 (T*ourn. de Phys.* according to Dežman, sine dato, *2r*).

Dele **Chiaje,** Stefano (* 1794; † 1860), 1840: *Ricerche anatomico biologiche sul Proteo serpentis.* Napoli.

C**onfigliachi,** Pietro (* 1779; † 1844), **Rusconi**, Mauro (* 1776; † 1849), 1818: *Del proteo anguino di Laurenti.* Pavia: Fusi (6 pictures, 119 pages, price 24 fr.). Reprint: 1819: Fusi, Pavia.

Configliachi, P., **Rusconi**, M., 1820: *Isis*. 570-590.

Configliachi, P., *Rusconi*, M., 1821: Observatons on the Natural History and Structure of the Proteus Anguinus (3 pictures). *Edinburgh Phil.Journal*. **4**: 398-406; **5**: 84-112. A. Constable, Edinburg.

Configliachi, P., **Rusconi**, M., 1828: *Sopra un Protes femines.* Pavia.

Dalton, John Call, 1853: Some Account of the Proteus Anguinus in Sillimans Amer. Journ. (2) **15**: 387-393. Reprint: 1853: *Edinburgh new Phil. Journal.* **55**: 332-340.

Van **Deen**, Isaac (Izaäk, * 1804; † 1869), 1834: Over de rijdelingsche takken van de zweraende zenum (Neron vagus) van den Proteus anguineus (1 picture). *Tijdiche voor natuurl. Geschied.* **1**: 112-129.

Fitzinger, Leopold Joseph (* 1802; † 1884), 1850: Ueber de Proteus anguinus. *Wien. Ber. Mat. Nat.* **5**/3: 291-303. – Separate: 1850: Carl Gerolds Sohn, Wien.

Freyer, Heinrik (* 7. 7. 1802 Idrija; † 21. 8. 1866 Ljubljana), 1842: Ueber einen neue art von Hyposhthon (Proteus). *(Wregman, W.F. Erichson) Archiv für Naturgeschichte.* **1**: 289-290.

Hyrtl, Joseph (* 1811; † 1894), 1850: Bemerkungen über de Proteus anguinus. *Wien.Ber. Mat.Nat.* **5**/3: 303.

Mandl, Louis (* 1812; † 1881), 1839: Dimensions des globules sanguines du sang chez le Proteus. *Compt. Rend.Acad.Sc. (Paris).* **9**: 739.

Mandl, L., 1839: Dimensions des globules sanguines du sang chez le Proteus. *L'Institut.* **7**/310: 427.

Mandl, L., 1839: Note sur les globules sanguines du Protée et des Crocodiliens (mit Abbildungen). *Anal. Scienc.natur.Ver.Zool.* **12**: 289-291.

Michacheles, C., 1829: Proteus Anguinus Aristoteli prorsus igntus suit. *Isis*. 1270-1273.

Michacheles, C., 1831: Beiträge zür Naturgeschichte des Proteus. *Isis*. 499-509.

Oken, Lorenz (* 1779; † August 11, 1851 Zürich), 1817: Ueber de Oben (Proteus Anguinus). With Pictures. *Isis*. 641-645.

Rudolphi, Karl Asmund (* 1771; † 1832), 1819: Ueber de Proteus Anguinus. *Isis*. 1017-1019. – Translation: 1819. *Phil. Magaz.* **53**: 181-182.

Rusconi, M., 1817: *Descrizione anatomiza degli organi della circulazione delle larve delle salamandre aquatiche.* Frisi, Pavia (with 4 tables).

Rusconi, M., 1827: Descrizione di un Proteus femina notabile per lo svilupo delle parti della generazione. With Pictures. *Isis*. 94-100. Translation: 1826: *Froriep's Notizien und der Natur und her Kunde.* **16**/332: 17-20.

Rusconi, M., 1843: Nuove observazioni sopra il Proteus Anguino di Laurenti. Lettera al Alessandrini. *Nuovo Anal. Delle Scienze nat. Bologna.* **9**: 177-179. – Reprint: 1744: *Giornale del Instituto Lombardo e Bibl. Italiana.* **6**: 288-290. – Abstract: 1844: *Isis*. 502-503.

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Many Dežman's references were published in Oken's *Isis, oder encyclopädische Zeitung von Oken.* Oken, himself an active researcher of *Proteus*, was born as Lorenz Ockenfuss and studied at the University of Würzburg and Göttingen. He began to publish *Isis* Journal in 1816. He printed it monthly until 1818 and later continued with two volumes per year. The publication ended with Volume 41 during the "time of troubles" of the revolutionary Spring of Nations in 1848.

Oken got the title of adviser after publishing the natural philosophy textbook in 1810. In 1828 he became the private docent in Munich, Professor in 1832, and finally the Professor of natural philosophy at the new University of Zürich in 1833. In 1821 he purposed the organisation of the later famous Meetings of the German Natural

Historians and Physicians, that began with the very first Leipzig gathering in 1822.

Rusconi was the dentist in Pavia (Dežman, sine dato, 4r) and he performed detailed anatomical research of Proteus probably under the influence of Janez Anton Scopoli. Scopoli taught at the University of Pavia between 1777 and his death in 1788 when Rusconi was still a teenager.

Schmidl's research of caves all over the monarchy and especially at Planinska Jama (Planina-Höhle) earned him a funny nickname "Höhlen Schmidl". Fitzinger, Hyrtl, and Schmidl participated at the debate about *Proteus* in Vienna Academy held on October 3 and October 31, 1850, and published in *Wien.Ber.* (**5**/3: 228-231, 291-303) later in the same year. Several other important scientist also took part in 1850 academic Vienna polemics about *Proteus*. Wilhelm Karl Knight Haidinger (* February 5, 1795 Vienna; † March 19, 1871 Dornbach), the director of the State Geological Bureau and section mine adviser, researched the Proteus habitus in Idrija very deep under the surface with the help of the mine commander, Rudolf. (*Wien.Ber.* **5**/3: 229). The correspondent member of the Vienna Academy and the Academy general secretary Ettingshausen's close friend, Freyer, draw the map of *Proteus* habitus in Carniola. The samples from Magdalena's cave were sold for 2 fl up to 5 fl at that time. With the same money you could buy 6 to 15 kg of beef in Ljubljana at that time (Melik, 1981, 31). The wealthy put the *Proteus* in the glass bottles and showed them in their saloons like they used to show the goldfishes. 12 samples of Proteus were exported from Ljubljana to England (*Wien.Ber.* **5**/3: 296).

In Planina Mali Grad *(Kleinhäusler)* near the ruins of the castle they found new samples of Proteus. Curator-Adjunct Fitzinger reported about the well known *Proteus* researcher of Celovec (Klagenfurt), the general vicar, Count Sigmund Hohenwart (* June 7, 1745 Celje; † 1825 Linz). Sigmund studied with Ljubljanese Jesuits, Janez Jožef Lucius Erberg (* February 11, 1712 Ljubljana; SJ October 18, 1732 Vienna; † June 29, 1787 Dol), and Franc Ksaver Wulfen (* 1728 Beograd; SJ October 14, 1745; † March 17, 1805 Celovec). During the school years they made natural history researches around Ljubljana, and during holidays they visited Alps. Sigmund lived in Carinthia until 1809 as a Wulfen's close friend. In 1792 and 1812 Count Sigmund published his natural historical researches of Carinthia. In 1809 he became the Archbishop at Linz. His collections of animals, plants, and minerals were later given to Joanneum of Graz (Dežman, 1856, 9; SBL, 1: 335-336).

Fitzinger mentioned that Schreiner got his Proteus from Žiga Zois in 1807. Löwengreif researched *Proteus* in Magdalena's cave in 1797 and 1808. Sigismund's relative, Count Franc Jožef Hanibal Hohenwart (* May 24, 1771 Ljubljana; † 1844 Kolovec), was recognized as the best Carniolian researcher. He studied *Proteus* in 1825 at the creek near Lož (Laas). He made many tours to Alps, and headed the Carniola Land Museum as the president of the Museum curators and the president of the Carniola Agricultural Society between 1827 and 1834.

Fitzinger was also interested at the *Proteus* research outside Carniola. Dr. Zohar of Zadar and the Professor Carrara of Split found Dalmatian *Proteus* samples *(Wien. Ber.* **5**/3: 296).

PROTEUS DRAWINGS

Dežman actually copied parts of Rusconi 1817 and 1827 Italian publication with his drawings included. Dežman sketched the Rusconi's Proteus with pencil in a somewhat curved form (ARS, *Privatae a* archive of Karl Dežman, signature AS854, fascicle 12, sine dato, 4r). He showed all *Proteus'* inner organs from Rusconi's studies (1817, 1827). On the left margin Dežman separately drew some organs of *Proteus* and discussed their particularities (Dežman, sine dato, 3r). With that in mind, we claim that Dežman was quite an expert for *Proteus* in Carniola of his time.

Dežman drew the details with the letters a-l indicating the important parts of the picture. He used Italian language with excellent skill. Besides figure 1 of female Rusconi's *Proteus* Dežman also discussed figure 2, which he did not reproduce (Dežman, sine dato, 4r, 4v). Dežman described Rusconi's opinion against the amphibian nature of *Proteus* (Dežman, sine dato, 4r).

Dežman's copying was one of his very useful habits. He also copied part of Hacquet's *Oryctographia* (ARS, *Privatae a* archive of Karl Dežman, signature AS854, fascicle 13) and German translation of Hallerstein's Latin letters (ARS, 730, Gospostvo Dol, fasc. 194: 810-850). Some of the originals which Dežman copied are now considered pretty rare. Dežman also copied parts of Blanville 1819 publication in French language (Dežman, sine dato, 2r). Dežman cited Blanville, Cuvier (1801), and Humbolt's critiques of Laurenti's *Proteus* research (Dežman, sine dato, 2r, 3v, 4v). Dežman mentioned Rudolphi's letter to *Isis*, Scopoli's work, and Kitaibel's letter about Lika in Strelovachka Pojana below Badany Alps and Velika

Stirovachka below Berdo (Hill) Vissesruga (Dežman, sine dato, 2v). Hungarian Pál Kitaibel (* February 3, 1757 Nagymarton; † December 13, 1817 Pest) was one of the best chemistry and botanic student of Jacobus Winterl (* 1739 Eisenerz; † 1809) in Hungarian capital.

CONCLUSION

Dežman was the best versed and the most influential Ljubljanian natural historian of his time. The karst and cave research are just some aspects of his works, many of them published with the Vienna Academy of Science. Dežman's work show that domestic Ljubljanian researchers of the caves and *Proteus* were well informed and able to perform some first rate work of their own.

It's a pity that Dežman's work was simply forgotten for political reasons. Our publication is just one of the key-stones needed for his scientific rehabilitation, to end the sorrowful neglect of his scientific achievements.

ACKNOWLEDGEMENTS

We thank Tanja Žigon and dr. Janez Šumrada for useful suggestions, and Mellon grant of the University of Oklahoma for financial support of this research.

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POVZETEK

Muzejski kustos Dežman je leta 1855 oživil Kranjsko muzejsko društvo in v njem dajal pomembno spodbudo ljubljanskim naravoslovnim raziskovanjem. V tem prispevku prvič v slovenskem zgodovinopisju podrobneje opisujemo Dežmanova raziskovanja kraških jam, flore in favne, kot jih je objavljal v poročilih z mesečnih predavanj in sestankov Društva. Ob tem smo si ogledali še Dežmanove skice jam in *proteusa* v njegovi zasebni rokopisni zapuščini shranjeni pri Arhivu Republike Slovenije. Poleg skic smo našli še številna pisma o kranjskih jamah, popis Dežmanu dosegljive literature o človeški ribici in Dežmanovo natančno analizo fizioloških posebnosti *proteusa,* povzeto oziroma kar prepisano iz Rusconijevih raziskav. Preučili smo Dežmanov popis najnovejših, predvsem domačih, italijanskih in britanskih objav o *proteusu*. Tako z uporabo objavljenih del in rokopisov prvič podrobneje predstavljamo Dežmanovo bogato znanje, ki je segalo celo do matematičnih in astronomskih ved.

Popisali smo dela, ki jih je Karl Dežman objavil ali pa le napisal o krasu in o sorodnih vedah v Ljubljani ter v pomembnih dunajskih akademijskih publikacijah. S svojim delom je razširil sloves svojih in z njimi kranjskih znanstvenih dosežkov po celi Evropi. Slabo poznavanje Dežmanovega dela pojasnimo z njegovim političnim delovanjem, ki ga je kmalu odtujilo poklicnim zastopnikom slovenskih narodnostnih prizadevanj; nerodna politična stališča so ga oddaljila od tedanjih in poznejših voditeljev slovenskega naroda. Žal je zato doma kot naravoslovec slejkoprej ostal neznan: *Nemo propheta in Patria.*

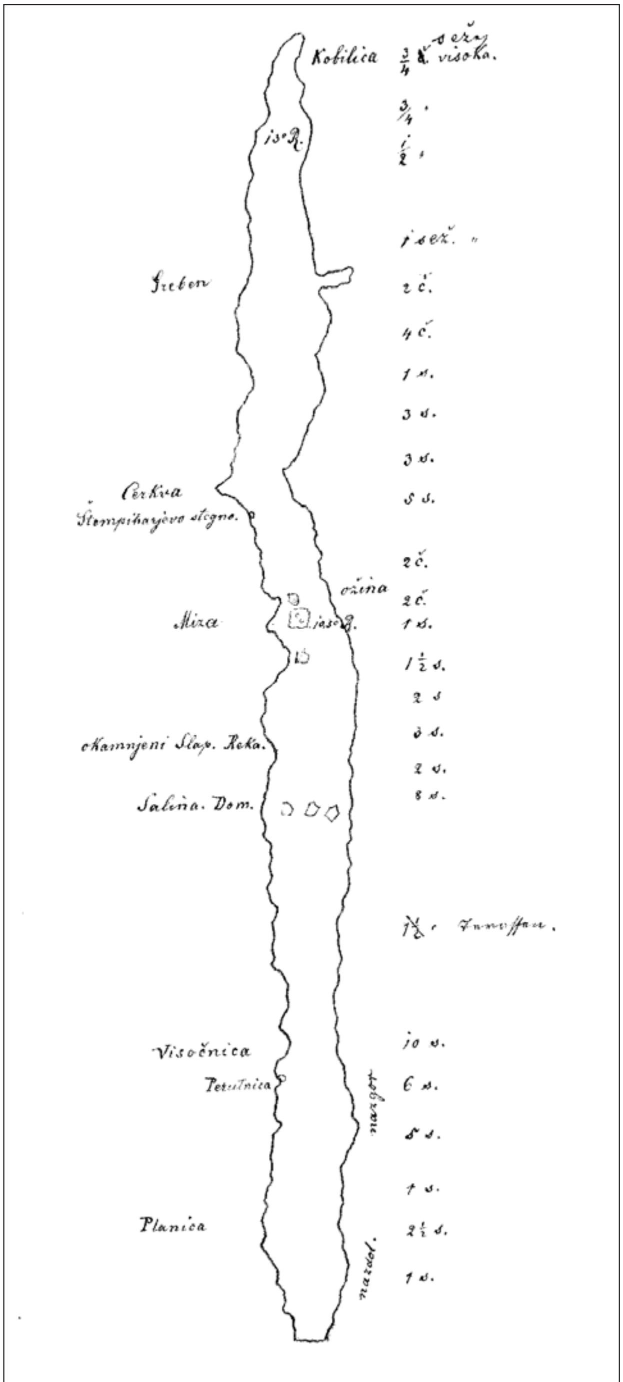

Fig. 2: Dežman and Franc Plemel's drawing of the cave Vihled near Kolpa (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 13 "Speleology").

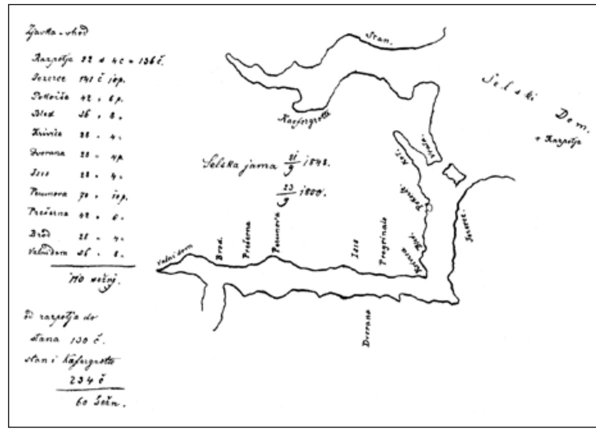

Fig. 3: Dežman and Franc Plemel's drawing of the cave Selska in Kočevsko region (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 13, "Speleology").

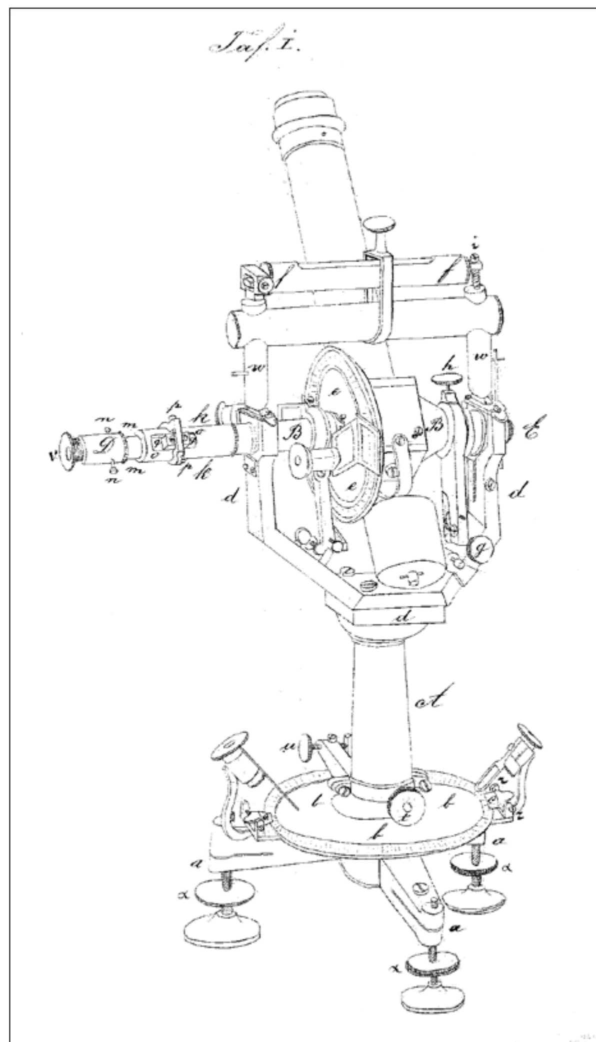

Fig. 4: Dežman's Passage Instrument, probably used for the determination of the geographical coordinates (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 12, "Kosmographia").

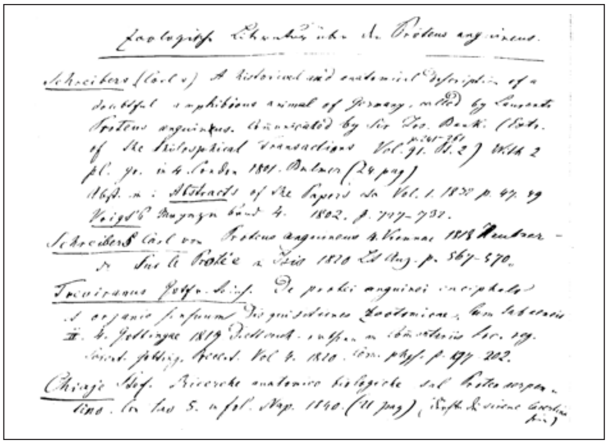

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Fig. 5: The title page of Dežman's manuscript about literature and anatomy of Proteus (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 12 "Proteus" 1r).

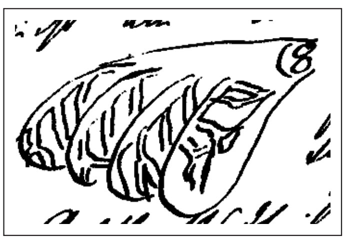

Fig. 6: Dežman's drawing of Proteus' inner organs (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 12 "Proteus" 3r).

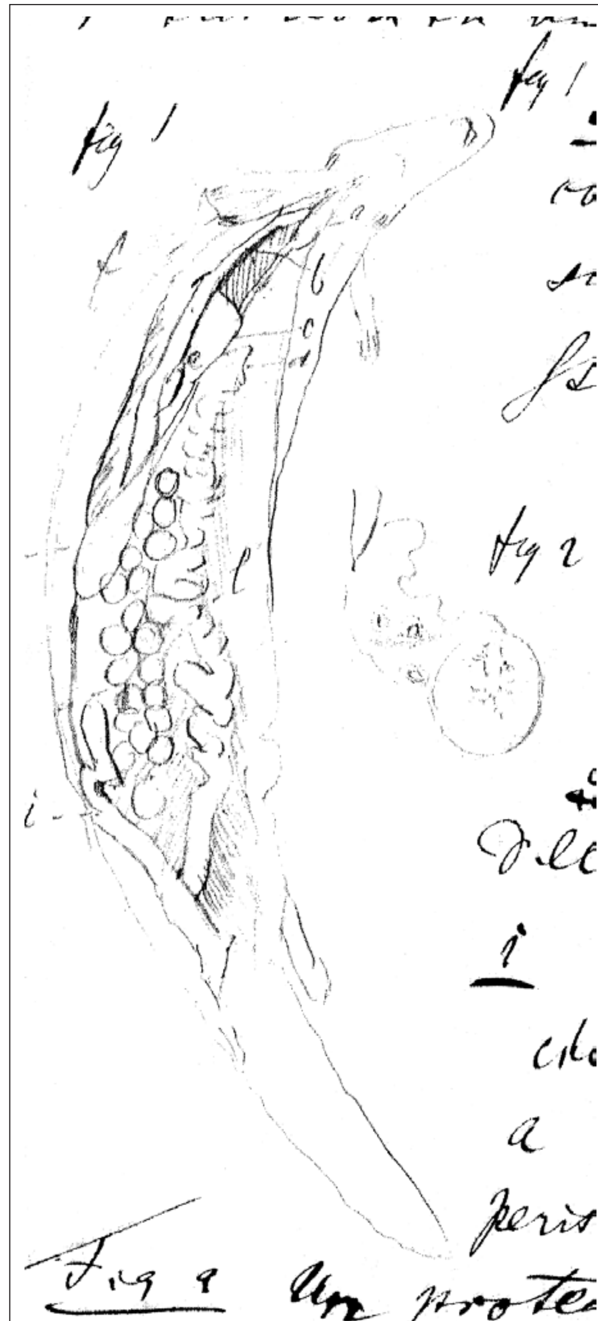

Fig. 7: Dežman's drawing of Proteus as a copy of Rusconi's study of female sample in 1827 (ARS, Privatae a archive of Karl Dežman, signature AS854, fascicle 12 "Proteus" 4r).

COBISS: 1.01

E. A. MARTEL, THE TRAVELLER WHO ALMOST BECAME AN ACADEMICIAN

E. A. MARTEL, POPOTNIK, KI JE SKORAJ POSTAL ČLAN AKADEMIJE

Pierre-Olaf SCHUT[1]

Abstract UDC 551.44(44):929 Martel É. A.
Pierre-Olaf Schut: E. A. Martel, the traveller who almost become an academian
Edouard-Alfred Martel lives in Paris. Like his father he studies to become a lawyer. This social position, fruit of the paternal heritage, does not fulfil his desire to become famous in the field of science, which he considers as the source of progress for mankind. He has a passion for travelling and, in the course of his journeys, finds a way to satisfy his ambitions, which run far beyond his Parisian legal practice. Almost by chance, he comes across what he would soon institutionalize as a new branch of natural science: speleology, that is to say the study of natural, underground caves. Will Martel, the ambitious traveller, manage to distinguish himself in the scientific world? The man's biography, supported by an analysis of his writings and his correspondence, illustrates the career of a tourist who wished to be acknowledged as a scientist. Showing the anonymous member of the Club Alpin Français rising up to being candidate at the Academy of sciences, this biography illustrates the path of a self-made man right up to the highest spheres of science. It also demonstrates the distinction this illustrious man created between trips for tourist and explorations dedicated to scientific purposes.
Key words: History of speleology, Martel, France, tourism, science.

Izvleček UDK 551.44(44):929 Martel É. A.
Pierre-Olaf Schut: E. A. Martel, popotnik, ki je skoraj postal član Akademije
Edouard-Alfred Martel je živel v Parizu. Tako kot njegov oče je študiral pravo. Ta družbeni položaj, očetova dediščina, ni mogel izpolniti njegovih želja po slavi na polju znanosti, za katero je sodil, da je vir napredka človeštva. Zelo rad je potoval in ta popotovanja so bila zadoščenje njegovim željam in so visoko presegala njegovo pariško advokatsko prakso. Skoraj po naključju je naletel na, kar je sam kmalu uzakonil kot novo vejo naravoslovnih znanosti – speleologijo, to je preučevanje naravnih podzemeljskih jam. Ali se bo Martel, popotnik z visokimi cilji, uspel odlikovati tudi v znanosti? Biografija tega moža, podprta z analizo njegovih del in njegovega dopisovanja, prikazuje življenjsko pot turista, ki je želel biti priznan kot znanstvenik. Biografija prikazuje pot tega »samouka«, ki se je od anonimnega člana Francoskega planinskega društva (Club Alpin Français) povzpel do kandidata za Akademijo znanosti, to je prav v najvišje znanstvene kroge. Prikazana je tudi razlika, ki jo je ta znani mož ustvaril med turističnimi izleti in raziskovanjem v znanstvene namene.
Ključne besede: zgodovina speleologije, turizem, znanost, Martel, Francija.

INTRODUCTION

The discovery and exploration of the furthest and most inhospitable areas of the world signals the end of the global conquest in the 19th and 20th centuries. These explorations had been led by colonists and soldiers, but also by scientists and sometimes even plain tourists. Whatever their motivations, these men all opened up new

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spaces and gave them meaning according to the way they viewed them. This is where the traveller's personality plays an essential part. The underground world is one of these inhospitable places which became the objects of systematic exploration from the end of the 19th century. This happened under the influence of a man called E.A. Martel (1859 – 1938).

Through a biography of this active and somewhat ambiguous character – both a tourist by temperament and a scientist by inclination – we shall try to understand the meaning E.A. Martel gives to caves: are they to be considered as jewels for regional tourism; as privileged standpoints from which to observe natural phenomena: or both?

The scientific aspirations of a man who would turn out to be the world specialist in underground research – limited by his social position and his inclination for tourism – were to give a specific meaning to caves and the underground world for times to come.

Martel's passion for caves is an opportunity for us to search into both the development of tourism and the many scientific discoveries of the late 19th and early 20th centuries. We shall analyze, in the course of his life's events, the active role he played in the development of tourism and how he somewhat uncertainly went up the high spheres of science.

The biographic perspective leads us to use a corpus of documents essentially made of Martel's own publications[1] and his correspondence[2].

[1] For a complete bibliography of E.-A. Martel, see: Chabert, C., Courval, M. de, 1971: E.-A. Martel 1859-1938 Bibliographie. – Travaux scientifiques du Club Alpin Français, Paris.

[2] E.-A. Martel's correspondence is published in: André, D., Casteret, M., Carlier, P., Gautier, A., Kalliatakis, G., Renouard, C. & L., 1997: La Plume et les gouffres. – Association E.-A. Martel, Hyelzas-Meyrueis.

BOURGEOIS CHILDHOOD

The cradle which received young Edouard-Alfred in 1859 in Pontoise, Paris area, belongs to an upper middle-class family.

His father is a lawyer. Through hard work and a definite sense of money saving, he has managed to haul himself up to this conquering social class of the 19th century. His own father before him had also worked hard to ensure the future of his family. According to the inheritance strategy, Edouard-Alfred's father expects his son to follow in his steps and keep taking the family still a little higher up the social hierarchy.

Respectful of parental authority, the young man accepts his fate. He studies law, becomes a clerk in 1881 then graduates and takes up the function of lawyer to the Paris court of appeal in 1883. When, soon afterwards, he buys his Parisian practice, it seems like the natural reward for several generations of hard working lawyers in the Martel family.

To imitate the higher social classes, his family often goes on holiday trips (Boyer, 1999). At times when the father, dedicated to moneymaking, is too busy working, he sends off his wife and son alone. They follow the classic itineraries of the time, visiting Chamonix and Switzerland or the Pyrenees, which attract increasing numbers of visitors, thanks to their spas.

Then they start travelling abroad. After Germany and Austria, E.A. Martel makes the classic trip to Italy (Boyer, 2000). He is just a child, but his travel journal testifies of a definite taste for picturesque landscapes, which seem to impress him more than any of works of art seen in museums or churches. This taste for natural beauties leads him to join the ranks of the Club Alpin Français. The latter, a scholarly society, gathers together middle-class people, tourists and scientists around a common passion for the mountain environment. Together they work for its development, especially from the point of view of tourism (Rauch, 1986; Hoibian, 2000; Lejeune, 1988). Soon Edouard-Alfred takes an active part in the activities of the club. In the Austrian Alps, for example, he climbs the Gross Venediger (3673 meters), the Dachstein (2996 meters) and the Gross Glockner (3789 meters) one after the other in difficult weather conditions. He also takes part in the social life of the club, giving conferences.

Even though his professional obligations forbid him to travel as much as he would like to, Martel is able to talk about many places around the globe as he reads extensively, especially the *Petermann's Geographische Mitteilungen as well as the Tour du Monde magazines.*

His keen interest in geography appears very early in his life – probably sparked by his family trips – and he later deepens his knowledge through reading. In high school he gets the first prize of the Paris schools geography contest, which gives him the opportunity to join the prestigious Société de Géographie. The latter's policy is to promote travelling in view of developing geographic knowledge. Martel's own knowledge was added to a topographer's skill, which led him to work at map adjustments in the Pyrenees and the Esterel.

PICTURESQUE CEVENNES

In 1883, Martel discovers a region of France totally ignored by tourists, despite geographer A. Lequeutre's praise of it: the Cevennes. Tourists tend to all follow the same tracks, trying to see what ought to be seen and thus missing unknown picturesque places. From his very first, short stay in the Cevennes, E.A. Martel happens to row down the Tarn gorges. He is extremely impressed by what he sees: a lovely stream falling into the narrow gorges of a canyon, tall figures carved in the rock and even some mediaeval vestiges. This discovery was like a revelation to him, inviting him to write and share his enthusiasm with many. He writes an article for the annual publication of the Club Alpin Français. After praising the beauty of Haut Tarn, he tries to reorient the traditional tourist axis towards the Cevennes. He writes: "It is a shame to see, year after year, herds of French tourists invade areas turned fashionable by the English, when places like Haut Tarn remain ignored and neglected" (Martel, 1883).

The following year Martel goes back to that region. He discovers the Causse Noir and uncovers a natural site: Montpellier-le-Vieux (Martel, 1884). Heaps of stone blocks so strangely shaped as to appear hand carved, to the point that the name of the place evokes the picture of a long forgotten city. From then on, his admiration for the area is such that he starts officially promoting it with tourists. As a spokesman to the Parisian travellers, an experienced lecturer and an inspired writer, he starts a real campaign in favour of the Lozère area (Poujol, 1999).

The climax of this wave of enthusiasm is indisputably the publication of his book, *Les Cévennes,* in 1890. This work wins over a large number of readers always on the look-out for new journeys and practical books to organize them. The demand is such that it is reprinted several times. As luck would have it, the publishing and success of the book take place just before the setting up of an association which will be unequalled in its work for tourism: the Touring-Club de France. Martel naturally becomes one of its first members and, due to the success of his book, he enjoys a special status. Inevitably, the Touring-club de France is influenced by his enthusiasm and directs its interest towards the regions Martel favours and promotes: the Esterel all the way to the Cevennes. Supported by the constant growth of the Touring-Club, his campaign is a success. But reducing his role to that of a propagandist would be too limiting. His true merit is to have uncovered the natural beauties of a region.

After the Tarn gorges and Montpellier-le-Vieux, Martel's attention turns to the dark caves that open up in several surrounding places. In Languedoc, the exploration of the Demoiselles cave by Marsolier des Vivetières (1785) had contributed to the tourist fame of the area. Well, the caves in Cevennes are shining with decorations and, entering them, Martel immediately senses their potential in terms of tourism development. Therefore he immediately starts planning this.

The Dargilan cave is one of the first ones he explores methodically in 1888. What he sees there makes him most enthusiastic. Martel's own reputation contributes to the fame of the Cévennes. The whole area soon becomes a favourite for the larger public. The French Touring Club, inspired by E.A. Martel's writings, organizes there its first cycling trip. A few years later it remarks that the whole area had benefited from a growing tourist success.

Martel's work begins with the discovery of the Cevennes in the early 1880s and stops only at his death. Indeed his last book, *Causses et Cévennes,* an updating of the first one, is published at a time when his health is already declining. The man is responsible for revealing the most popular tourist sites of the region. His unceasing work was consecrated by many trophies. But his enduring love for that place also pulled him into another adventure, one which he had aspired to since early childhood.

A GREAT DISCOVERY?

Martel's interest for natural sites and tourism is mixed with a desire to understand the world in which he lives. Since an early age, as an inheritor of A. Comte's positivist philosophy, he has been especially sensitive to scientific progress and the understanding of natural phenomena. This is the reason why he reads so much. He reads magazines like *La Nature,* which informs him of the latest discoveries, as well as many scientific publications from scholarly societies. Thus, though a self-taught man, he is perfectly aware of the latest acquisitions of knowledge in many scientific fields. For Martel this interest for science does not simply reflect a strong attraction; it is perceived as a path that will help him realize his full potential and deepest ambitions. He wants to acquire knowledge, but he also and mostly wants to be acknowledged for his work. However, whereas mountain tourism suits his social position, can his excessive scientific ambition – which we shall now study in detail

– adjust to the Parisian lawyer's hard working life he has inherited?

The whole adventure starts in a Cévennes cave – the Nabrigas cave – that Martel has heard of from his guide, H. Causse. Causse was enthusiastic about the potential scientific interest of the prehistoric vestiges he had found there. As a matter of fact, since the beginning of the century, the cave had regularly been visited by famous palaeontologists and historians like N. Joly, M. de Serres, P. Cazalis de Fondouce and E. Cartailhac (André, 1999), but this does not deter Martel. He is extremely keen on this new science that keeps revealing information relative to the history of mankind. Martel, young, curious and ambitious, sees here an opportunity to bring his own contribution to science. This is how he starts working at excavations with the help of his brother-in-law, the geologist Louis de Launay. The latter finds part of a human jaw in a cave where many vestiges of *URSUS speleus* had already been discovered, thus confirming that the cave had been inhabited by men in the Palaeolithic era. Martel is enthused by this first discovery and throws himself into the work with redoubled vigour until he finds pieces of pottery. From then on, he senses that this is his opportunity to contribute meaningfully to scientific progress. His aim is to demonstrate through his findings that men in the Palaeolithic era mastered the art of pottery. Prehistory had been especially fashionable since the early 1860s (Groenen, 1994). Even though palaeontology had been legitimized by G. Cuvier, at the end of the 18th century, the religious taboo linked to the existence of a form of evolving mankind kept pushing off further official study in Prehistory for half a century. Consequently, in the last third of the 19th century, discoveries are many, contributing to the celebrity of the great characters standing for it.

Soon Martel gets in touch with the most famous professors in order to present his work, confirm his hypotheses and get their support. When his work is done, his first report to the Academy of Science is read out by A. de Quatrefages. During the sitting following this presentation, E. Cartailhac answers E.A. Martel and L. de Launay, refuting their conclusions. Martel lashes back by publishing several articles answering the expert's points one by one. Only academic customs manage to put an end to the debate. Martel's penetration of the prehistorians' circle is now compromised. Aware of it, he turns his back on that science, but several people in that field will keep a grudge against him.

This episode is evidence both of Martel's pugnacity and of his will to become famous through scientific discoveries. It also shows how difficult such a task was to be. Well, if Prehistory, which had fascinated him so much up till then, rejected him, never mind! This was not going to dishearten him. There were many other sciences and he would find his own somehow. This sudden change of course shows not only how interested he was in science in general, but also how much he craved for acknowledgement from the highest scientific circles.

CAVE STUDY

Soon Martel finds interest in something else: cave study. His journeys in the Cévennes and the excavation work in Nabrigas had taken him into a dark world that was only waiting for the lights of science to be shed on to it. Earlier on, as he was touring through the Causses, he had wondered about one of the many mysteries of the underground world: hydrogeology. In 1884 E.A. Martel had written: "How many mine explosives should be used, how many dangers should be faced, in order to discover the capillaries and reservoirs of the Causses and solve the mystery of the communication between the swallowholes and the valley caves? Who knows if some day, a brave explorer will extract from these limestone plateaux the secrets of their hydrography." (Martel, 1884). Little did he know then that he himself would be that "brave explorer" a few years later.

Martel's new vocation can be understood on various levels. One thing is sure: this new path was all the more attractive to him as it synthesized his deepest aspirations. Since early childhood he had been a dedicated traveller and this interest was confirmed in the context of the Club Alpin Français. Also as a tourist always on the lookout for picturesque landscapes, he finds under ground level the change of scenery and the natural beauties that have always fascinated him and that make this region so lovable to him. Lastly, as a potential scientist, he is facing uncovered mysteries in a field which has hardly been touched upon in Austria, but which seems to be starting to interest French science too. Indeed, in a book published in 1887, the eminent geologist, A. Daubrée, had opened the way to hydrogeology by showing the relationship between the localisation of water, its movements and the geological structures.

In the summer 1888, Martel starts on his first underground campaign. His objectives then are to cross the Bramabiau abyss and explore the Dargilan cave (Martel, 1888). This plan testifies again to the perfect mixture of his many interests in one and the same activity: as he draws a precise map of the cave and lists all its beauties, the fitting out of the cave can be set into motion for the greatest benefit of the Cévennes. As for the Bramabiau abyss, it is a hydrological special feature as well as a remarkably picturesque site. Next to Mont Aigoual, a small stream of water sinks underground and seems to reappear 440 meters further and 90 meters deeper. Everybody assumes that these two streams are one and the same, but E.A. Martel demonstrates it irrevocably by following the water upstream. In his report of this experiment, he makes interesting remarks regarding underground water circulation.

The success met during this first campaign encourages Martel to persevere along those lines. He soon gets in touch with A. Daubrée in order to have his opinion concerning his writings and also because the man is a member of the Academy of Science and, as such, can present his notes to his fellow academicians in his name. Indeed thanks to the man's support, he can publish his first reports to the Academy of science and develops his study of the underground. At first he concentrates on the Cévennes and Causses region, but then considers doing the same sort of work abroad. First because this would allow him to make comparisons and therefore generalize his results and then because it would keep him in touch with his predecessors in underground study, especially in Austria.

His acquaintances make it possible for him to set up a scientific project sponsored by the Ministry of Public Education. Through this project he meets his Austrian counterparts in the Austrian Karst. Thus completing his experience, bibliography and knowledge, E.A. Martel becomes an authentic expert in limestone massif hydrology. After six search campaigns in France and studies in the caves of Belgium, Greece and Austria, Martel decides to publish a synopsis of his work in a book entitled *Les Abîmes,* in 1894. In this book, he does not just report the results of six years' research, but tries to put forth the basis of a new branch of natural sciences: speleology or the science of caves.

The very word "speleology" is brand new. Martel claims it was created by prehistorian E. Rivière. The Greek root spelaion meaning "cave" and logos, meaning "discourse", give a scientific ring to the name of the practice. Martel defines a vast program for this new science. Subjects appear according to his personal logic. He mentions hydrology, geology and mineralogy, meteorology and topography, which are all fields in which he has already been distinguished. Next to these are a few specific aspects which either interest him personally or have been the object of subsidy requests to the Ministery of Public Education, like agriculture and public hygiene. Martel's definition also includes fields like fauna, flora, prehistory and palaeontology which brings everyone together by common consensus and through which he gets the support of famous scientists who have already worked in the underworld, like botanists and archaeologists (Gauchon, 1997).

This sense of compromise is based on a desire to see speleology obtain full status as a science and more specifically as a branch of natural sciences. The whole process was quite a touchy thing considering that the man was standing alone and had met with a few disappointments in the past. However, he now feels confident that he has found his own true path. Having associated his name to a specific field of research, his personal fulfilment and acknowledgment by the highest scientific institutions – and especially the Academy of Science – has to go through the legitimization of speleology, a science of which he would forever remain the precursor. But the point then was: could a Parisian lawyer, a "tourist", create a science?

THE LEGITIMIZATION OF SPELEOLOGY AND THE CONQUEST OF THE SCIENTIFIC WORLD

The cultural atmosphere of the late 19th century is favourable to the development of sciences. More than ever, science is synonymous with progress in the widest sense of the term. Nevertheless society has its own ways and Martel knows it. He uses this knowledge to get the means to acquire the much coveted status. His strategy is developed on several levels that build up progressively. First, aware of the fact that he cannot achieve his aim alone, E.A. Martel, after publishing *Les Abîmes,* decides to create a "Société de Spéléologie". His book ensures both the definition of speleology and its promotion. Its success confirms Martel's status as an expert in the field and makes it possible trustfully to consider support for the new Society. So in the year following the publication of his book, he starts recruiting the founder members of the Society.

On September 15, 1894, Martel sends off a mailing to individuals and societies and publishes the same letter in several scholarly magazines like the *Bulletin de la Société Géologique de France* and the *Revue d'Anthropologie*. In return Martel finds 121 founder members ready to support the creation of the Société de Spéléologie on January 1st, 1895. As a lawyer living in Paris, he is a man of many connections. Being supported by celebrities in the world of science – like Dr Blanchard, member of the Academy of Medicine or G. Vallot, founder of the Observatory of the Mount Blanc – and the friend of influential politicians like the deputy F. Deloncle – is assuredly a strong advantage for this new scholarly society. In the first few years, the number of its members increases regularly.

Martel does not limit membership to the French territory. Indeed, as opposed to many scholarly societies, the name of the Société de Spéléologie does not imply any geographical limitations. Martel has obviously understood that science can only be an international affair. From the very early days, he attracts into his society foreign counterparts he had a chance to work with, like Greek and Austrian researchers. Later his many missions in England, Russia, the United States, Italy and Spain give him opportunities to make useful contacts and attract more members. The way he went about it has been called "a true international strategy" (Shaw, 1988). As a matter of fact, in 1895, one fourth of the Society members comes from foreign countries, numbers grow up to one third in 1904 and then remain in this proportion. This representation contributes to the credibility of the Society in France and to its recognition worldwide, thanks to a widespread diffusion of its works.

From the very beginning of the Society, E.A. Martel creates a review in which he publishes reports from its members' research. The Latin title of the review, *Spelunca*, stresses its scientific character. It is entirely edited by E.A. Martel himself. *Spelunca* soon turns out to be the main part of the Society activity, but this did not happen by chance. Martel is well aware that magazines are the perfect vehicle in the intellectual spheres of the late 19th century. They stress the legitimacy of a group and make their publishers and writers famous (Prochasson, 1991).

Besides the publication of magazines, Martel takes part in many congresses in wich he explains what speleology is. These are perfect communication places for an interested public. They are aimed at an audience from various intellectual spheres, which contributes to the legitimization of sciences and groups. This is how, in 1893, Martel had announced the publication of his book *Les Abîmes,* by presenting a memoir on "speloelogy" at a congress organized by the Association pour l'Avancement des Sciences in Besançon. Every year, from 1896 onwards, speleology is represented at the Congrès des sociétés savantes through a couple of members from the Société de Spéléologie.

However Martel's battlelines would not be complete without speleology pushing open the doors of University. Indeed since its reformation, university has become the most favoured place for developing scientific research. In those days, the Sorbonne was inaugurating new courses in new subjects. E.A. Martel takes advantage of this opportunity. From 1901 he teaches a class on « Underground Geography ». The recent appearance of physical geography and its development at university may appear to Martel as an entrance door to this world. Indeed by then he was famous as a geographer, not only for his work about the Cévennes, but also as a member of the Société de Géographie. As a matter of example, the famous geographer O. Reclus asked for his services to complete his major work, *La Grande Géographie,* published in 1911 and 1914.

With regard to these realizations added to the sheer hard work of its promoter, speleology seems to acquire some destination or at least be acknowledged. Its spokesman benefits from it and by the end of the century he has become a celebrity. The Comité des Travaux Historiques et Scientifiques invites him to give a talk on speleology at their congress in 1899. He speaks after Mr Loude who talks about X rays and before Mr Lumière who presents his study on the photography of colours. Honoured and acknowledged by his peers, Martel feels ready to ask for the consecration he has always aspired to: a seat at the Academy of sciences.

THE ACADEMY

Martel always attached a major importance to the Academy of Sciences (Choppy, 1999). Even though the least of his explorations is the object of several reports and publications; even though he regularly writes columns in *La Géographie,* a scientific journal, as well as more popular magazines like *La Nature* and is published by several tourist magazines like the *Annuaire du Club Alpin Français,* the *Revue du Touring-club de France,* the *Tour du Monde* or *Causses et Cévennes,* E.A. Martel has a special reverence for the old institution. This is where he always sends the very first reports of his discoveries. By the time he applies for a seat there, he has sent 82 reports, 66 of which have been published. The Academy has honoured Martel with the Gay prize of physical geography as a tribute to his work, *Les Abîmes* in 1894 and with the Grand Prix des Sciences Physiques in 1907.

This success leads him to believe that he can apply for the seat left vacant by the death of J. Tannery in 1910. To this effect he writes a letter to the Academy on December 11 of that year, but his application is turned down. In 1911, in order to prepare his next application, Martel writes out a document in which he presents a detailed account of his work and publications. He applies for a vacant seat in the free academicians section in February 1913, but there again, he is turned down. That same year in May he applies for the seat left vacant by the death of E. Cailletet, only to be refused again. After this third failure, E.A. Martel has to face the truth: the Academy will never accept him. This is all the more obvious when he learns that he never got a single vote at any of his applications, not even from his own brother-in-law, L. de Launay. As a matter of fact, this was to become a matter of contention between them in the future.

Martel explains his failure by the absence of the people who had supported him in his early days. A. Daubrée, for example, with whom he shared many views on hydrogeology and whom he wished to emulate, had died in 1896. A. Gaudry, who had presented his prized works as well as thirty five of his reports to the Academy, had died in 1908. In the absence of these men, he could still hope that L. de Launay, his childhood friend and brother-in-law, would support him. The fact that he did not was a sore point for E.A. Martel. Getting a seat at the Academy had become a matter of personal importance to him. He wished to be at least equal to his brother-in-law in this respect. L. de Launay had often explored caves with him and shared his views on geology and other matters. As a professor at the Ecole des Mines, he was also interested in the richness of the underground and appreciated by the Academy for his discoveries. Why would E.A. Martel be less?. Probably feeling bad when confronted with Martel's resentful disappointment, L. de Launay tried to make up for his disavowal by supporting him when the Academy awarded Martel the Joseph Labbé Prize in 1921 for his work entitled Nouveau traité des eaux souterraines.

E.A. Martel desperately needed a consecration of his work on caves as a compensation for a difficult private life. Indeed Aline, his wife, had had a miscarriage in an accident with a hot air balloon her husband had insisted she flew with him. After that she could no longer conceive babies and Martel's in-laws never quite forgave him for that. As for his own parents, they resented the fact that he had dropped his attorney practice to dedicate his life to the modest trade of an underground explorer. So E.A. Martel did not get the longed-for recognition from the scientific world, but the reasons may be found in the ambiguity of his position.

When he first started on his scientific career, E.A. Martel was just a traveller but not in the manner of a tourist. He travelled in the way geographers used to at the beginning of the 19th century, bringing back from his trips precise observations and maps, thus contributing to the development of knowledge regarding known or unknown territories (Laboulais-Lesage, 2000). This way had been supported by the Société de Géographie since its creation in 1821, but it differs from that of physical geography which becomes an official institution entering the university in the 1890s (Broc, 1994). This explicative geography is totally different from the previous descriptive one. It is mainly based on a new concept coming from the famous American geographer, Davis and supported in France by Margerie. Being deeply nationalistic, Martel refuses to accept the theory presented by the American. In the same narrow-minded way, he is soon taken over by progress in geology, but keeps judging and criticizing the latest theories. As a consequence, more and more often he quarrels with the scientists of his time, defending his outdated views in his "aggressive lawyer's way" as he himself puts it. This is why P. Renault (1999) said about him: "Martel is a 19th century man who missed the 20th century transition for lack of a scientific mind".

His lack of scientific training appeared when E.A. Martel had to take position in a debate relative to dowsing. Unlike his colleague, E. Fournier, a geologist at Besançon University, who spent a long time studying this "divinatory science" to finally state it was scientifically null, E.A. Martel could never quite make up his mind about the subject and even once declared it of value.

Even his qualities as an observer were disparaged by some scientists besides the prehistorians. Thus R. Jeannel, a biologist researching cave fauna, went on a campaign with E.A. Martel, after which he reproached the speleologist with the somewhat careless character of his observations. It may not be a matter of chance that prehistorian H. Breuil collaborated with the biospeologists for many years, whereas no archaeologist or biologist took part in the activities of the Société de Spéléologie.

E.A. Martel tried to make up for his lack of scientific training by reading a lot. He thus acquired a vast knowledge which enabled him to popularize many fields of science. This quality made him a popular writer, but discredited him with the scientific community. Indeed only scientists benefiting from a well established position can afford to produce such works without prejudice to their reputation.

In the end, E.A. Martel's scientific career raises many criticisms. Lack of scientific training and methodology, and difficulty in participating constructively in the debates of his time, contribute to keeping him on the fringe of the scientific establishment.

CONCLUSION

E.A. Martel was deeply wounded by the rejection of the scientific institutions. Also the First World War, which breaks out the year following his double rejection by the Academy of Sciences, weighs hard on him. Being too old to fight at the age of 55, he volunteers as a nurse, but his own health is weakened by arteriosclerosis. Therefore, after the Armistice, he stops his exploration campaigns and does not do much to prevent the extinction of the Société de Spéléologie. He forsakes every ambition to enter the Academy of sciences, but keeps a scientific activity within the Société de Géographie of which he becomes president in 1928 and puts more effort into the development of tourism, especially in the context of the Touring-club de France. There he finds himself in a sphere where he is appreciated and praised. He receives many awards and, when he is still alive, even has the privilege to have his statue made in the Cévennes region he so much loved and glorified. His last work, at the end of his life, was to complete his action in favour of tourist development in the Causses and Cévennes.

This life story demonstrates the capacity of a self-trained man to assert himself in the late 19th century intellectual spheres which were especially open to scientific initiatives. However integration has its limits: being allowed to express oneself does not mean being accepted and acknowledged by one's peers. Martel's law training and his tourist inclinations contributed to limit the quality of seriousness with which his works were evaluated. E.A. Martel felt he had not been well represented, but really his theoretical reflections were probably not up to what can be expected from an Academician. No matter how many caves he explored and how many plans he drew, a scientist's quality stays more with his analysis of data than with his collection of them.

However Martel certainly left his print in the discovery of the underground. Following his tracks and example, many speleologists went underground to discover new networks, taking precise notes in the course of their explorations. His inheritance is still alive in the way people keep exploring caves: drawing surveys and trying to understand the working of the water networks. Indeed such activities would otherwise be surprising on the part of people who are now considered as "sportsmen".

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POSTOJNSKA JAMA IN SLOVENIA, THE SÜDBAHN AND THE VISIT OF JOHN CHARLES MOLTENO: THEIR INFLUENCE ON THE DEVELOPMENT OF RAILWAYS IN SOUTH AFRICA

POSTOJNSKA JAMA, JUŽNA ŽELEZNICA IN OBISK JOHNA CHARLESA MOLTENA V SLOVENIJI: NJIHOV VPLIV NA RAZVOJ ŽELEZNIC V JUŽNI AFRIKI

Stephen A. CRAVEN[1]

Abstract UDC 551.44(497.4 Postojna)(091)

Stephen A. Craven: Postojnska Jama in Slovenia, the Südbahn and the Visit of John Charles Molteno: Their Influence on the Development of Railways in South Africa.

In November 1871 a successful businessman and politician from South Africa toured Europe with his daughters. They arrived at Postojnska jama by train from Vienna. He wrote to the governor that it would be very desirable that the engineers should visit the Südbahn which crosses a rugged terrain comparable to that of the Cape mountains where technical problems and increased construction costs slowed the advance. The discovery of diamonds inland was eventually responsible for the extension of the railway to Beaufort West and beyond.

Key words: history, Molteno, Southern railway, Slovenia, South Africa.

Izvleček UDK 551.44(497.4 Postojna)(091)

Stephen A. Craven: Postojnska jama, Južna železnica in obisk Johna Charlesa Moltena v Sloveniji: njihov vpliv na razvoj železnic v Južni Afriki

Novembra 1871 je uspešni poslovnež in politik iz Južne Afrike potoval s svojima hčerama po Evropi. Obiskali so tudi Postojnsko jamo, kamor so prispeli z vlakom z Dunaja. Pisal je guvernerju, naj si inženirji ogledajo južno železnico, ki poteka po še bolj razgibanem terenu kot so gore v Kaplandiji, kjer se je gradnja upočasnila zaradi tehničnih problemov in dviga stroškov. Vendar je odkritje diamantov pospešilo dokončanje železniške proge v notranjost do Beaufort Westa.

Ključne besede: zgodovina, Molteno, Južna železnica, Slovenija, Južna Afrika.

INTRODUCTION

For three centuries the spectacular Postojna Cave in Slovenia (Habe 1986) has attracted the great, the good and lesser mortals. Until the collapse of the Austro-Hungarian empire in 1918 the cave was known as the Adelsberger Grotte. Fortunately for the historian since 1819 the early visitors were required to sign the visitors' books which have survived, and which are kept at the Karst Research Institute in Postojna. Most of the visitors came from Europe, but also from the Americas and from Asia (Shaw 2000; Shaw & Čuk 2002). There were very few visitors from Africa.

There are two reasons for the paucity of South African visitors. There were, compared with the northern hemisphere, very few people with the necessary financial and temporal resources. The Cave was difficult of access from the Cape. The Union-Castle Mail Steamship Company and its predecessors operated fast mailships from Cape Town via Las Palmas to Southampton in England. There were also intermediate ships which served Cape Town and the east African ports. The much slower round-Africa ships sailed through the Suez canal and the Mediterranean, calling at Naples, Genoa and Mar-

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seille before docking in England (Harris & Ingpen 1994). Trieste, the port of access for Postojna, is situated at the north-easterly limit of the Adriatic Sea. Ships plying the South African trade did not call there because there was insufficient demand for a diversion from the standard routes to a port which offered very little South African business.

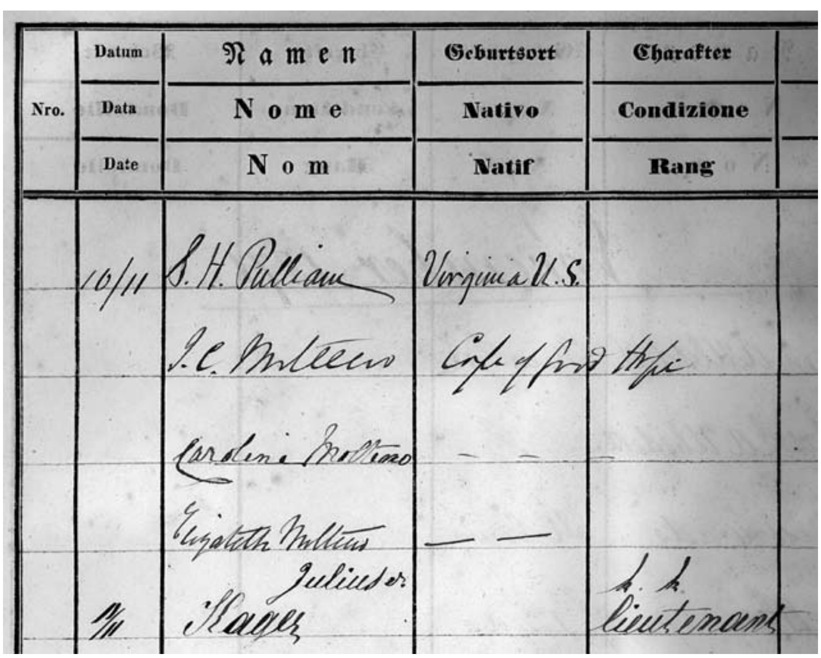
Trieste was a busy and important port, being the most convenient maritime access which was controlled by the Austro-Hungarian empire. The Government in Vienna in 1841 decided to build the Southern Railway (or Südbahn). The tracks reached Postojna in 1856 and Trieste in the following year (Enciklopedija Slovenije, 1990). This railway greatly facilitated visitors' access to Postojna and the Cave.

Three such visitors were John Charles Molteno and his two eldest daughters, Caroline and Elizabeth Maria (Betty), on 10 November 1871 during their European tour (Fig. 1). Molteno was born in London on 5 June 1814 and emigrated in 1831 to the Cape where he soon prospered in business, and in sheep farming at Nelspoort near Beaufort West. He became a wealthy and influential man (Harrington 1972). In 1854 he was elected Member of the Legislative Assembly for Beaufort West (Cape of Good Hope Almanac 1855). Following the achievement of internal self-government in 1872 he was re-elected Member for Beaufort West (General Directory and Guide Book to the Cape of Good Hope 1872), and was appointed Prime Minister on 1 December 1872 (Kilpin 1938).

During their tour of Europe Molteno and his daughters wrote letters to their family and friends (University of Cape Town Archives and Manuscripts Department BC 330: Molteno – Murray Papers). On 6 November 1871 Betty Molteno wrote from Vienna to her brothers Charlie, Percy and Frank announcing her intention to visit the Adelsberger Grotte. On 18 November 1871 her father wrote from Venice to his wife confirming the visit:

"I write [sic] *you last from Linz in Austria. Since we have visited several places, Vienna, Adelsberg Grotto, Trieste &c and reached this on the 15th. but as usual I must leave the girls to tell you all this … The Adelsberg Grotto which we were in for near three hours is a truly wonderful sight a large (river) runs up to the hill where you enter the grotto and entering (the) cave entirely disappears and the water comes out again some 20 or 30 miles off."*

The daughters were not impressed with Postojna and its Cave. Betty's next letter, dated 21 November 1871 and written from Brindisi to her step-mother, made no mention of the Cave. Her diary is similarly silent. Caroline likewise wrote no letter between Graz and the east coast of Italy, and overlooked the Cave.



Nro.	Datum / Data / Date	Namen / Nome / Nom	Geburtsort / Nativo / Natif	Charakter / Condizione / Rang
	10/11	S. H. Pulliam	Virginia U.S.	
		J. C. Molteno	Cape of Good Hope	
		Caroline Molteno	—	
		Elizabeth Molteno	— —	
	11/11	Julius v. Hager		k. k. lieutenant

Fig. 1: The entries of Molteno and his daughters in the Postojna Cave visitors' book, 10 November 1871.

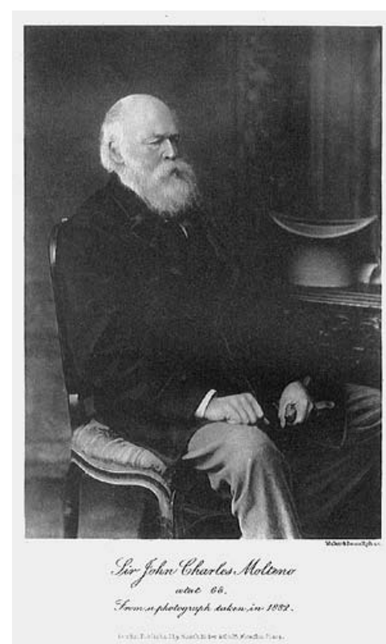


Fig. 2: Sir John Charles Molteno in 1882, aged 68 years (Molteno 1900).

Although Molteno was prompted to write a couple of sentences about the Cave, his mind was clearly on other things including the inter-related Cape politics and Cape railways. Indeed, he had always been an enthusiastic supporter of railways in the Colony. The Cape Town Railway and Dock Company had been floated in London in 1853 and had reached Wellington, 96 railway km. (Durrant, Jorgensen & Lewis 1981) from Cape Town over easy country, on 4 November 1863 (Cape Argus 1863). This slow rate of construction is explained in part by the sparsely populated countryside and lack of industry (Houghton 1978). The 1865 census reported a population of 236,300 in the Western Division, of which only 16% were economically active, and a low population density of 3.25 per square mile (1.25 per square km.) (Cape of Good Hope 1866; Colony of the Cape of Good Hope, 1866). To proceed beyond Wellington into the hinterland the railway had to cross the Cape mountains. This led to technical problems and increased construction costs per kilometre, a possible solution to which occurred to Molteno as he travelled on the Südbahn across the mountains from Vienna (Wien) through Graz (Gratz), Maribor (Marburg) and Ljubljana (Laibach) to Postojna (Adelsberg) and Trieste (The Times Atlas 1898). A visitor to Slovenia in 1845 during the construction of the Südbahn well summarised its significance for Molteno:

"Until Marburg you ride along the [route of the] miracle railway under construction from Graz to Trieste. Tunnels several hundred metres in length, viaducts, and stone-walled cuttings will make this railroad one of the greatest." (Windisch-Graetz 1908).

A later advertisement for the Cape Government Railways did not exaggerate:

"The Pioneers of railway construction were faced with apparently insurmountable difficulties in climbing over and winding round Nature's great upheavals before the tracks could be laid which were to connect the coastal towns with the interior." (The Mountain Club Annual 1908).

Accordingly Molteno wrote to the Governor, Sir Henry Barkly, from Suez on 8 December 1871. After discussing the Egyptian railways which had been constructed over easy, flat, country he waxed eloquent about the Südbahn:

"But of all the railways I have yet seen, that from Vienna to Trieste is the most difficult, and is acknowledged to exhibit the greatest amount of engineering boldness and skill, and the similarity of some of the mountain gorges and other difficulties which will have to be overcome if railways extend very much at the Cape, would, I should imagine, render it very desirable that the engineers who have to plan and construct these should visit this line; it is 365 miles in length, and would in itself repay all the trouble and expense of a visit from the Cape for those who take an interest in such undertakings. But on the whole I find that what we shall have to contend with in constructing lines from the two ends of the Colony inland traversing the more level parts, especially say from the Wellington terminus towards the Diamond Fields, is small comparatively speaking, and looking to the changed condition of things consequent upon the Diamond Fields and extension of the Colony in every way, I think that even those who are inclined to be most cautious in committing the Colony to large and expensive undertakings, must admit that things which might have fairly been looked upon as tasks a few years ago, may be viewed in a very different light now." (Molteno 1900).

There is no record that an engineer was sent to inspect the Südbahn. Indeed, there would have been insufficient time between receipt of the letter by the Governor and the appointment of the Select Committee in May 1872.

Molteno returned from his European tour on the R.M.S. Northam from Southampton on 18 April 1872 (Cape Argus 1872), and resumed his political activities. The railway problem had become more urgent with the discovery of diamonds near what became Kimberley in the northern Cape, and with the subsequent expansion of that industry in 1868 (Rosenthal 1964). On 10 May 1872 the House of Assembly appointed a Select Committee to report on the Cape Town Railway and Dock Company, which was tabled the following month. Molteno attended every meeting. The Committee confined its enquiry to the financial implications of exercising the Government's option to buy the railway. There was no discussion about its extension beyond Wellington (Cape of Good Hope Report 1872). The problem was solved by the purchase of the railway company by the Cape Colonial Government at midnight on 31 December 1872 (Cape Archives Depot), and by reducing the gauge from 4 ft. 8½ ins. (1.435 m.) to 3ft. 6 ins. (1.067 m.).

Sir John Charles Molteno retired in 1883 (Molteno 1900), and died in Cape Town on 1 September 1886 (Cape Argus 1886). He was doubtless content in the knowledge that the railway which he had encouraged throughout his political career had eventually crossed the Cape mountains, and had reached his adopted Beaufort West on 6 February 1880 (Cape Argus 1880).

ACKNOWLEDGMENT

Dr. Trevor Shaw of the Karst Research Institute in Postojna spotted the "Cape of Good Hope" entry in the visitors' book, and kindly supplied the author with a photocopy. I am grateful to Mrs. Maja Kranjc, Librarian at the Karst Research Institute in Postojna, for the reference from Enciklopedija Slovenije.

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IN MEMORIAM

IN MEMORY OF MARIAN PULINA (1936-2005)

On October 22, 2005 in Katowice Prof. Dr. Marian Pulina, our good friend for many years, died of a treacherous disease. It was only at the end of June 2005 that he attended the International Karstological School at Postojna and visited his Slovene friends. Alas, for the last time! Poland lost one of its grand men and scientists whose figure and work adorned the whole country. His compatriots write that they lost a legendary speleologist, karstologist and explorer of Polar Regions, an outstanding geographer and geomorphologist. In his youth Marian Pulina created Polish speleology and karstology from almost nothing and, helped by his adherents and co-workers, established the science internationally. We may add that numerous karstologists in Europe and in the world lost an exceptional friend and co-worker who never differentiated whether one comes from a large, important country or from a smaller one.

Since 1957 when he probably visited our country for the first time Marian Pulina cherished friendly sentiments to Slovenia and Slovenes. This he proved by several ways, either by inviting us to regular Polish karstological days in the south of Poland, regularly held in February or we were his guests at some important professional expeditions of Polish geomorphologists (Siberia, Ural, Svalbard). It was never difficult for Marian to wake up in the earliest morning hours to wait us at the railway station in Katowice and then drive us through densely populated mining industrial Śląsk either to his home where he lived with his wife Mrs. Maria Pulinova, professor at the same Faculty at Sosnowiec or to his beloved faculty – Laboratory of Karst Geomorphology in Będzińska Street or to karstological meetings in Polish Sudetenland. During our contacts he never forgot to mention his earliest experiences which he obtained in the company of Slovene, in particular Ljubljana cavers at the exploration of Triglavsko brezno and other caves; he remembered many Slovene songs and he was an excellent story-teller both of serious and funny events.

It was never boring in the company of Marian Pulina, his spirits were always high and his company inspired confidence and safety. He found a solution for every problem, in particular when he received numerous friends from abroad. Scientific contacts with foreign countries were the highest imperatives for Marian Pulina as his motto was since the first days of his career »Dla kontaktów!« This is why he was persona grata not only in Slovenia but also in Italy, Spain, and the former Soviet Union, Russia today, in particular in Irkutsk and specially in France and the Czech Republic. In his professional sphere he had contacts with Croatian karstologist and also Norwegian, Canadian and others.

Marian Pulina was born on August 3, 1936 in Bydgoszcz in the north of Poland in a family of teachers where he spent his childhood. He studied geography in Wrocław from 1954 to 1959. At this time he started caving in the Sudety and Tatra Mts. At that time already Marian Pulina was becoming one of the leading Polish speleologists, organizing expeditions or taking part at them into shafts in the Tatras and abroad, to Triglavsko brezno for example. About the exploration of Jaskinia Śnieźna he wrote in Naše jame (1961, 3, 22-27). The first scientific treatise about Naciekowa cave was published in 1957. When he finished studies he worked at first as a technician in a quarry and in a Research Station of the Polish Academy of Sciences in Wojcieszow and continued speleological explorations in the Sudety. In the years 1962 – 1964, as a scholar of the Polish Academy of Sciences, he was in Warszawa and within this research grant he visited in 1963 Prof. Jean Corbel in Lyon. The contact with the topmost expert and modern research methods in karstology was extremely important as he achieved a deepened knowledge about karst and Polar Regions at the same time. Not only for the French and the international community but also for Pulina personally, at that time young and promising Polish researcher, the loss of mentor Jean Corbel was extremely painful. Pulina's longing for knowledge brought him to the Lomonosov University in Moscow where he specialized in ice physics and a little later to the Institute of Earth's Crust of the Siberian Branch of Russian Academy of Sciences in Irkutsk. At that time he got familiar with karst hydrology in the area of new Bratsk reservoir construction on the Angara River. In 1965 he defended his doctoral thesis at the Institute of Geography of the Polish Academy of Sciences. So there opened his career starting at the Institute of Geography of the University in Wrocław, Department of Geomorphology supervised at that time by Prof. Alfred Jahn. Prof. Jahn as an excellent expert on the Polish Pleistocene geomorphology exerted an influence on young Pulina also. He stayed in Wrocław until 1976. During this time he lectured at the universities in Grenoble and Lyon thus starting a fruitful cooperation with many French universities and their karstologists, in the last time especially with Strasbourg and Bordeaux. In 1972 he successfully reached habilitation and this was another opportunity further to promote his scientific and didactic growth. In 1975 he started to establish a new scientific and didactic centre in a form of a Laboratory or School of karst geomorphology in the Department of Geomorphology, Silesian University in Sosnowiec. He was also a co-founder of Geosciences Faculty at the same university and its deputy dean. At the Silesian university he was vice-chancellor for research activity and international cooperation (1990-1993), member of senate and, obviously, numerous commissions. He was the head of the Geomorphology Department and for many years the head of the School of Karst Geomorphology. In this context we remember his efforts for cooperation between the Ljubljana and Silesia Universities, which due to lack of interest on our side, regretfully did not come to life. Since 1976 and up to his premature death he was all the time the head of this sole School of karst in Poland.

In 1966 he took part in the discovery and exploration of Jaskinia Niedzwiedzia in the Sudety Mts. and organized a multidisciplinary speleological research group. This group protected this cave opened in a marble quarry, and displayed it as a show cave. The case and practice connected with Jaskina Niedzwiedzia helped to protect and touristically develop not only other caves in Poland but also elsewhere. This success encouraged M. Pulina to found in 1975 regular annual meetings of karstologists and cavers within the Speleological School, held every February in Lądek Zdrój at the south of Poland. At the beginning these were only Polish-Czech meetings related to Sudety karstological topics organized by the University in Wrocław. Since 1977 they have been international meetings of karstologists organized by the Silesian University. In 1991 he added the organisation of international meetings of karstological and nature conservation experts, named International School of Nature Protection in Karst Regions; the authorities of Landscape Parks in Poland and Moravian karst are included. The meetings and exchange of experiences between the experts from west and east undoubtedly proved efficient to development of karstology.

M. Pulina studied Sudety Mts., Tatras and Silesia – Krakow Upland but also karst areas abroad, for example in central Siberia. He organized numerous explorations and multidisciplinary scientific expeditions or excursions to Siberia, Bulgaria, Czech, Cuba, Svalbard and Iceland. In karstology he was mostly interested in the chemistry of karst waters, chemical denudation, dynamic karstology, karst development in mentioned regions, karst climatology, periglacial phenomena in caves and cryochemistry. The result of his studies are more than 150 papers and many books, among them the first one related to karstology in Polish language. The last book was published in France in September 2005. M. Pulina brought up hundreds of students, as founder of the Polish karstological school he bestowed his specific karstological knowledge on more than 100 students (not only Polish). As supervisor he educated many top experts and teachers.

A special love of M. Pulina was Svalbard. For a Pole aware of Polish history of arctic endeavours since the end of the 19th century this is not uncommon. Very quickly M. Pulina established that in the polar world almost nobody is interested in the phenomena, entirely or partly karstic or when they are similar to karst. First of all these are caves in glaciers, excavated by glacier water during the summer but also true sinking streams and hydrothermal phenomena. This is why M. Pulina is considered as the initiator of cryokarst explorations, in particular cryochemistry and glacier caves. In later years he attended almost every year several months long explorations of Svalbard's glaciers, around Hornsund specifically and took part in the origin and development of the huge Polish research station there. Among other things he was the leader of the second one-year scientific expedition to Hornsund 1979/1980. He succeeded in attracting the international experts and karstologists or speleologists, such as Adolfo Eraso (Spain), Jacques Schroeder (Canada) and Josef Rehak (Czech). All these efforts contributed to M. Pulina becoming the main Polish coordinator of polar researches. His work also is the scientific geomorphological and glaciological workshop on Svalbard with international participation in the years 2002 and 2003.

Let us stress another Marian's quality connected both with his character and width of his geographical visions. On the way to objective scientific goals he swore to cooperation between experts and professions, an interdisciplinary approach, in particular in karstology and polar researches. Beside geomorphology, very close to him were geology, chemistry and hydrology. As he was thinking he was also acting, he knew how to unite, connect and compare different views, attitudes and methodologies and their representatives. M. Pulina was a man with an extremely large circle of friends and co-workers, not only among geographers but also among many colleagues of other professions. This is the heritage to be cherished.

In 1959 M. Pulina founded a journal named Speleologia and later, in 1977 the journal Kras i speleologia. He was a member of editorial board of French Karstologia, International Journal of Speleology, Polish Polar Research, Geographical Journal, etc.

Permit me some words about Pulina's contacts with Slovenia and Slovene karstologists. Quite early he has visited Slovenia and made contacts with some speleologists, for example Peter Habič. He visited Postojnska jama and Škocjanske jame. I think that for the first time he visited the Department of Geography in summer term of 1957 when he lectured the students in Balcony hall about the Polish karst. According to oral communication of M. Vojvoda this visit left an impression on students, as he was a foreigner from the other side of the iron curtain. Thus he came to Slovenia already as a caver and, so to say, in the middle of his studies he was a valued expert for caves and karst. At that time he made contacts with the Society of Cave exploration of Slovenia and some of its members took part in the expedition into Jaskinia Śnieżna. In Slovenia Pulina was mostly interested in middle- and high mountainous karst very similar to the Polish. Together with P. Habič, they visited his field area between Idrijca and Vipava valley. In the autumn 1957 he went with me to the high mountainous karst of Kriški podi for several days. Pulina met A. Melik also, who presented him with one of his books Slovenija with dedication and he visited Prof. Ilešič.

In 1959 the nestor of Polish speleologists Štefan Zwolinski, a person that Pulina highly respected, led the team of Wrocław Academic Tourist Club in cooperation with Wrocław University. Pulina had an important role in the expedition as he measured physico chemical properties of high mountainous karst waters and he reported about the expedition (Pulina 1960). He visited Kamniške Alpe also. In 1963 he came to Slovenia again, sampling water for chemical analyses near Vrhnika and in the mountains. The next visit was in autumn 1965 when he participated at the 4th International Congress of Speleology and it pre-congress excursion into mountains around Triglav. His visits in Slovenia became more frequent when the summer Karstological School started and he became tightly connected with the Karst Research Institute ZRC SAZU and also as a tutor of post-graduate studies at Polytechnics Nova Gorica. With special joy we remember his presence at Slovene-Polish-French round table in 1991 in the time when Slovenia fought for independence and he enthusiastically congratulated us and then he had great difficulty to reach Ljubljana and home to Poland by side roads.

Marian Pulina had a vivacious and adventurous life of scientist and researcher, always aiming high. Dangers did not avoid him. Twice he was in a mortal danger, the first in a mineshaft in Upper Silesia by a stroke of lightning and the second time he fell into glacier fissure on Svalbard and had a narrow escape.

All the time of his fruitful and rich life Marian was the member of Wrocław caving club, coordinator of a caving club in Warszawa and honorary member of Caving Club Aven, Sosnowiec.

Slovene karst was a permanent inspiration for Marian Pulina and for us were many other precious karst and geomorphological horizons that he showed us in 40 years of uninterrupted fidelity. May the Polish earth rest light on him!

Jurij Kunaver

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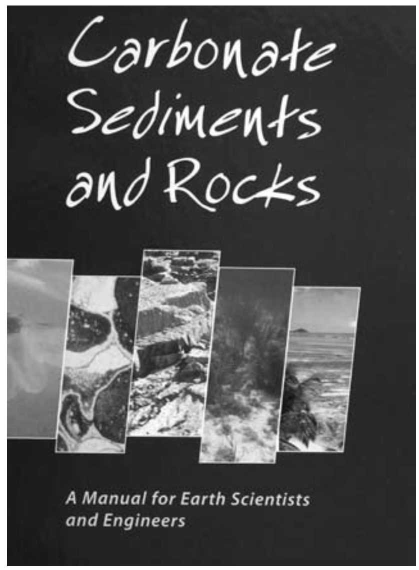
COLIN J. R. BRAITHWAITE: CARBONATE SEDIMENTS AND ROCKS, A MANUAL FOR EARTH SCIENTISTS AND ENGINEERS, WHITTLES PUBLISHING, ORSA PRESS, ISBN 1-870325-39-7, © 2005



The subtitle of the book Carbonate Sediments and Rocks is »A Manual for Earth Scientists and Engineers« and it is designed as a manual mostly for engineers. Yet this is a really useful book for others, not only engineers, but also and maybe specially for students of geology and earth sciences. The hardback book 241 x 170 mm includes 196 pages, 37 black and white and 96 colour pictures (20 pp section).

The work is divided into 16 chapters: from mineralogy and composition of carbonate sediments and rocks to their preservation. Some chapters are very short (Evaporites associated with Carbonates); some others are much longer and divided into subchapters (Carbonate Diagenesis: from Sediment to Rock covers 21 pages with 5 subchapters). The first six chapters deal with carbonate sediments from mineral composition to geochemistry, with characteristics of carbonate sediments, marine carbonate environments, evaporites associated with carbonates and continental carbonate environments to classification of carbonate sediments and rocks. The seventh chapter treats diagenesis, a passage from sediment to rock. Special chapters are dedicated to dolomites and calcrete. In the last seven chapters there are more topics directly connected with karst. In the chapter entitled Limestones, Dolomites and Karst the author deals with dissolution of carbonate rocks, karst landforms, caves, precipitation of calcite, biogenic facies, karst and sea-level change and paleokarst. Special chapters are dedicated to karst hydrology and (engineering) hazards of karst.

Although the book is relatively thin, the text is concentrated but on many places the topic is treated surprisingly in detail. The classification of carbonate rocks does not mention standard authors only (Dunham and Folk) but considers relatively archaic Garbau (1904) and also more recent works, such as Choquette & Pray (1970) and Embry & Klovan (1971). Clear sketches and tables illustrate the subject, relatively complicated for a layman. The diagenesis is similarly explained in detail. In general karstologists do not study calcrete, as this is mostly the domain of pedologists and other specialized branches (for example climatic geomorphologists). Yet, a karstologist must be aware of origin of calcrete, as this is an important process. Although on five pages only a reader gets acquainted not only with the process but also with many professional terms, not much used in karstology, such as globules, nodules, ooids, pisoids, pedotubules, rhizoliths, rhizoconcretions, crystallaria, etc.

The chapters 10 (Limestones, Dolomites and Karst) and 11 (Karst Hydrology) are the most important for karst. It is not an easy task to explain all the theories of karstification, superficial and underground features, including paleokarst and karst hydrology on 17 pages. It is nicely said from where the name derives and what does it mean. Dealing with dissolution of limestone there are many chemical formulas, but no equations. Does it simplify the understanding or not? Superficial karst features are divided to small-scale features, dissolution pits (including also spitzkarren and shilin), and large-scale features; here dolines and poljes seem to be the most important. Cvijić's explanation of uvala is mentioned also (the author wrongly call it uvula). To the same group belongs also cockpit and tower karst. This chapter ends by precipitation, biogenic facies, karst related to sea-level change and paleokarst.

The chapters from 12 to 15 are dedicated to engineering geology of carbonates; they treat the engineering properties, methods of extraction, the hazards of karst, and deposits (hydrocarbons and mineral) within carbonates. Maybe there is not much new for engineering geologists but it could be very interesting for researchers treating karst theoretically or from other points of view. A reader learns that, for instance calcrete, of minor importance for us and maybe a disadvantage only for agriculture, is somewhere else the main building material for road construction. Physical properties of single carbonate rocks are presented particularly in detail. Although shortly described the cases of hazards on karst can be very instructive. The methods how to identify the underground cavities are limited to boring and geophysical methods, including »georadar«. Instructive are examples of building collapses, cases of unsuccessful construction of dams on karst, subsiding and collapse of bridges, hazards on roads, railways and airports. The chapter ends by water supply on karst and hazards related to karst in evaporites. All these examples show that engineer geologists and building engineers do not know enough of karst therefore such manuals, as this one of Braithwaite, are without doubt necessary and useful. In the area of »Classical Karst« we do not even think that the carbonate rocks, this means in karst and paleokarst, may hide important stock of oil. The 15^{th} chapter gives ore and oil finding places in karst. The cross sections illustrate the ore bodies near Pliberk in Triassic carbonates and structure of one part of famous Elk Point Basin in Alberta (Canada).

The last, 16^{th} chapter, speaks of carbonate landscape protection, mostly related to quarries, physiognomy of the landscape, caves and fossils. For the last one the book gives an interesting example from France (Digne). Instead of selling 200 m^2 of exposed Jurassic limestone with more than 500 ammonites to Japan, the elastomer mould was made. In 1991 the casts weighing 24 tonnes were assembled and the replica attracted already two million of visitors in Japan.

The book contains a comprehensive list of 399 references. There are authors of basic karstological and geomorphological works, from Curl, Cvijić, Ford, Gèze, Hutton and Sweeting. From our point of view is maybe surprising relatively small number of authors from so-called »classical", Dinaric karst. Beside Cvijić the list contains only Roglić. Every author keeps to his individual choice of literature. But, as this is a book about carbonate rocks and not about karst one must not complain if the selection of literature is anglophone. On the other side this is a manual aimed to students also and it would be good if the literature is slightly more balanced. One can understand that there are no Russian, Polish, Czech or Hungarian authors, but there are no leading French authors either, such as Fénélon or Nicod, not to mention Mangin's contribution to theoretical knowledge of karst hydrology and this is less understandable. As quite a lot of time passes from time when the manuscript is delivered to time when the book is published, one can understand that the most recent literature is hard to be considered. But in this case the gap is considerable. From 399 cited works only 52 were published in 1990 or later, among them only two with year 2000, there are no younger. I regret this mostly because in the last time some very important works were published, such as, for example Encyclopedia of Caves and Karst Science edited by J. Gunn. Some other statements are out-of-date too, for example the list of the deepest caves in the world, which is understandable because of the quick changes in this field.

The last pages contain a well composed and exhaustive index, including more than 600 entries which essentially improve the use of the book as a manual or textbook. For me, being karstologist, it is difficult to judge what such a manual means to engineer geologists but I can say that the book is very useful for our students of geology and geography and also to third degree karstologists.

The book can be ordered by orders@booksource.net for the price of 40 GBP.

Andrej KRANJC

T. WALTHAM, F. BELL, AND M. CULSHAW: SINKHOLES AND SUBSIDENCE; KARST AND CAVERNOUS ROCKS IN ENGINEERING AND CONSTRUCTION. SPRINGER (IN ASSOCIATION WITH PRAXIS), 383PP. BERLIN, NEW YORK, CHICHESTER, 2005.

One of the informal conclusions of the 13th International Karstological School, held at Postojna (Slovenia) in June 2005, was that the application of engineering geology approaches to general karst geomorphology has become urgent. Just a short time later, an echo appeared in the arena – in the form of the present book. Perhaps this coincidence is a good indication that such a book was really needed. The names and backgrounds of the authors – among them Tony Waltham, a caver who is known throughout the world – promise a book of high quality.

The contents of this hard-back book, produced in the B5 format, are arranged into 13 chapters, each covering a specific aspect of the central topic. The text begins with a list of contributors, a list of figures (240 in total), a list of tables (20 in total), a list of boxed articles (7 in total), and a glossary. At the end of the book there are references (441 in total), an index of locations and a subject index. The list of all contributors (the 3 main authors plus 20 concerned with details of specific topics), including their E-mail addresses, promises to be very useful. This comprehensive suite of ancillary information says a lot about the very useful arrangement of the book as a whole.

The main text begins with a chapter entitled Rocks, *dissolution and karst.* This is a short but comprehensive summary of the fundamentals of karst science, important to an engineering geologist. Carefully chosen illustrations (photos as well as diagrams) make the topic clear even to readers who are not acquainted in detail with the karst and the engineering problems that it poses. The next chapter, *Sinkhole classification and nomenclature,* even manages to astonish someone who has some experience with collapse phenomena in the karst. The variety of forms and related processes that are considered is truly wide, covering the span between solution sinkholes and subsidence, suffosion and dropout sinkholes. Table (2.1), which is supported by drawings, makes the proposed classification clear. A useful section relates various types of sinkholes to different types of karst, while a "boxed example" introduces a general style feature of the book – the constant mutual inter-relation of general information and topic-specific case studies. The 3rd chapter, entitled *Rock failure in collapse and caprock sinkholes,* deals with perhaps the most attractive, but – as it turns out – generally less important aspect of collapse in the karst. A short, concise introductory section, covering various possible cases and some basic geomechanical views, is followed by a number of field examples, which are well documented by photographs and very enlightening drawings. The authors' interests and coverage also extend to gypsum and salt. It turns out that *Soil failure in subsidence sinkholes,* as covered by the fourth chapter, appear less spectacular, yet (p.85), "*The vast majority of ground failures within karst are due to the erosion, transport and failure of the soils that overlie cavernous bedrock.*" The text here is organized in similar fashion to that in other chapters. What is attempted is the exposure of the relationships between surface features and their underground roots, whether in soil or in bedrock. Sections covering the evolution of sinkholes, the spatial distribution of sinkholes and subsidence sinkhole geohazards are a gold mine of ideas and information for a practical geologist. The following (5th) chapter lists various forms of *Buried sinkholes and rockhead features,* including phenomena found in chalk. Chapter 6 covers *Sinkholes in insoluble rocks,* dealing mainly with lava tubes. Various examples from all over the world are so convincing that, though they are less well known, it is clear that related problems should not be overlooked. Again, the presentation of an engineering solution to a practical problem (Portland) makes the book into a kind of manual. *Rock failure under imposed load over caves* (Chapter 7) is a problem that is growing, as karstified regions of the world become more and more heavily populated. The text covers a theoretical view of the problem, as well as providing practical examples. The following chapter discusses *Sinkholes induced by engineering works.* It becomes apparent that changes in ground water behaviour (introduction of new water, the decline or oscillations of ground water level) trigger off the worst damage.

Having completed discussion of the actual phenomena of sinkholes and related features, in the following chapter the authors consider *Ground investigation in sinkhole terrains,* as the first step in actively dealing with the problems. The spectrum of useful methods presented is really large. Tables 9.2 and 9.3 present a concise survey of the methods available and the circumstances in which they should be used. The 3-D simulations that are provided will prove interesting even to less practically oriented karstologists. The 10th chapter, entitled *Hazard and risk assessment of sinkholes* continues the logical extension of the text. Flow charts, case studies and various tables offer a rich source of suggestions for the field geologist. Sections covering *Legislation*… and … *insurance* discuss topics that are too often overlooked, but which may greatly influence the course of investigation and remediation. The main part of the book culminates in chapters 11 *(Prevention and remediation of sinkholes)* and 12 *(Construction in sinkhole terrains).* A selection of practical guidelines, encompassing the most important situations and based on practical examples provide a source of inspiration for any civil engineer faced with sinkhole problems during constructional and remedial works in the karst. Finally, Chapter 13 presents a collection of sixteen carefully chosen case studies, each section written by authors who have directly faced the individual problems.

Whereas the book discusses very diverse topics, while still managing to cover the central problem, it remains systematic and, above all, lucid. The figures have been carefully chosen and matched, and even those taken from existing literature have been redrawn to the same common (high) standard. Photographs are of high quality, and related directly to the text. Numerous practical examples are elaborated in Boxes, and usually supported by figures. Some readers might wish for a deeper theoretical analysis of the geomechanical background of various sinkhole-related events, but to the present reviewer this possible lack is not a weak point. Instead it provides a warning that the gap between theory and practical experience (in fact, insufficient knowledge of controlling parameters) is still large.

Problems with sinkholes and related types of hole are widely known and are being wrestled with in many parts of the world. Nevertheless, before the present book the related data have never been put together in such a systematic way. It is, and it will remain, the essential work in this specific field of applied karstology. It is difficult to imagine that anyone will produce something more exhaustive and better founded in the foreseeable future.

From the viewpoint of more general karstology, this book has also cleared up many a partial question concerning this specific kind of karst dynamics. As mentioned above, it emerges that the main problem in the karst is not spectacular collapse phenomena in bedrock, but various failures of a soil mantle upon the rocky basement. Consequently, the problem does not originate in basically karstic processes, but in specific relationships that originate at the interface between the karst (in a narrow sense) and non-karstic cover. Thus, the dynamic is less related to speleogenesis (or decay), and more to the karst surface phenomena. Additionally, the extent of collapse features in non-carbonate karstic rocks has become well related to carbonate karst features. And – finally – the plea of the 13th International Karstological School has been resolved in the best way. It is now in the hands of karst geomorphologists to pick up what has been offered to them and then to apply it. One might expect that this will become one of the most cited books in the karstological literature in the near future.

For a Slovene karstologist the book is of special interest, as it covers a number of cases in Slovenia. It becomes clear, that though perhaps among the most spectacular – except for the Chinese ones, which dwarf anything else – collapse phenomena in the Slovene karst do not pose serious problems. In Chapter 13 a section, written by Slovene authors, is dedicated to the experience acquired during motorway construction in Slovenia. The importance of the contribution is manifold. Besides its promotion of the Classical Karst, it provides a good overview of the technical problems encountered during building works, as well as yielding an insight into the interface between the surface and the endokarst in the region that gave its name to these natural phenomena.

France ŠUŠTERŠIČ

ACADEMICIAN JOSIP ROGLIĆ AND HIS WORK (INTERNATIONAL SCIENTIFIC MEETING, MAKARSKA 19th – 22nd APRIL 2006)

Josip Roglić is the most important Croatian geographer and geomorphologist and world renown karst geomorphologist, the greatest expert on Dinaric karst. His most important achievements are the explanation of the genesis of corrosional plains ("zaravan"), the process of border-corrosion and the fluviokarst, including the term itself. His most influential work in the field of karstology is "Zaravni na vapnencima" (Corrosional plains in limestones), at least the most cited in Slovene karstological literature. When still at Belgrade University he was intended to become Cvijić's successor, which was never realized. After setting at Zagreb Roglić initiated Natural History and Mathematical Faculty, he was the founder of so-called Zagreb karstological school, and he edited Croatian Karst Terminology. Taking into account international relations he was the member of Karst Commission of International Geographical Union. He held close relations with Slovene karstologists and accordingly he has a great influence upon the karstology in Slovenia.

In 1906 Josip Roglić was born at a hamlet Roglići, Župa Biokovska, on the continental side of the Biokovo Mountain, karst ridge directly above the Adriatic coast. This is the reason why Geographical Society of Croatia and Croatian Academy of Sciences and Arts, Classis of Natural History Sciences, decided to organise this international meeting. The motor of the organisation was without doubt Prof. Mate Matas from Petrinja High School.

The charming small littoral town of Makarska, south of Split, still quiet as the tourist season did not yet started, was the place where 125 participants gathered for 4 days. They were from Croatia mostly and among them the most eminent teachers and researchers, numerous Roglić's former students. The work of the symposium included presentation of papers and the field work. After the solemn opening of the conference two plenary papers by M. Matas and D. Feletar presented the life of J. Roglić and particularly his role at establishment the Faculty of Natural History and Mathematics in Zagreb. During mornings 29 papers have been presented. Seven of them have J. Roglić and his work as the main topic while the others touched his work indirectly, taking into account topics and regions studied by Roglić (geomorphology, cartography, regional geography, littoralisation, globalisation). Four papers were dedicated to Roglić's work on karst: on karst geomorphology, on speleology, on karst toponimy and on his influence upon karstology in Slovenia. But it does not mean that the topics were historically oriented, turned towards the time of Roglić. Far from this. There were papers talking about digital maps and computer informatics basis too. I found very interesting the paper about karst research in the frame of military sciences. Among the others the author has shown digital maps of dolines: they counted 350.000 of them on the karst of Croatia! The papers of Roglić's younger colleagues and former students gave a special atmosphere to the conference.

According to the fact that the main field of interest of geography are space and landscape, half of the conference time was devoted to the field work. In his degree work on Biokovo region J. Roglić divided the region in three belts: "blue" – littoral, "green" – foot of the mountain, and "white" – limestone karst mountain belt. According to this the fieldwork was organised. During two afternoons and one full day the participants got opportunity to be acquainted with the littoral belt (between Split and the mouth of the Neretva river), with the foot of karst mountain (specially the contrast between the Eocene flysch and Mesozoic limestone) and the karst mountain ridges, including the highest belt of the Biokovo Mt. Visit to this mountain has also a special connection to J. Roglić: the excursion stopped at his humble native house at the

Polje "Jezero" behind the Biokovo Mountain.

hamlet of Roglići, far behind the main ridge. The participants attended a ceremony: the unveiling of a memorial plate to Roglić and the opening of the Roglić's mountain trail in Biokovo. That the evenings are not too long, the organizer provided professional and cultural events too. Of the last one the excellent performance of opera singers and the theatre actor must be mentioned.

The organizer was specially successful regarding publishing activities. The Proceedings of the meeting was published at the beginning of the meeting already. Nice, hard back book of 566 pages, containing 34 papers which gives a well balanced view of Roglić's life and work as well as various geographical aspects of Croatia and its karst. A special attention deserves Matas' contribution on "Life and work of Academician Josip Roglić" (40 pages!), and regarding the karst, "Jezero – a contribution to understand the problems of the karstic poljes" by J. Markotić.

The Croatian geographers started the preparation of the celebration of Roglić's 100 anniversary quite early, early enough to achieve great publishing achievement: during the years 2005 – 2006 they published Roglič's works in 5 volumes, which were presented at the meeting. I am glad to say that the first volume is just "Krš i njegovo značenje" (Karst and its significance), proving that Roglić is really the most important as a karstologist. The other 4 volumes contain Roglić's geomorphological works, works on Adriatic and works of regional geography, and the introduction to the cartography. Beside the first volume also other volumes contain some works on karst or are treating karst too.

Looking from the distant point of view, including Dinaric karst as a whole, where the term "karst" and karst science came from, we can state that there are republished complete works of two first and the most important geographers – karstologists. The first one is a Serbian geographer Jovan Cvijić, whose complete works were published 1994 – 2000 in 14 volumes, and now Roglić's work is completed too. Is it the turn of Slovene geographers to start to think about publishing the complete work of our greatest karstologist?

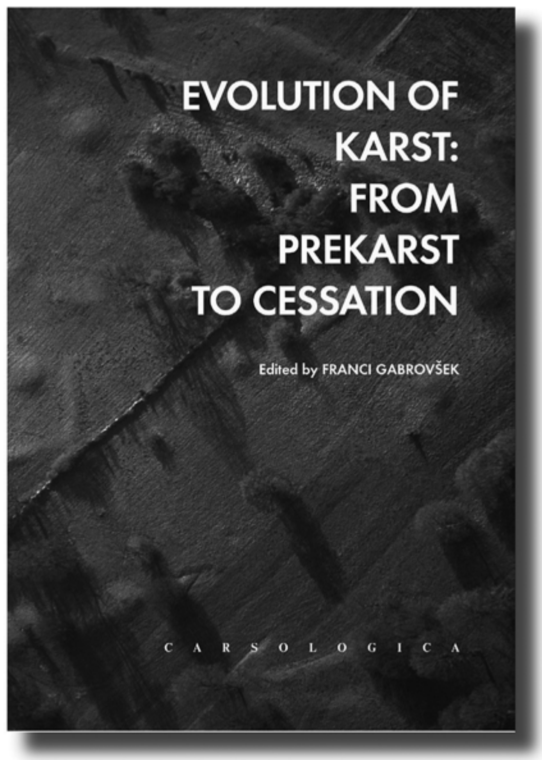
Andrej KRANJC

Solution flutes on the Biokovo Mountain karst.

EVOLUTION OF KARST: FROM PREKARST TO CESSATION

Edited by Franci Gabrovšek

The book comprises proceedings of the symposium »Evolution of Karst: From Prekarst to Cessation«, organised by the Karst Research Institute ZRC SAZU in September 2002 in Postojna. The aim of the book is to answer questions like: When does karst start and when does it end? Which processes and events determine the evolution of karst? How do caves develop? How is subsurface hydrology and distribution of hypogean fauna connected to the state of karst evolution? How do we date processes in karst? The first half of the book contains invited papers where authors give answers to the questions quoted above, each author from the perspective of his own research. The second half of the book comprises papers covering current research on karst geomorphology, speleology and speleogenesis, karst hydrology, paleokarst, karstification in various settings, dating of events in karst and use geophysical methods in karst systems.



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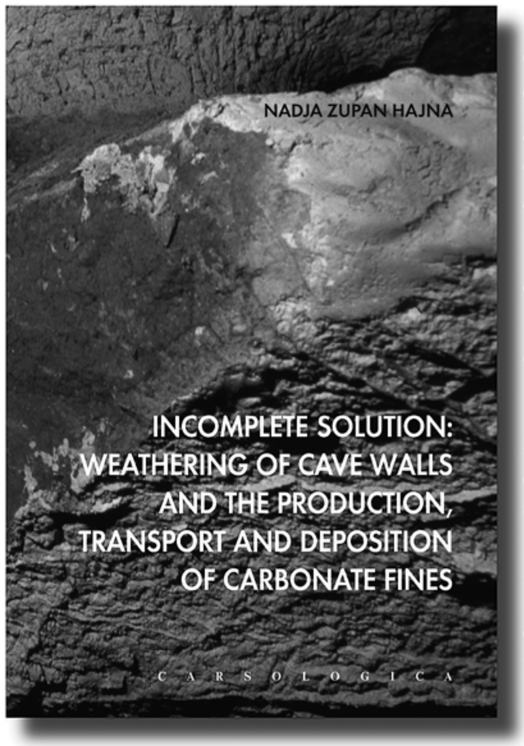
Nadja Zupan Hajna

INCOMPLETE SOLUTION: WEATHERING OF CAVE WALLS AND THE PRODUCTION, TRANSPORT AND DEPOSITION OF CARBONATE FINES



The main topic of this monograph is the weathering of carbonate rocks on the walls of cave passages. Of particular interest were the characteristics and peculiarities of the limestone and dolomite weathering processes, the type of solution and why all of the carbonate rock does not dissolve immediately. The results of incomplete solution of carbonate rock are weathered zones that remain on the cave passage walls. During weathering the rock gradually discolours and by increased porosity looses its mechanical strength. Mineral and chemical composition of the weathered zone is almost identical to composition of parent rock, yet it is much more porous. In described cases an incomplete dissolution may just prepare the carbonate rock for the mechanical transport of its weathered particles by the flowing water.

154 pp., 133 figures, 170 x 240 mm, paperback, ISBN 961-6358-85.
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PRELIMINARY ANNOUNCEMENT
SYMPOSIUM ON "TIME IN KARST"

We would like to invite you to a symposium on "Time in Karst" to be held in Postojna, Slovenia, March 14 to March 18, 2007. The meeting will be held at the Karst Research Institute ZRC SAZU in Postojna, and participants will stay at the nearby Hotel Jama and Hotel Sport. Registration details will be available in September of 2006 at www.karstwaters.org. Registration will be $350 US ($200 for students).

The idea of the symposium is simple one—to examine what we know and what we can infer about the ages of caves, of karst landscapes, and of the organisms that inhabit them. This work is often scattered in the literature of different disciplines, and we think that there is much to be gained by bringing together leading researchers who work on time processes in karst. The presentations will be grouped around six themes, which have strong interdisciplinary character:

- Age of karst landscapes
- Age of animal lineages
- Cosmogenic dating methods
- Historical biogeography
- Paleokarst
- Sediment records

The sponsoring organizations (the Karst Research Institute ZRC SAZU in Slovenia and the Karst Waters Institute in the United States) both have a history of sponsoring important small meetings with an interdisciplinary character, and we are excited to be joining forces in this endeavor. In the Marie Curie programme sponsored by the European Commission, the Karst Research Institute ZRC SAZU is leading a project SMART-KARST, which provides the grants for early-stage researchers. Participants of the symposium on "Time in karst" will be able to apply for this grant, which covers travel and living allowance, and registration fee. We hope you will participate in "Time in Karst" in March of 2007.

For further information please visit the web site of the symposium:

http://www.karstwaters.org/timeinkarst/tikannouncement.htm

Tadej SLABE
The Head of Karst Research Institute ZRC SAZU

David CULVER
Karst Waters Institute

WORLD KARST SCIENCE REVIEWS

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